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13 Patent Statistics as Economic Indicators: A Survey

Overheard at a Catskills Resort
(one guest to another):
—The food is so terrible here.
—Yes. And the portions are so small.

13.1 Introduction

Patents and patent statistics have fascinated economists for a long time. Questions about sources of economic growth, the rate of technological change, the competitive position of different firms and countries, the dynamism of alternative industrial structures and arrangements all tend to revolve around notions of differential inventiveness: What has happened to the "underlying" rate of technical and scientific progress? How has it changed over time and across industries and national boundaries? We have, in fact, almost no good measures on any of this and are thus reduced to pure speculation or to the use of various, only distantly related, "residual" measures and other proxies. In this desert of data, patent statistics loom up as a mirage of wonderful plentitude and objectivity. They are available; they are by definition related to inventiveness, and they are based on what appears to be an objective and only slowly changing standard. No wonder that the idea that something interesting might be learned from such data tends to be rediscovered in each generation.

I shall try, in this survey, to show why I think patent statistics are interesting in spite of all the difficulties that arise in their use and interpretation. To do so I shall first describe the nature of patents and the types of data generated by their issuance, their current availability, and some of the major problems that

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I am indebted to my friends and collaborators for many ideas and comments. Parts of this survey borrow heavily (often verbatim) from our earlier work on this topic, especially from Griliches, Ariel Pakes, and Bronwyn Hall (1987), Griliches, Hall, and Pakes (1988), and Griliches (1989). I am indebted to the National Science Foundation (PRA85-12758 and SES 82-08006) and the National Bureau of Economic Research Productivity Program for financial support of this work and to B. Hall, A. Pakes, K. Pavitt, M. Schankerman, and F. M. Scherer for their comments on an earlier draft. The first draft of this survey was begun while I was a guest of the Rockefeller Foundation at the Bellagio Study and Conference Center in Italy. An earlier version of this paper was presented as the W. S. Woytinsky Lecture of 1989 at the University of Michigan.

arise when one tries to use them in economic analysis. I shall next review briefly some of the earlier work on this range of issues, focusing particularly on Jacob Schmookler's work and the questions raised by it. This will be followed by a review of the more modern, "computer age" work of the NBER group (Griliches, Hall, Hausman, Jaffe, Pakes, Schankerman and others), and I shall allude also to similar work of others, especially that of Scherer and the Yale group (Levin, Nelson, Klevorick, Winter, Reiss, Cohen, and others), and the SPRU group (Freeman, Pavitt, Soete, and others). I will not be able to do justice to all of this work (the work of others, of my collaborators, and even my own) but I hope to put up enough guideposts so that the interested reader can find his own way to and through this literature.[1]

Over all this work hovers the question, "What can one use patent statistics for?" Can one use them to interpret longer-term trends? If so, did inventiveness really decline in the 1930s and early 1940s, as indicated by such statistics, and again in the mid-1970s? Does the fact that large firms have a lower patents per R&D dollar ratio imply diminishing returns to such investments? Can one use such numbers to conclude that demand forces are stronger determining factors in the evolution of technological progress than supply factors, than the evolution of science, as Schmookler could be interpreted to say? These are the type of substantive questions that I will explore, though not necessarily answer, in this survey.

There is much that will not be covered in this survey. I will not discuss the literature that deals with the social value of the patent system and with alternative lengths of protection and licensing arrangements. Nor will I deal with the recent and rapidly growing theoretical literature on "patent races" and related game-theoretical topics. One has to draw the line somewhere and the task outlined above may be already too large for one article and one person to deal with. Nor will this be a fully "balanced" survey. I shall, perforce, concentrate more on topics that I and my research associates have found most interesting, slighting thereby, sometimes unwittingly, some of the work of others in this field.[2]

13.2 Patents and Patent Statistics

A patent is a document, issued by an authorized governmental agency, granting the right to exclude anyone else from the production or use of a specific new device, apparatus, or process for a stated number of years (17 in the U.S. currently). The grant is issued to the inventor of this device or process after an examination that focuses on both the novelty of the claimed item and its poten-

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[1] There are several other good surveys on this range of topics. See especially B. L. Basberg (1987), Keith Pavitt (1978, 1985), Pakes and M. Simpson (1989), Mark Schankerman (1989), and the earlier books by Jacob Schmookler (1966) and C. T. Taylor and Z. A. Silberston (1973).

[2] This is especially true of some of the European work on related topics, because it often asks somewhat different questions in a different intellectual framework.

tial utility. The right embedded in the patent can be assigned by the inventor to somebody else, usually to his employer, a corporation, and/or sold to or licensed for use by somebody else. This right can be enforced only by the potential threat of or an actual suit in the courts for infringement damages. The stated purpose of the patent system is to encourage invention and technical progress both by providing a temporary monopoly for the inventor and by forcing the early disclosure of the information necessary for the production of this item or the operation of the new process.

The standard of novelty and utility imposed on the granting of such a right is not very high. (In this it probably does not differ greatly from the standards imposed in most fields on the publication of scientific journal articles.) In the U.S., for example, about 104,000 applications were filed in 1980 for ("utility") patents, of which about 65,000 were granted by the end of 1984; 1,400 more were granted by the end of 1988, with another 300 or so to follow over the next three to five years. These numbers are typical. In the U.S. the granting success rate fluctuated around 65 percent in the 1970s. Roughly speaking, two out of three applications are eventually granted. The granting rate, the stringency of examination, varies greatly across countries and also somewhat over time. It has been over 90 percent in France (until the mid-1970s), about 80 percent in the U.K., and only 35 percent in Germany (Schankerman and Pakes 1986, Table 1), and has varied in the U.S. from a low of 58 percent in 1965 to a high of 72 percent in 1967 (of domestic applications between 1965 and 1980). This variability is, as I will show later, largely associated with differences in the procedures and resources of the various patent offices, implying, therefore, also differences in the average "quality" of a granted patent across countries and periods.

Of the approximately 62,000 patents granted in 1980, 24,000 or 39 percent were granted to foreign inventors, a ratio that has been rising sharply over the last decades, from 19 percent in the early 1960s to 48 percent in 1988. U.S. corporations have accounted for about 73 percent of the total patents granted to U.S. inventors (in 1988), with 2 percent being granted to agencies of the U.S. government, and the rest, 25 percent, going to individual inventors. The fraction accounted for by foreign corporations of total foreign patenting in the U.S. has risen from 64 percent in the mid-1960s to 82 percent in 1988. The general trends in such numbers are depicted in Figures 13.1 and 13.2.

Even though grants can be thought of as a moving average of past applications, it can be seen in these figures that they tend to fluctuate as much or more than the number of patents applied for. It is also clear that economic conditions impinge on the rate of which patents are applied for. Applications were lower during the Great Depression and also during World War II, and their growth was retarded in the 1970s. Moreover, patents assigned to U.S. corporations have not grown at anywhere near the rate of growth of total R&D expenditures in industry (and hence even less than the rate of growth in company-financed R&D in industry). Because I will argue below that patents are a good index of

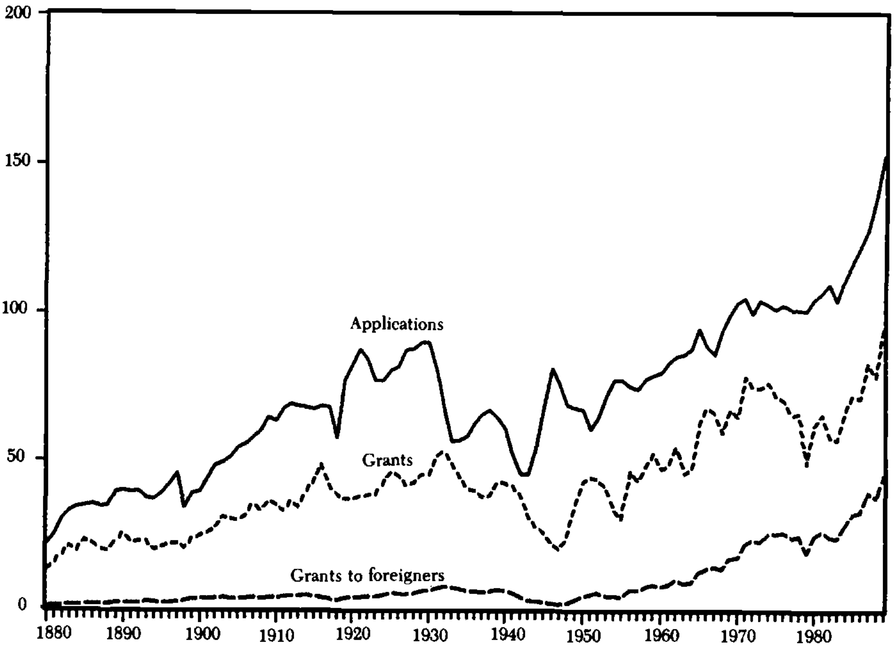

Fig. 13.1 U.S. patent applications and grants, 1880–1989, in thousands
Sources: National Science Board (1987); U.S. Patent and Trademark Office (1977, 1989 and subsequent releases).

inventive activity, a major aspect of which is also measured by R&D expenditures, this view will need reconciling with the aggregate facts depicted in Figure 13.2.

Data are also available at the firm level. In 1984 the largest patenters were General Electric, IBM, and Hitachi with 785, 608, and 596 patents granted respectively. Most of the major U.S. patenting firms experienced a declining trend in patents granted during the 1970s with some recovery in the 1980s, while there has been a rapid growth in U.S. patents granted to the major Japanese electronics and motor vehicles firms (see Griliches 1989, Figure 5).

What I have done in the preceding paragraphs is to discuss the information implicit in patent counts, in the number of patents issued at different times, in different countries, and to different types of inventors. This is the type of information that economists have largely focused on, also cross-classifying it by industry and firm, and it is the use of such numbers in economic analysis that will be the main topic of this survey. But a patent document, which is public after it has been granted, contains much more information than that. Besides information on the names of inventors and their addresses and the name of the organization to which the patent right may have been assigned, it also lists one or more patent classes to which it has been assigned by the exam-

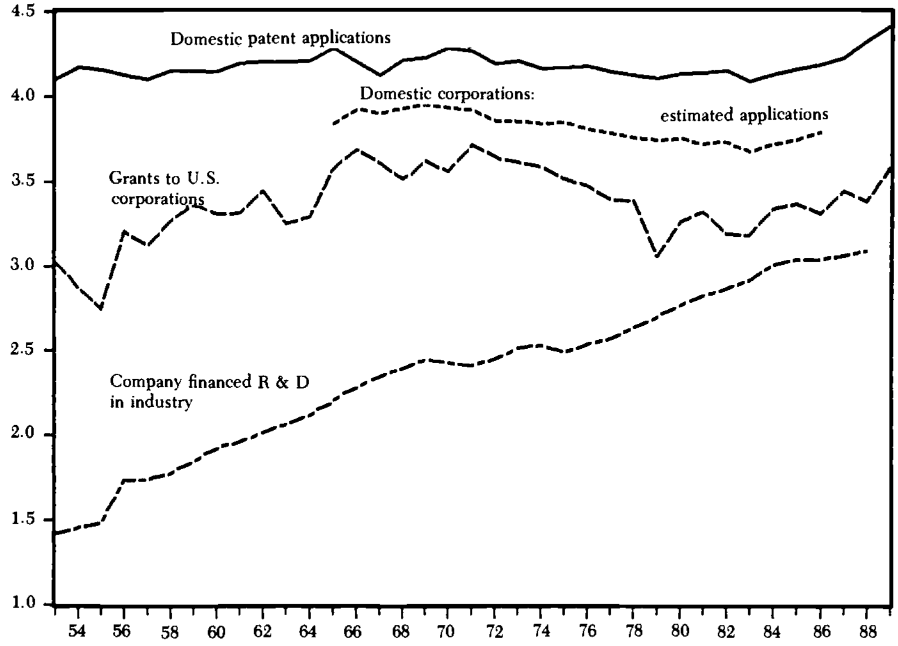

Fig. 13.2 U.S. domestic patents and R&D, 1953–89, log scale

Note: Domestic corporations: estimated applications—U.S. corporate grants by date applied for, inflated by 1/0.65, the average success rate.

iners, cites a number of previous patents and sometimes also scientific articles to which this particular invention may be related, and also finally, but from the social point of view most important, provides a reasonably complete description of the invention covered by this particular patent. Thus, there is much more information derivable from the patent documents than just simply their aggregated number in a particular year or for a particular firm. One can study the geographic distribution of particular inventions, one can investigate citation networks and patterns, and one can actually read the detailed text of a series of patents in a particular field as raw material for an economic-technological history of it. Also, in a number of foreign countries, and in the U.S. since 1982, a non-negligible renewal fee, which rises with the age of the patent, has to be paid. This results in a significant abandonment of patents before their statutory expiration date and generates, in passing, a set of potentially very interesting patent mortality statistics.

In the U.S., aggregate patent statistics classified in a variety of ways are released by the Office of Documentation (formerly the Office of Technology Assessment and Forecast) at the U.S. Patent Office. Major series are published in the National Science Foundation's biannual *Science Indicators* compendium. More detailed tabulations are available from or can be prepared by the

Patent Office and summary information on all recent patents is now also available on CD-ROM disks. The full text of the patents can be found in a number of depository libraries in the U.S. and now can also be accessed via several bibliographic computerized data base services, such as Dialog and BSR. Given the advanced search software available on these services it is possible to conduct a variety of specific searches of such data bases, looking for patents in a particular area or those mentioning a particular material, instrument, or a specific earlier patent, and tabulate the results at a reasonable cost. Patent data for other countries are being collected by the International Patent Documentation Center in Vienna, Austria, and published annually in *World Intellectual Property Annual.* Country summaries are published in OECD, *Main Science and Technology Indicators,* and by various country statistical offices, such as Statistics Canada. Current information on individual foreign patents is available on line from Dialog.

There are two major problems in using patents for economic analysis: classification and intrinsic variability. The first is primarily a technical problem. How does one allocate patent data organized by firms or by substantive patent classes into economically relevant industry or product groupings? I shall discuss this question shortly. The second problem is fundamentally much harder and will be discussed at some length below. It refers to the obvious fact that patents differ greatly in their technical and economic significance. Many of them reflect minor improvements of little economic value. Some of them, however, prove extremely valuable. Unfortunately, we rarely know which are which and do not yet have a good procedure for "weighting" them appropriately. I shall discuss the available scraps of evidence on this topic in Section 13.5 of this survey.

Patents are awarded for an invention of a chemical formula, a mechanical device, or a process (procedure), and now even a computer program. The Patent Office classifies patents into many classes (300+ in the mid-1950s) and even many more subclasses (over 50,000), based on its need to ease the search for prior art. The resulting classification system is based primarily on technological and functional principles and is only rarely related to economists' notions of products or well-defined industries (which may be a mirage anyway). A subclass dealing with the dispensing of liquids contains both a patent for a water pistol and one for a holy water dispenser. Another subclass relating to the dispensing of solids contains patents on both manure spreaders and toothpaste tubes (Schmookler 1966, p. 20). Nevertheless, with one notable exception (Scherer 1984a) and the more recent Canadian data-based studies, almost all attempts to relate patent numbers to industrial data use the subclass system as their basic unit of assignment.

Before any classification is attempted one has to face the inherent ambiguity of the task. Do we want to assign the invention to the industry in which it was made ("origin"), to the industry that is likely to produce it, or to the industry that will use the resulting product or process and whose productivity may benefit thereby (destination or industry of "use")? Consider, as an example, the case of a new plow invented in a chemical firm's research laboratory as part of its project on new combined fertilizer and tillage systems. It depends on what question is to be asked of the data. If we want to study the returns to R&D expenditures we may wish to count it in the chemical industry whence the money came to develop it. If we want to analyze the impact of technological change on the rate of investment, on the sale of new equipment, we may wish to count it in the farm equipment industry. If we are interested in its effects on measured productivity we are more likely to count it as being relevant to agriculture. This difference in questions reflects itself also in different classification strategies pursued by different researchers.

Schmookler, in his main work, chose to construct data on capital goods patents relevant to a particular industry by reviewing carefully a set of subclasses, sampling a number of patents in them, and deciding whether most of them were indeed likely to be used in the industry in question. He then aggregated the total number of patents in each of the accepted subclasses into an industry-wide total. In this way he constructed time series for capital goods inventions of relevance for the railroad industry, the paper-making industry, petroleum refining, and building construction. By focusing on capital goods inventions only and on a few selected and better-defined industries, and by not insisting on completeness or inclusivity, he made life quite a bit easier for himself. This choice forced him, however, to forgo any serious analysis of the patenting of consumer goods or manufacturing processes. His industrial classification was based on the third type: the locus of potential use for the new or improved capital good.

In the mid-1970s the Patent Office established a research unit, the Office of Technology Assessment and Forecast (OTAF). One of its first jobs, on a contract from the Science Indicators Unit of the National Science Foundation (NSF), was to try to produce patent statistics at the three- and two-and-a-half-digit standard industrial classification (SIC) levels corresponding roughly to the NSF's classification of applied research and development by product field. This was done by developing a "concordance" between the patent class and subclass classification and the SIC. Where a subclass did not obviously belong in a single SIC industry, it was counted in all of the relevant ones, resulting in significant double counting. The industrial allocation was based primarily on the second notion of the relevant industrial classification: Patents were allocated to the industries that were expected to produce the products designed by them or to use the new processes in the manufacture of their products. The new plow patent, in the previous example, would be assigned by the OTAF concordance to the farm equipment manufacturing industry.

The OTAF concordance was criticized early on because of both the arbitrariness in the assignment of some of the subclasses and the misleading inferences that could arise from the pervasive double counting (F. M. Scherer 1982a; Luc Soete 1983).[3] One of the two most glaring examples of problems raised by such procedures was the appearance of significant and fast-growing patenting by the Japanese in the aircraft industry, a rather surprising and mysterious development given the rather rudimentary state of the Japanese aircraft industry at that time. It turned out to be the result of allocating the "engines" patents category to both motor vehicles and aircraft. Almost all of the Japanese engine patents were automobile engine patents and because patenting in the engine category was high relative to other kinds of aircraft patents, it came to dominate the aircraft patents category almost entirely. The other example was provided by the agricultural chemicals and drug industries where the assigned patents overlapped at the rate of 90 percent (!). That is, only 10 percent of the patents counted in those industries were unique to them. It is doubtful whether such heavily overlapping data can be used in economic analyses that try to learn something about sources of technical progress by examining the contrasting experiences of different industries. The OTAF "industry" data contains too little independent information on the patenting history of actual industries.

As a result of such criticisms, the 1985 version of this concordance has been improved by correcting some of the more obvious errors and by fractionalizing the allocation of dubious subclasses, reducing thereby their overall importance in the final totals. But most of the basic questions of classification still remain to be answered.

One way to get around some of these problems is to have the patent examiner assign the individual patent to one or several SIC industries, based on potential use. This is now being done in the Canadian patent system. One possibility, currently being pursued by Robert Evenson and his students, is to take a sample of U.S. patents also patented in Canada and to cross-tabulate the Canadian SIC assignments against the U.S. patent classification system, deriving thereby an empirically based and already naturally fractionalized alternative concordance (see annex A of A. S. Englander, R. Evenson, and M. Hanazaki 1988; Evenson, S. Kortum, and J. Putnam 1988; Kortum and Putnam 1989).

An alternative approach, first pursued by Scherer (1965a and 1965b) and more currently by the NBER group (see John Bound et al. 1984), starts from patent totals for particular firms and then groups them into industries according to the firm's primary activity. This is an "origin" classification. It may be useful for the analysis of firm level data, relating patents to R&D investments and the subsequent fortunes of the firms where they had been originally developed. But it is much less useful for the analysis of industrial data, both because of the conglomerateness of many of the large U.S. corporations and because particular patents may be having an impact far beyond the boundaries of their industry of "origin."

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[3] See OTAF 1985, the proceedings of the conference on the concordance, for a more detailed discussion of some of these issues.

The extensive diversification of many firms and also the various merger waves create severe technical problems in trying to use the patent data even at the individual corporation level. What is noted on the patent is the name of the organization to which it has been assigned. This organization can easily be a subsidiary or a separate division of a larger company. Moreover, a company may change its name and/or may merge. Because the patent office does not employ a consistent company code in its computer record, except for the "top patenting companies" where the list of subsidiaries is checked manually, the company patenting numbers produced by a simple aggregation of its computer records can be seriously incomplete (see B. H. Hall et al. 1988 for additional detail on this range of issues).

Because of such considerations and because he was interested in tracing through the spillover effects of R&D on productivity in industries that were most likely to benefit from them, Scherer (1982b, 1984a) undertook the large task of examining over 15,000 patents awarded from June 1976 through March 1977 to the 443 largest U.S. manufacturing corporations represented in the Federal Trade Commission Lines of Business survey in 1974. There are at least two unique aspects to this data construction effort: First, each patent was examined individually, classified as to product or process invention, and assigned to up to three potential industries of "use" or two possible general use categories. In addition, the patent was also assigned to an industry of "origin" on the basis of the information on the location of the inventors within the Lines of Business structure of the particular company. That is, and this is the second unique aspect of these data, the industry of origin was defined "below" the company level, at the more relevant "business" or divisional level, and the R&D expenditures of the companies were similarly subdivided and matched at this more appropriate industrial level. One of the final products of this work was a "technology flow" matrix, using the resulting cross-classification of patents by industry of origin and industry of use to "link" the industries in which R&D expenditures have been incurred to industries whose productivity growth may reflect the fruits of such expenditures. (Such a matrix was suggested by Schmookler 1966, p. 167.) Unfortunately, this large, one-time data construction effort does not really have a time-series dimension to it. Moreover, the FTC discontinued collecting data at the Lines of Business level in 1979, making it less likely that it could be replicated in the future.

A less ambitious but somewhat more extensive data construction effort was pursued by the NBER group (see Bound et al. 1984; Griliches, Pakes, and Hall 1987; and Hall et al. 1988), who tried to match the patent office data on patents issued to all organizations from 1969 through 1982 with income and balance sheet and stock market value data for all publicly traded manufacturing corporations, defined as of 1976, and also create a consistent historical record for them for the period 1959–81. The resulting data sets consisted of a cross-section of about 2,600 firms in 1976 (with over 1,700 firms receiving at least one patent between 1969 and 1979, about 1,000 firms applying for at least one, ultimately granted, patent in 1976, and about 1,500 firms reporting R&D expenditures in 1976) and a panel of about 1,000 to 1,800 firms with detailed data between 1963 and 1981, with a subset of about 700 firms reporting consistent R&D data between 1972 and 1980. These data sets formed the basis for a number of studies that will be discussed below.

13.3 Patents as Indicators of What?

There are two ways of asking this question: What aspects of economic activity do patent statistics actually capture? And, what would we like them to measure? Ultimately, only the first question is of relevance but it is useful to spend some time on the second, because it provides some understanding of the research in this field.

Roughly speaking, we would like to measure and understand better the economic processes that lead to the reduction in the cost of producing existing products and the development of new products and services. We would like to measure both the inputs and the outputs of such processes, to understand what determines the allocation of resources to such "technology changing" activities, and also what is happening and why to the efficiency with which they are pursued in different times and in different places. Assuming that different new products can be brought to a common denominator through the use of some meta-hedonic function, one can think of invention as shifting outward the production possibilities frontier for some generalized aggregate of potential human wants. Ideally, we might hope that patent statistics would provide a measure of the output of such an activity, a direct reading on the rate at which the potential production possibilities frontier is shifting outward. The reality, however, is very far from it.

The dream of getting hold of an output indicator of inventive activity is one of the strong motivating forces for economic research in this area. After all, a patent does represent a minimal quantum of invention that has passed both the scrutiny of the patent office as to its novelty and the test of the investment of effort and resources by the inventor and his organization into the development of this product or idea, indicating thereby the presence of a non-negligible expectation as to its ultimate utility and marketability. One recognizes, of course, the presence of a whole host of problems: Not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in "quality," in the magnitude of inventive output associated with them. The first two problems, one thinks, can be taken care of by industry dummy variables, or by limiting the analysis to a particular sector or industry. For the third, one tries to invoke the help of the "law of large numbers": "The economic . . . significance of any sampled patent can also be interpreted as a random variable with some probability distribution" (Scherer 1965b, p. 1098). The question whether our samples are large enough, given the underlying heterogeneity in what is measured by a patent, is a topic to which I shall return below.

It is interesting to note that Schmookler started out thinking that he could use patent statistics as an index of inventive output and as an explanation of the growth in the aggregate efficiency of the U.S. economy. Schmookler was the first, as far as I can tell, to publish numbers on aggregate "total factor productivity growth" (Schmookler 1952) (though he never seemed to have claimed much originality for it), and to relate them to patent statistics (Schmookler 1951). Unfortunately, the relationship did not work. There seemed to be little correlation between aggregate total factor productivity and total patenting numbers. Schmookler did not give up on patent statistics but ultimately redefined what he thought they could do. In his hands patents became an index of inventive "activity," primarily an input rather than an output index.

He moved, essentially, in the direction of what patents can measure rather than what we would want them to measure. His interpretation of inventive activity became quite narrow. It excluded research, which he interpreted as a search for new knowledge, an attempt to discover new properties of classes of objects or processes, and it also excluded development, which is largely the development and refinement of already made inventions (even though quite a few patents are likely to be generated also during this phase). Inventive activity per se is "work specifically directed towards the formulation of the essential properties of a novel product or process" (Schmookler 1966, p. 8). This is an "input" definition, to be thought of as computable in man-hour equivalents, and corresponds to only a very thin slice, both quantitatively and in the time dimension, of what is usually covered by the notion of R&D and the associated R&D statistics.

One should keep in mind, however, the historical context of most of the earlier work on patents. There were no R&D expenditure statistics of any generality before the late 1950s and only scattered numbers on scientists employed in different industrial laboratories or on the distribution of the technically trained labor force (see David Mowery 1983). Thus, an indicator of input was also valuable. There was almost no substitute for it. Even today, with data much more plentiful, the available detail in the published R&D statistics is still quite limited. Thus, as I shall argue below, showing that patent statistics are a good indicator of inputs into inventive activity is a useful accomplishment on its own merit. It allows us an insight into what is going on in more areas and also in much more detail than is possible to glimpse from the available R&D statistics.

How does one come to know whether patent statistics measure anything interesting? Input or output? One way is to look for correlations between patent counts and other variables that are thought to matter: input measures such as R&D expenditures, and output measures such as productivity growth, profitability, or the stock market value of the firm. It is useful, therefore, to introduce here a figure (Figure 13.3) from Pakes and Griliches (1984) which essentially restates the previous sentence in graphic terms and allows a more detailed discussion of its underlying assumptions.

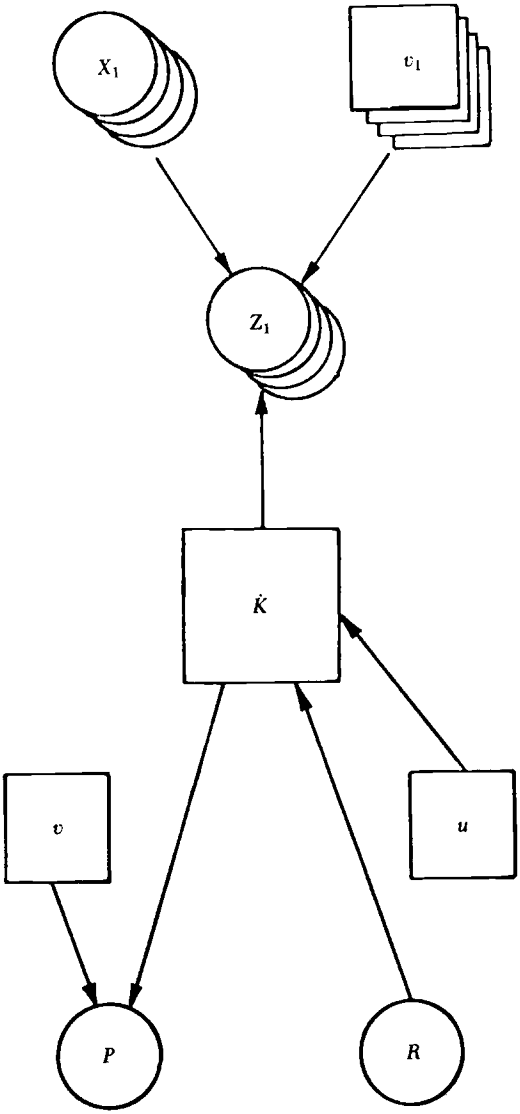

Fig. 13.3 Knowledge production function: a simplified path analysis diagram
Source: Pakes and Griliches (1984), figure 3.1.
Notes: R = research expenditures.
$\dot{K}$ = additions to economically valuable knowledge.
P = patents, a quantitative indicator of the number of inventions.
Z's = indicators of expected or realized benefits from invention.
X's = other observed variables influencing the Z's.
u, v = other unobserved influences, assumed random and mutually uncorrelated.

In the center of Figure 13.3 is an unobservable variable, $\dot{K}$, the net accretion of economically valuable knowledge. This is the variable that we would like to measure. It is the measure of "inventive output" which one would hope that patents would be a good indicator of. The diagram indicates that and adds an error v to the determinants of patenting, making them an imperfect, fallible measure of $\dot{K}$. The causal part of this diagram starts in the lower right-hand corner with some observable measure of resources invested in inventive activity (R), usually R&D expenditures, or the number of research scientists, which are directed at the production of $\dot{K}$. Because knowledge production is stochastic, the u term is added to reflect its changing efficiency and the impact of other informal and unmeasured sources of $\dot{K}$. The variables that we are ultimately interested in explaining are represented by the Z's. These could be various measures of growth, productivity, profitability, or the stock market value of a firm or industry. They are all affected by the unobservable $\dot{K}$, by other measurable variables X, and by additional random components, the e's.

A number of extreme simplifications were made in drawing this figure and in defining the various terms. For example, the relationship between $\dot{K}$ and K should be defined explicitly to allow for the possibility of decay in the private value of knowledge. Also, R is taken as exogenous. If, as is likely, the u's are correlated over time, then one might expect them to feed back into R in subsequent periods. Nor do patents play an explicit economic role here. They are just an indicator of $\dot{K}$. The assumption being made is that some random fraction of $\dot{K}$ gets patented. It is a statistical descriptive model rather than a "theory" of patenting. A "theory" would have to be more explicit about the conditions (economic, technological, and legal) under which the benefits from applying for a patent outweigh the direct costs of application and the potential consequences of disclosing the technology. This would add more structure to the relationship between P and $\dot{K}$.

Such a theory would start with the underlying notion of a research project whose success depends stochastically on both the amount of resources devoted to it and the amount of time that such resources have been deployed. Each technical success is associated with an expectation of the ultimate economic value of a patent to the inventor or the employer. If this expectation exceeds a certain minimum, the cost of patenting, a patent will be applied for. That is, the number of patents applied for is a count of the number of successful projects (inventions) with the economic value of the patent right exceeding a minimal threshold level. If the distribution of the expected value of patenting successful projects remains stable, and if the level of current and past R&D expenditures shifts the probability that projects will be technically successful, an increase in the number of patents can be taken as an indicator of an upward shift in the distribution of $\dot{K}$. Whether the relationship is proportional will depend on the shape of the assumed distributions and the nature of the underlying shifts in them. What is depicted in Figure 13.3 is at best a very crude reduced-form-type relation whose theoretical underpinnings have still to be worked out. But one has to start someplace.[4]

There are also ambiguities in the definition of $\dot{K}$ and K. Are we talking about private or social returns to knowledge? That depends on the Z's available to us and the question we are particularly interested in answering. For an analysis of productivity movements at the level of industries, it is the social value that we care about. For an analysis of the stock market value of different firms, only the private value version makes any sense. One may also wish to distinguish between the value of patent *rights* and the economic value of a particular patent. It is the latter notion that we might be interested in, though it is the former that is likely to show up in survey responses of patentors or be implicit in the decision whether to pay a fee and renew a particular patent. Nevertheless, Figure 13.3 does provide a schema for discussing much of the research in this area and in particular the question of the "quality" of patent counts as indicators of economically valuable knowledge.

There are several different ways of rephrasing this question: (1) How good is P as an indicator of $\dot{K}$? (2) If P is an "output" measure and R is an "input" measure, are we better off in having one or the other if we had to, or could, make such a choice? (3) What is the value added of P, above and beyond R, to the explanation of the Z's? Because $\dot{K}$ is intrinsically unobservable, the first question cannot really be answered without embedding it in some model such as is sketched out in this figure. It may be helpful, at this point, to write down the simplest possible model that might correspond to this figure:

$$\dot{K} = R + u\,,$$

$$P = a\dot{K} + v = aR + au + v\,,$$

$$Z = b\dot{K} + e = bR + bu + e\,,$$

where the first equation is the "knowledge production function" with the unobservable $\dot{K}$ being measured in units of R; the second equation is the indicator function relating P to $\dot{K}$; and the third equation represents the influence of $\dot{K}$ on subsequent variables of interest. The important assumption that will be made here is that the various random components u, v, and e are independent of each other. I need not repeat the caveats about the simplicity of this model. It is adequate, however, for making the following points: (1) The "quality" of P as an indicator of $\dot{K}$ depends on the size of v, the error in the indicator relationship. If we take its variance as a measure of its error and we substitute R for $\dot{K}$ in this relationship, as in the right-hand part of the second equation above, we see that under the assumptions of the model the "quality" of the

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[4] Of course, one need not start here. It is a particularly American view, which finds thinking in terms of a "production function of knowledge" congenial and useful, and looks for patents to serve as a proxy for the "output" of this process. Less "neoclassically" oriented economists would deny the usefulness of this view or the uniform direction of causality that it implicitly espouses.

relationship between P and R provides a lower bound on the "quality" of P as an indicator of $\dot{K}$. That is, $\text{var}(au + v) > \text{var}(v)$. This argument suggests looking at the correlation between P and R and claiming that if $\dot{K}$ is the output of the R process and P is an indicator of its success then the correlation between P and $\dot{K}$ would have been even higher, if it could have been measured. This is the sense in which the correlation coefficient between P and R provides a downward biased measure of the quality of P as a indicator.[5] (2) The comparative qualities of P and R as proxies for $\dot{K}$ depend on the relative size of the variance of v and u. If the error of measurement in P is large relative to the stochastic fluctuation in $\dot{K}$, then R may be the better variable even if it does not reflect u. (3) If the stochastic component of $\dot{K}$ is important and if P actually captures any of it, there should be some value added in P above and beyond R. But if the error of measurement in P is large and the samples are small, we may not really see it in the regressions results when P is included as an additional variable.

13.4 Patents and R&D

In the attempt to "validate" patents as an economic indicator, investigators have repeatedly examined the relationship of patents to R&D activity. Schmookler (1966, ch. 2) and Scherer (1965a) are leading examples of earlier investigations. More recent results can be found in Bound et al. (1984), Hall, Griliches, and Hausman (1986), Pakes and Griliches (1984), Scherer (1983), and Acs and Audretsch (1989). Several conclusions as well as a number of unresolved questions emerge from this work.

A major conclusion, emphasized by Pakes and Griliches, is that there is quite a strong relationship between R&D and the number of patents received at the cross-sectional level, across firms and industries. The median R-square is on the order of 0.9, indicating that patents may indeed be a good indicator of unobserved inventive output, at least in this dimension. That this relationship is not just due to size differences can be seen in Figure 13.4 (taken from Bound et al. 1984), which plots both patents and R&D per unit of a firm's assets.

The same relationship, though still statistically significant, is much weaker in the within-firms time-series dimension. The median R-square here is on the order of 0.3 (in contrast to the 0.9 in the cross-sectional dimension). Nevertheless, the evidence is quite strong that when a firm changes its R&D expenditures, parallel changes occur also in its patent numbers. The relationship is

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[5] This conclusion depends on the additive nature of the error in the indicator function. If $\dot{K}$ were to be looked at just as an aggregation of inventive events, each with a potential value of its own, drawn independently from some value distribution, and P counted only some fraction of such events and was not related to their values (as in the calculations outlined in Section 13.6), then the above inequalities would not hold anymore. If, on the other hand, the patenting decision itself were a function of the size of the expected gain from the invention, as noted in the text, then the situation would be somewhere in between.

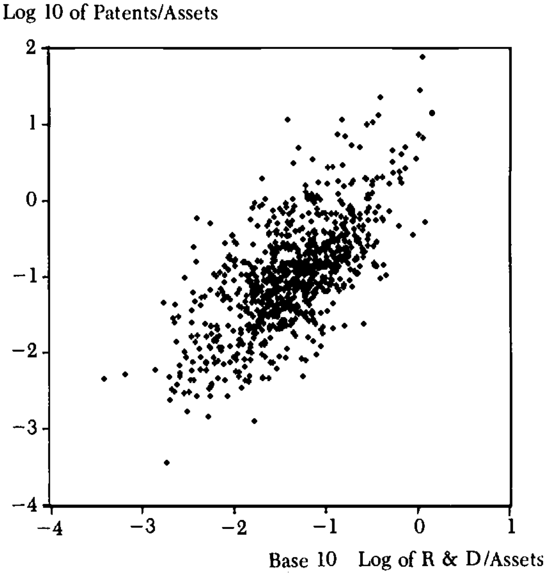

Fig. 13.4 Log of patents/assets versus log of R&D assets
Source: Bound et al. (1984), figure 2.4.

close to contemporaneous with some lag effects which are small and not well estimated (Hall, Griliches, and Hausman 1986). This is consistent with the observation that patents tend to be taken out relatively early in the life of a research project. Because the bulk of R&D expenditures are spent on development, most of the time-series variance in this variable must come from the differential success in the further development of existing projects rather than from the initiation of new ones.[6] The relatively low correlations in the time dimension should, therefore, not be all that surprising, but they imply that patent numbers are a much poorer indicator of short-term changes in the output of inventive activity or the "fecundity" of R&D.

The question "Are there diminishing returns to R&D?" hovers over much of this work. In the cross-sectional dimension it is related to the "Schumpeterian" question whether large firms and large R&D labs are more or less efficient as "engines of innovation" (see William Baldwin and John Scott 1987, ch. 3, and Cohen and Levin 1989 for more general reviews of this topic). In the time-series dimension one is faced with the declining ratio of patents received per R&D dollar spent and the worry that technological and inventive opportunities are being exhausted. There is also the question of how one reconciles the significantly larger estimates of the elasticity of patenting with respect to R&D in the cross-sectional versus the time-series dimension.

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[6] To the extent that some patents arise in the development stage, they would also be related to R&D with only a short lag.

At the cross-sectional level the story is relatively simple. Small firms appear to be more "efficient," receiving a larger number of patents per R&D dollar. This can be seen most easily in Figure 13.5 (from Bound et al. 1984), which plots the patents per R&D ratio as a function of the size of the R&D program. It shows both the much higher ratio for small firms and the fact that this relationship becomes effectively flat beyond some minimum size. At the larger firm level, where antitrust policy might be relevant, there is no strong evidence of diminishing returns to the size of the R&D effort. (This is also the conclusion reached by Scherer (1983) on the basis of a different and better set of data.) Given the nonlinearity and the noisiness in this relation, the finding of "diminishing returns" is quite sensitive to functional form, weighting schemes, and the particular point at which the elasticity is evaluated.

All of this can be seen in Figure 13.6, also taken from Bound et al., which plots the original data and the results of fitting various different models to the same data. Two of the estimation techniques, Poisson and nonlinear least squares (NLLS) indicate diminishing returns, while the other two techniques, ordinary least squares (OLS) and negative binomial (NB), imply increasing returns. A glance at the figure will make it clear how a differential emphasis on parts of the data (large versus small firms and the treatment of zeroes—not visible in the figure) could result in such conflicting estimates. Basically there is a sharp contrast between smaller and larger firms. For larger firms the relationship is close to linear while there is a reasonably large number of smaller firms that exhibit significant patenting while reporting very little R&D. When divided into two samples, small (N = 1,015) and large (N = 483), with $2 million in R&D expenditures as the dividing line, the estimated average elasticities are 0.44 and 1.04 respectively. The latter number falls to 0.8 (0.1) if one allows separately for the zero patents observations. Though this estimate of the elasticity of patenting with respect to R&D for the larger firms is still "significantly" less than unity at conventional test levels, allowing for the possibility that the R&D numbers are themselves subject to error, one cannot really reject the hypothesis of constant returns in this size range, because the "reciprocal" regression of R&D on patents implies increasing returns to or decreasing costs of getting a patent. (The estimated elasticity of R&D with respect to patents is 0.76.)

The appearance of diminishing returns at the cross-sectional level is due, I think, primarily to two effects: selectivity and the differential role of formal R&D and patents for small and large firms. Most of the data sets available to us are not based on a random or carefully stratified sample from the relevant underlying population. Rather, they are "opportunity" samples, based on other criteria. For example, the 1976 cross-section of Bound et al. is based on all manufacturing firms listed on the New York and American stock exchanges and also on the over-the-counter market. But while almost all relevant large firms are so listed, only a relatively small number of the smaller firms trade in these markets. To be included in (listed on) the market, a small firm has to be

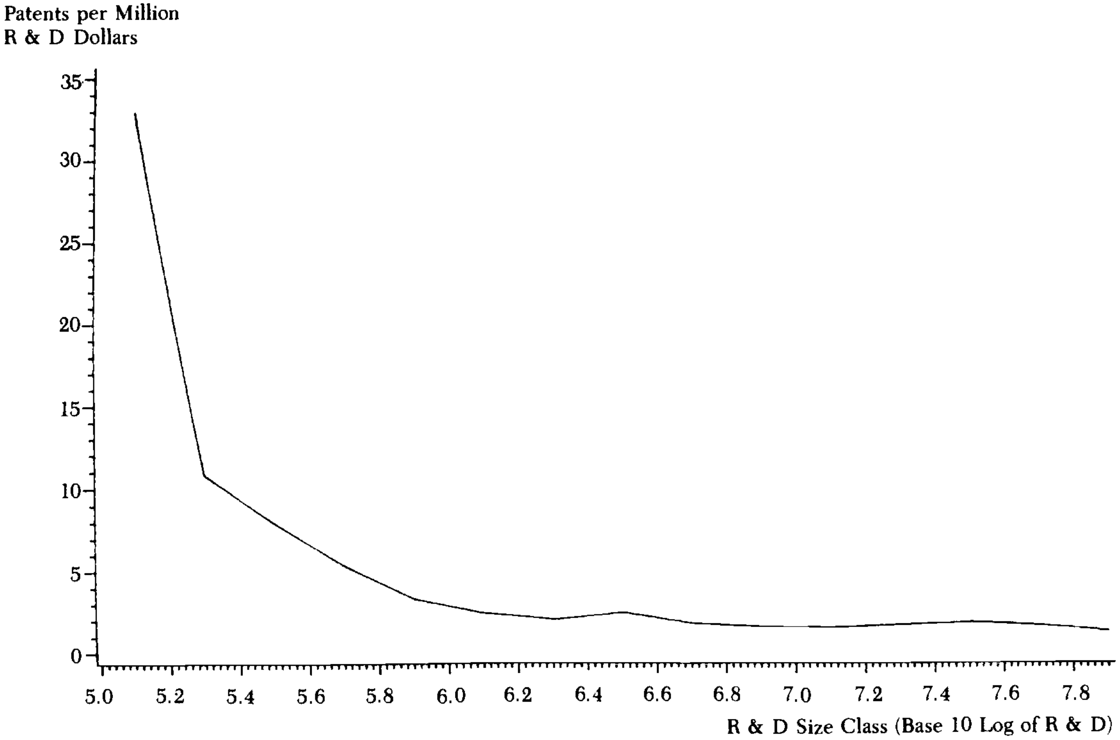

Fig. 13.5 Patents per million R&D dollars by R&D size class for firms with both R&D and patents

Source: Bound et al. (1984), figure 2.6.

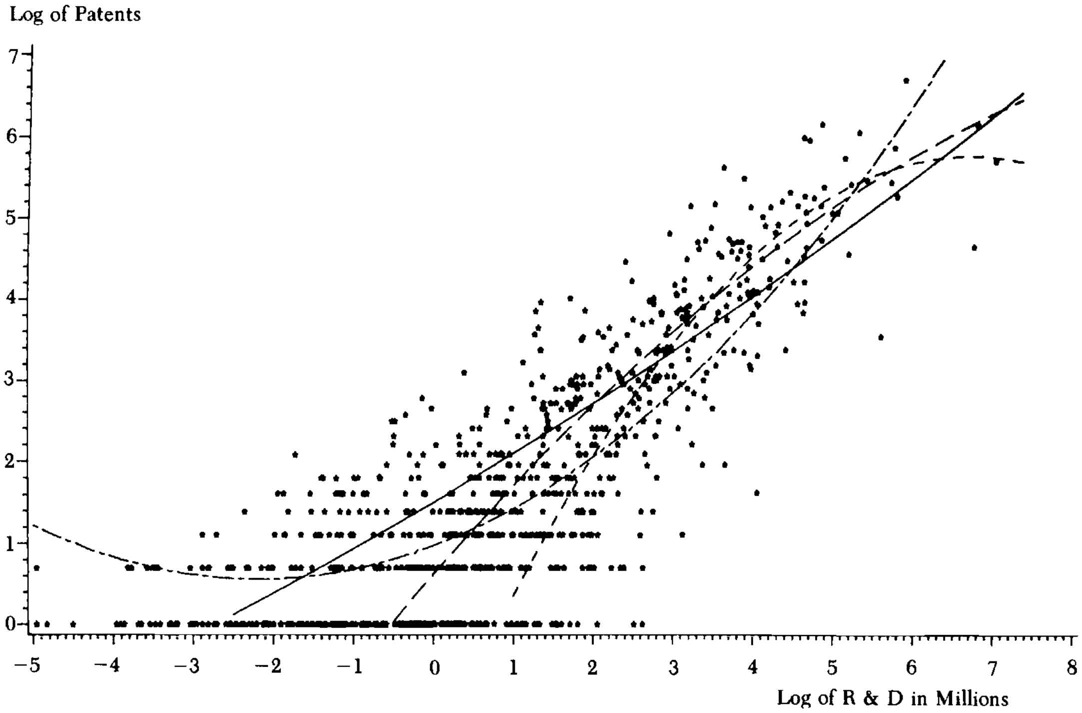

Fig. 13.6 Predictions of various patents models

Source: Bound et al. (1984), figure 2.5.

Note: *** = data; — = negative binomial; - - - = nonlinear least squares; — — — — — = ordinary least squares; — — = Poisson.

in some sense more "successful" than those that are not, more "interesting" to the traders. Thus, it is not surprising that it may also hold more patents than might be expected, given its size and R&D program. How atypical these small firms might be is suggested by the rarity of their selection. Table 13.1 shows the number of firms by size (employment) in this cross-section and the corresponding numbers in the relevant population. While about two-thirds of the large manufacturing firms are included, the smaller ones represent less than 1 percent of all small firms and are obviously a heavily selected lot. Unfortunately, we have no information on the firms not in the sample and hence cannot make an appropriate sample selectivity adjustment.

Another source of the difference between small and large firms is in the role of formal R&D in them and the differential importance of patents to them. A significant amount of patenting is not the result of formal R&D activities though the relative importance of organized R&D rises with the size of the company. Small firms are likely to be doing relatively more informal R&D, reporting less of it, and hence providing the appearance of more patents per reported R&D dollar.[7] Also, for such firms patents may represent their major hope for ultimate success and hence would lead them to pursue them with more vigor. A well-established major firm does not depend as much on current patenting for its viability or the survival of its market position. Thus, even at equal underlying true inventiveness rates, the propensity to patent may be lower for large firms, at least relative to the successful new entrants in their field. But in the major range of the data, from middle size to giant firms, there is little evidence for diminishing returns, at least in terms of patents per R&D dollar.[8] That is not surprising, after all. If there were such diminishing returns, firms could split themselves into divisions or separate enterprises and escape them.

The time-series dimension has been examined most extensively by Hall, Griliches, and Hausman (1986) (see also Pakes and Griliches 1984 and Jerry Hausman, Hall, and Griliches 1984). The estimated total elasticity of patents with respect to R&D expenditures is between 0.3 and 0.6, even after allowing for several lagged effects. This finding, in contrast to the cross-sectional results, is robust with respect to differential weighting and alternative estimation methods. It is tempting then to accept the diminishing returns result in the

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[7] Sirrilli (1987) shows that in small firms in Italy (fewer than 100 employees) over a third of the inventors (36 percent) come from production and quality and control activities, while in the large firms (more than 1,000 employees) only 11 percent of the inventors come from this category. The proportion of patents originating in formal R&D rises from 39 percent in small firms to 63 percent in the large ones with the rest (25 and 26 percent) being in the more ambiguous "design" category. Similar conclusions can also be inferred from A. Kleinknecht (1987), who reports a significant underestimate of R&D activities in small firms by the conventional data collection methodology.

[8] See Jensen (1987) for similar results using new chemical entities rather than patents. For contradictory evidence, using other measures, see Scherer (1984b, ch. 11) and Acs and Audretsch (1989).

Table 13.1 **Selectivity of Firms in 1976 Cross-Section, by Size of Employment**

Employment	Number of Firms in Cross-Section[a]	Number of Firms in Census of Enterprises[b]	Ratio
<10	24	16,000	.0015
10–99	301	14,300	.021
100–999	952	9,000	.106
1,000+	1,267	1,900	.667
Total	2,541	41,200	.062

[a] With good employment data. Computed from the data used in Bound et al. (1984).

[b] In comparable manufacturing industries. From U.S. Bureau of the Census (1981), table 3, pp. 152–98.

within-time-series dimension and interpret it as reflecting real diminishing returns, in terms of patents received, to the expansion of existing research programs. But this conclusion is unnecessary. The relationship between annual changes in R&D and in patenting is very weak, although "statistically" significant, at the firm level. If one allows for the possibility that much of the annual fluctuations in R&D has little to do with that part of inventive activity that generates patents, being largely the result of fluctuations in and vagaries of the development portion of the various research projects, then the "relevant" R&D is measured with error and the estimated coefficients are downward biased. This is not a pure "measurement error" case, because reported R&D may be correctly reported as far as its own definition goes, but not exactly in the way we want (R&D directed at patentable inventions). This is parallel to the transitory-permanent distinction in consumption theory and is isomorphic to the "errors-in-variables" model. Invoking the latter, we may be able to "bracket" the true returns to scale coefficient by running the regression the other way, R&D on patents, and computing the reciprocal of the resulting coefficient. The low correlation between the two rates of change results also in a very low coefficient in this second dimension, on the order of 0.1–0.2, and an implication of *increasing* returns. The latter should not be taken seriously either, because it is the result of the great randomness in the patent series themselves. The point of this digression is, however, to remind one that the appearance of diminishing returns in such data could be an artifact of the incompleteness of the underlying data rather than a reflection of the characteristics of the invention process itself. As of the moment, the evidence is suggestive but not conclusive.

Besides differing by size of firm, the R&D to patents relationship differs also across industries. In absolute terms, the industries with the largest numbers of patents are drugs, plastics, other rubber products, and computers (in Scherer's line of business-based data) and instruments, communication equipment, and industrial chemicals (in the OTAF concordance–based data). In terms of the "propensity to patent" (patents per R&D dollar), the differences are less apparent and more difficult to interpret. One can look at the tables (5–9) in Griliches (1989) or the appendix to Iain Cockburn and Griliches (1988) and observe that industries with a "low" propensity to patent include obvious cases of large R&D industries with significant governmental research support, such as motor vehicles and aircraft, who patent very much less than would be predicted from their R&D numbers alone. Among the industries with a "high" propensity to patent, besides the expected presence of communication equipment, there are a number of industries (such as screws, nuts, and bolts) whose appearance is due to their doing very little R&D but still taking out occasional patents. An attempt to explain the dispersion in such numbers across industries using data from the Yale Survey (Levin et al. 1987) on the perceived differential effectiveness of patents as a method of appropriating the benefits from innovation was largely unsuccessful. The patent to R&D ratios appear to be dominated by what may be largely irrelevant fluctuations in the R&D numbers and the Yale Survey responses themselves appear to have little relevant cross-industry variability in them (see Griliches 1987; Cockburn and Griliches 1988; and Cockburn 1989). For example, while the drug industry has the highest rating on the "patents provide protection" scale, its patents per R&D ratio is much lower than that for firms in the paper industry, where the effectiveness of patents is rated to be somewhat below average (see Cockburn and Griliches 1988, appendix C). Because the effectiveness of patents as an appropriability mechanism will affect also the incentive to do R&D, the resulting impact on the ratio of the two is far from obvious. In drugs it clearly encourages research with the result that even with extensive patenting the observed ratio is not much above average. Thus, it is probably misleading to interpret such numbers as being direct indicators of either the effectiveness of patenting or the efficiency of the R&D processes.

13.5 Patent Rights and Patent Values

Because the economic significance of individual patents is so variable, there has been continued interest in trying to estimate the average value of patent rights, the average value of the invention represented by a particular patent, and the dispersion in both of these concepts. Looking at patents as indicators of success of the underlying inventive activity or R&D program, we are mainly interested in the second concept. The available data, however, are mostly informative only about the first: the value associated with the differential legal situation created by the possession of the patent.

There are basically three sources of data on this topic: (1) Results of direct surveys of patent owners or assignees about past returns and the potential market value of their rights. (2) The valuation implicit in the decision whether to pay a fee to renew the patent, a decision that had to be made by European patent holders in the past and is now also facing U.S. patent holders. (3) Econometric analyses of the relationship of some other value-denominated variable, such as profits or stock market value, to the number of patents. An example is the use of patent numbers as a proxy for "intangible" capital in stock market value of the firm regressions.

The most detailed and extensive survey of patent holders was conducted over 30 years ago by Barkev Sanders and associates at the Patent and Trademarks Foundation (see J. Rossman and B. S. Sanders 1957; Sanders, Rossman, and L. J. Harris 1958; and Sanders 1962, 1964, and the discussion of it in Schmookler's book, 1966, pp. 47–55). They conducted a mail survey in 1957 of the owners and assignees of a 2 percent random sample of all patents issued in 1938, 1948, and 1952. There were two major findings in this survey: (1) A surprisingly large fraction of all sampled patents was reported to have been "used" commercially, either currently or in the past. The actual fraction "used" is sensitive to the treatment of nonresponse: It is over 55 percent for those responding and about 41 percent if one assumes that nonresponse is equivalent to nonuse. The "use" percentage is higher for "small" companies, but so also is the nonresponse rate (71 percent used among respondents, 40 percent if adjusted for nonresponse). Thus, it is not true that most patents are never used and are hence not associated with a significant economic event. This finding is also consistent with the renewal information to be discussed below. In Europe, about 50 percent of all patents granted are still being renewed and a renewal fee is being paid ten years after they had been applied for. (2) The reported economic gain from the innovations associated with these patents was highly dispersed. Among the patents reported to be in current use and with relevant numerical responses and a positive gain (accounting for about 20 percent of all the relevant responses), the mean value was $577,000 per patent, but the median value was only about $25,000 (implying, under the assumption of log normality, 2.5 as the coefficient of variation and a standard deviation of about $1.5 million). If one includes all the no gain, loss, and not yet used patents, the mean gain falls to about $112,000, and the median is close to zero or below (computed from the tables in Sanders, Rossman, and Harris 1958, pp. 355 and 357). Even this lower mean number is quite impressive, roughly equivalent to $473,000 per average patent in 1988 prices (using the GNP deflator to convert it from 1957 prices), but so also is the associated dispersion. Scherer (1965b) reports that fitting a Pareto-Levy distribution to these data graphically yielded an estimate of the exponent (α) of about 0.5, implying a distribution with no finite mean or variance. If this were truly the case, then even in large samples the mean value of patents would not converge rapidly, if at all, to its underlying population average.

There have been only very few other attempts at such a survey and they all reach rather similar conclusions. Schmookler (1966, pp. 54–55) reports on a small mail sample with a mean value of $80,000 and a median of about zero. In 1982 the Chemistry Program of the NSF decided to evaluate the economic value of patents attributable to its grants (Cutler 1984). Of the 96 patents surveyed, 52 had been licensed or were deemed licensable with an average "economic value" of about $500,000 per patent. (The concept of "economic value" is unclear in this study. It appears to refer to total potential sales of the product rather than net returns to the owners of the patent.) A related study, done for the NSF by SRI International (1985), examined a sample of patents received by the grantees of the Engineering Program and estimated the royalty potential of each patent, which turned out to be about $73,000 on average, again with a very large dispersion. A more representative and large-scale survey of patent holders is both feasible and desirable but nothing has been done in this regard since 1957 and there does not seem to be anything like it in the works either in the U.S. or abroad.

In many countries and recently also in the U.S., holders of patents must pay an annual renewal fee in order to keep their patents in force. If the renewal fee is not paid in any single year the patent is permanently canceled. If we assume that renewal decisions are based on economic criteria, agents will renew their patents only if the value of holding them over an additional year exceeds the cost of such renewal. Observations on the proportion of patents that are renewed at alternative ages, together with the relevant renewal fee schedules, will then contain information on the distribution of the value of holding patents, and on the evolution of this distribution function over the lifespan of the patents. Because patent rights are seldom marketed, this is one of the few sources of information on their value. In a series of papers Pakes and Schankerman (1984), Pakes (1986), and Schankerman and Pakes (1986) present and estimate models that allow them to recover the distribution of returns from holding patents at each age over their lifespan. Because the renewal decision is based on the value of patent protection to the patentee, the procedure used in these articles directly estimates the private value of the benefits derived from the patent laws.

In Figure 13.7 typical European data on renewal fees and patent survival proportions are reproduced from Schankerman and Pakes (1986). They indicate several interesting facts that should be kept in mind. About half of all patents are renewed through age 10, indicating a significant expectation of some "usefulness" for the majority of patents for some non-negligible time period. On the other hand, the same data indicate that about half of all patents are not renewed within ten years, indicating that the expected value of the future income stream from these rights has fallen below the rather low renewal cost. This implies that the majority of patents are either of low value, or that their value depreciates (obsoletes) rapidly, or both. About 10 percent of all patents survive and pay the fees for the whole statutory period and obviously include a smaller number of very valuable patents. Pakes and Schankerman use these facts in their various papers to construct models of the renewal process and estimate both a distribution of the underlying patent right values and also their rate of depreciation. Given the existence of an open-ended class of patents in these data (those paying the renewal fees throughout the whole period) and the rather low and relatively stable renewal fee schedules, serious

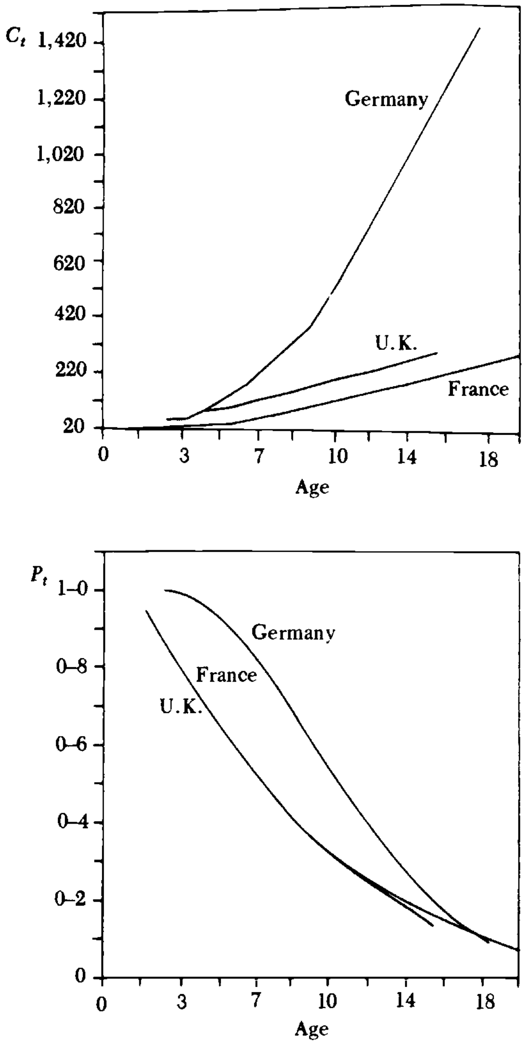

Fig. 13.7 Age paths of deflated renewal costs and renewal proportions
Source: Schankerman and Pakes (1986), figures 2 and 3.
Notes: *Age* = years since granting of patent.
C_t = deflated renewal costs.
P_t = proportion of patents renewed.

identification problems arise in such models. The estimates of the mean value of patent rights rest, therefore, on specific assumptions about the functional form of their distribution (how it looks in the unseen tail) and on assumptions about the form of the depreciation process. Some of these assumptions may be testable and some of the more interesting conclusions of their work do not depend on them, but ultimately we have to put some prior notions into such data to have them yield specific numerical answers. The issues of identification and estimation are discussed in much detail in the recent papers by Pakes and Simpson (1989) and Schankerman (1989), together with the presentation of interesting new results on additional countries and on industrial detail, and hence will not be pursued further here (see also J. O. Lanjouw 1989; Schankerman 1990; and Lanjouw and Schankerman 1989).

In the United States, patents that were applied for after 1980 have to pay renewal fees three and a half, seven and a half, and eleven and a half years after the granting date. These fees are currently $450, $890, and $1,340 respectively for corporations and somewhat less for individuals and "small entities." As of the end of 1988, 16 percent of the 1981–84 patents coming up to the payment of the first maintenance fee "expired," with a slightly higher expiration rate for the U.S. (17 percent) than for patents owned by foreign residents (15 percent) implying, possibly, a higher average value or "quality" for the latter.[9] An earlier study of a smaller sample of such data found that individually owned patents were expiring at a much higher rate than assigned patents (39 versus 13 percent for U.S. origin patents) and that "mechanical" patents had the highest and "chemical" patents the lowest rates of expiration (S. E. Manchuso, M. P. Masuck, and E. C. Woodrow 1987). The growing availability of such renewal data in the future will provide us with another very interesting window on the inventive process and its rewards in the U.S.

Returning to the specific results from the work on European patent renewals, using a learning model for the early years of a patent's life, Pakes (1986) finds that patents are applied for at an early stage in the inventive process, a stage in which there is still substantial uncertainty concerning both the returns that will be earned from holding the patents, and the returns that will accrue to the patented ideas. Gradually the patentors uncover more information about the actual value of their patents. Most turn out to be of little value, but the rare "winner" justifies the investments that were made in developing them. His estimates imply also that most of the uncertainty with respect to the value of a patent is resolved during the first three or four years of its life. Using this result, Schankerman and Pakes (1986) examine changes in the distribution of patent values over time and the correlates of these changes. The substantive results from these papers imply that the average value of a patent right is quite small, about $7,000 in the population of patent applications in France and the U.K. In Germany, where only about 35 percent of all patent applications are granted (about 93 percent and 83 percent were granted in France and the U.K. respectively), the average value of a patent right among grants was about $17,000. The distribution of these values, however, is very dispersed and skewed. One percent of patent applications in France and the U.K. had values in excess of

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[9] Based on unpublished tabulations of the Office of Documentation Information at the U.S. Patent Office.

$70,000 while in Germany 1 percent of patents granted had values in excess of $120,000. Moreover, half of all the estimated value of patent rights accrues to between 5 and 10 percent of all the patents. The annual returns to patent protection decay rather quickly over time, with rates of obsolescence on the order of 10 to 20 percent per year. Because about 35,000 patents were applied for per year in France and the U.K. and about 60,000 in Germany, these figures imply that though the aggregate value of patent rights is quite large, it is only on the order of 10 to 15 percent of the total national expenditures on R&D. Other means of appropriating the benefits of R&D must be, therefore, quite important.

Schankerman and Pakes used their results to adjust the aggregate patent time series for changes in their average "quality" (value). In their 1986 paper they find that even though the number of patents per scientist fell rather sharply between 1965 and 1975 in the three countries examined by them, the estimated "quality-adjusted" total value of patent rights per scientist and engineer was effectively stable in both Germany and the U.K., and dropped only slightly in France (Schankerman and Pakes 1986, table 6).[10]

13.6 Patents and Stock Market Value

Another line of work has used data on the stock market valuation of firms to investigate both the "value" of patents and the information content of the variability in their numbers. The use of stock market values as an "output" indicator of the research process has one major advantage. All other indicators of success, such as profits or productivity, are likely to reflect it only slowly and erratically. On the other hand, when an event occurs that causes the market to reevaluate the accumulated output of a firm's research endeavors, its full effect on the expected present value of a firm's future net cash flows should be recorded immediately. This, of course, need not equal what will eventually materialize. The downside of this type of measurement is the large volatility in stock market measures. The needle might be there but the haystack can be very large.

The simplest market value model starts from the market valuation identity, with the market value of the firm proportional to its physical ("tangible") and intangible capital, the latter being in part the product of its past R&D investments and possibly also reflected in its accumulated patent position (Griliches 1981; Uri Ben-Zion 1984; Hirschey 1982; Cockburn and Griliches 1988; among others). It can be written as follows:

$$V = q(A + gK) = qA(1 + gK/A),$$

where V is the market value of the firm, A is the current replacement cost of its tangible assets, K is its level of intangible ("knowledge") capital and g is its

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[10] See Pakes and Simpson (1989) and Schankerman (1989 and 1990) for an extension of these results and M. Trajtenberg (1990) for another approach to the same problem.

relative shadow price, and q is the current premium or discount of market value over the replacement cost of tangible assets.[11] Writing q as $\exp(a + u)$, where a represents individual firm differences in average valuation due to the exclusion of other unmeasured capital components or market position variables, taking logarithms, and approximating $\log(1 + x) = x$, we can rewrite the estimating equation as:

$$\ln Q = \ln(V/A) = a + gK/A + u\,,$$

where the dependent variable is the logarithm of what has come to be called *Tobin's Q*. Using different measures of current and past patents and current and past R&D expenditures as proxies for K, various researchers have estimated this kind of equation. Table 13.2 reproduces a number of results from the Cockburn and Griliches study. It shows that if we look at patents alone the estimated value of a recent patent is about $500,000. This estimate is halved when we put both past and current R&D expenditures in the equation. By and large, R&D is the "stronger" variable. The evidence for additional information in the patent variables varies from sample to sample (patents were stronger in the Griliches 1981 study, which was based on a much smaller sample of firms but also used the panel aspects of the data) and depends on which other variables are included in the equation (see the change in the coefficient from column 2 to 3 in this table).[12]

A more dynamic point of view is taken by Pakes (1985) in his analysis of the relationship between patents, R&D, and the stock market rate of return. Events occur that affect the market value of a firm's R&D program and what one estimates are the reduced-form relationships between the percentage increase in this value and current and subsequent changes in the firm's R&D expenditures, its patent applications, and the market rate of return on its stock. His empirical results indicate that about 5 percent of the variance in the stock market rate of return is caused by the events that change both R&D and patent applications. This leads to a significant correlation between movements in the stock market rate of return and unpredictable changes in both patents and R&D expenditures, changes that could not be predicted from past values of patents and R&D. On average, an "unexpected" increase in one patent is associated with an increase in the firm's market value of $810,000, while an unexpected increase of $100 of R&D expenditures is, on average, associated with a $1,870 increase in the value of the firm. Patents are estimated to contain a significant noise component (a component whose variance is not related to either the R&D or the stock market rate of return series). This noise component accounts for only a small fraction of the large differences in the number of patent applica-

[11] This equation would hold exactly in a world in which all assets were fully traded in the same market. More generally, such an equation is valid in a multicapital setting only under very stringent conditions, such as the linear-homogeneity of the profit function. See Wildasin (1984) and Hayashi and Inoue (1990) for more discussion.

[12] See Hall (1988), ch. 2, for similar results.

Table 13.2 **The Stock Market's Relative Valuation of R&D and Patents; Dependent Variable: Log (Q)**

SP/A	0.493	0.111	0.246
	(0.165)	(0.094)	(0.082)
K/A		1.374	0.741
		(0.182)	(0.152)
NR/A			11.99
			(1.556)
R^2	0.027	0.125	0.258

Source: Cockburn and Griliches (1987), table 3.

V = market value of the firm.

A = total net assets at replacement cost.

$Q = V/A$.

K = "stock" of R&D using 15 percent depreciation rate.

NR = "news in R&D": current R&D less depreciation of the R&D stock.

SP = "stock" of patents using 30 percent depreciation rate.

$N = 722$. Mean of the dependent variable = -0.272; standard deviation = 0.697.

Heteroscedasticitiy-consistent standard errors in parentheses.

All equations also contain an intercept term and the logarithm of assets, whose coefficient was small but consistently significant, on the order of -0.03 (0.01).

tions of different firms (about 25 percent), but plays a much larger role among the smaller fluctuations that occur in the patent applications of a given firm over time (about 95 percent). Similarly, the effect of unexpected increases in patents on market value is highly variable. Nevertheless, there is still some information in the time-series dimension. If we were to observe, for example, a sudden large burst in the patent applications of a given firm, we could be quite sure that events have occurred to cause a large change in the market value of its R&D program; but smaller changes in the patent applications of a given firm are not likely to be very informative.

The timing of the response of patents and R&D to events that change the value of a firm's R&D effort is quite similar. One gets the impression from the estimates that such events cause a chain reaction, inducing an increase in R&D expenditures far into the future, and that firms patent around the links of this chain almost as quickly as they are completed, resulting in a rather close relationship between R&D expenditures and the number of patents applied for. Perhaps surprisingly, Pakes finds no evidence that independent changes in the number of patents applied for (independent of current and earlier R&D expenditures) produce significant effects on the market's valuation of the firm. Hence it is not possible to distinguish between demand shocks, where demand shocks are loosely defined as events that cause increases in patenting only through the R&D expenditures they induce, and technological or supply shocks that may have a direct effect on patents as well as an indirect effect via induced R&D demand.

It is not obvious whether one can separate "demand" from "supply" factors in this area, even conceptually. One way of defining demand factors is to identify them with macro shifts in aggregate demand, population, exchange rates, and relative factor prices that make inventive activity more (or less) profitable at a given level of scientific information, a fixed "innovation possibilities frontier." Changes in technological "opportunity," on the other hand, are those scientific and technological breakthroughs that make additional innovation more profitable or less costly at a fixed aggregate or industry level demand. These distinctions are far from sharp, especially given our inability to measure the contributions of science and technology directly. Moreover, what is a technological opportunity in one industry may spill over as a derived demand effect to another. Nevertheless, there is something distinct in these factors, in their sources of change and dynamics.[13]

Patent data could help here if one were willing to assume that independent, "unanticipated" shifts in the level of patenting by firms represent shifts in technological opportunities and not responses to changes in economic conditions (demand forces). That is, the identifying assumption is that demand impinges on the level of patenting only through the level of R&D expenditures (and slowly changing trends) and that the "news" component in the patent statistics reflects technological "news," the information that a particular line of research has turned out to be more (or less) fruitful or easier (harder) than expected when the decision to invest in it was made originally. Changes in technological opportunity are thus identified with "abnormal," "unexpected," bursts (or declines) in the number of patents applied for.

Several implications of this formulation are immediate. If patent statistics contain additional information about shifts in technological opportunities, then they should be correlated with current changes in market value above and beyond their current relationship with R&D and they should affect R&D levels in the future, even in the presence of the change in market value variable because the latter variable is measured with much error. Patents should "cause" R&D in the sense of Granger (1969).

The available evidence on this point is not too encouraging: As noted above, Griliches (1981) found a significant independent effect of patents on the market values of firms, above and beyond their R&D expenditures, but Pakes did not detect a significant influence of lagged patents on R&D in the presence of lagged R&D and the stock market rate of return variables. Nor did Hall, Griliches, and Hausman (1986) find future R&D affecting current patenting as the "causality" argument might have implied. Griliches, Hall, and Pakes (1991) replicate some of Pakes's computations on a larger sample (340 firms) and expand his equation system to add equations for sales, employment, and invest-

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[13] This is, of course, related to Schmookler's distinction between patents classified by industry of origin versus industry of use. "Who does the invention" depends more on supply considerations. "For whom the invention is done" is more likely to be affected by demand shifts.

ment. Their results indicate that the addition of the latter variables is helpful, in the sense that fluctuations in their growth rates are related to fluctuations in both the growth rate of R&D and the stock market rate of return and hence should help in identifying the relationships we are interested in. But the expansion of the sample to include many small firms with low levels of patenting deteriorates significantly the informational content of this variable, raising its noise to signal ratio, and making it hard to discern a feedback from the independent variability in patenting to any of the other variables. Thus, at the moment, it does not look as if the data can sustain a model with two separate factors ("market" and "technological" innovations), even though in principle such a model is identifiable.

The difficulties in implementing such models arise to a large extent from the large "noise" component in patents as indicators of R&D output in the short-run within-firm dimension. While the problem may have been obvious from the beginning, it was the work of Pakes and Schankerman (1984) and their estimates of the dispersion and the skewness in patent value that alerted us to its actual magnitude.

To derive quantitative implications of such a skewed distribution of values for the quality of this indicator we can combine what we know about patent counts in both the time-series and cross-section dimension with estimates of the distribution of their values.

One can write the innovation in the value of the firm (net of its expected dividend and investment policy) as the sum of three components:

$$q_t V_t = w_t + \eta_t + u_t,$$

where q_t is the rate of return on stock holding, V_t is the total market value of the firm's assets, and the three components w_t, η_t, and u_t are defined to be orthogonal to each other; w_t corresponds to the change in the value of a firm's R&D "position" (program) arising from the "news" associated with current patent applications; η_t reflects revaluations of previous achievements associated with past patents (above and beyond their correlation with current patents); while u_t reflects all other sources of fluctuation in the value of the firm, including also possibly the contribution of not patented R&D. Looking first at w_t and the role of patent numbers as an indicator of it, we can ask about the possible magnitude of the variance of w_t (relative to the variance of $q_t V_t$). That is, how large could the contribution of current patents be to the explanation of fluctuations in market value, even if we had a perfect measure of these *values?*

To decompose the variance of the first component, we write it as

$$w = \sum_{i=1}^{p} y_i$$

and assume that (1) p, the number of patents applied for each year, is distributed as a Poisson random variable with a mean, λ, which is a distributed lag of past R&D expenditures (see Hausman, Hall, and Griliches 1984); and (2) y_i

is the underlying value of each patent and is distributed as a log-normal random variable with a mean and variance that will be derived from the earlier literature.

The first two moments of w (under independence) are

$$E(w) = E(py) = \lambda E(y) \qquad \text{where } \lambda = E(p)$$

$$V(w) = V\left(\sum_{i=1}^{n} y_i\right)\lambda V[y] + \lambda(Ey)^2.$$

The component of the variance of w that could be accounted for by patent *numbers* corresponds to the last term

$$\text{var}[p\bar{y}] = \lambda\bar{y}^2,$$

and its relative size is given by

$$\begin{aligned}\text{var}(py)/\text{var}(w) &= 1/[1 + V(y)/E(y)^2] \\ &= 1/(1 + \tau^2),\end{aligned}$$

where τ is the coefficient of variation in the distribution of patent values.

Turning to the literature for some order of magnitude estimates of various parameters, we have estimates of the mean value of the news associated with patents in the U.S. of between $200,000 (Griliches 1981) and $800,000 (Pakes 1985) per patent. There is also some information on this point in Griliches, Hall, and Pakes (1991): an estimate of $98,000 per unexpected patent at the geometric mean of their data (with a very large standard error). For the drug industry, where patents are more important, there is a larger and somewhat more precise estimate: an $821,000 average increase in the value of the firm per unexpected patent. This, in fact, is very similar to the Pakes estimate which was based on a smaller sample of larger firms and is therefore more comparable to their drug firms' subset.

Taking the upper range of these numbers, $800,000 per "unexpected" patent, and using $\lambda = 13$, the average (geometric) number of patents received in the Griliches, Hall, Pakes sample (per year, per firm), the expected contribution of the variance in patent *numbers* to the average variance in market value is $13(0.8)^2$ (mil\$)^2 = $8.3 million squared. To get an estimate of var(y), I borrow the estimated coefficient of variation of the distribution of patent values from Pakes (1986) and Schankerman and Pakes (1986).[14] Both of these articles produced coefficients of variation on the order of 2 to 3.6. Because we are looking for upper-bound estimates, taking 3.6 and applying it to the "upper"-range estimate of Ey = $0.8 million gives an estimate of the total variance of w as

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[14] Schankerman and Pakes estimate the value of the patent rights. I assume that the value of the underlying innovation is proportional to its patent right value and highly correlated to it.

$$13[(3.6 \times 0.8)^2 + (0.8)^2] = \$116 \text{ million sq.}$$

This is to be compared to the average variance of $q_t V_t$. The variance of q in the Griliches, Hall, and Pakes sample is 0.133 which, evaluated at the geometric average value of their firms ($276 million), yields a variance of market value changes on the order of $10,000 million squared. Comparing the two variances gives an estimate of the relative importance of fluctuations in the market value of new patented innovations as at about 1 percent of the total fluctuations in market value.[15] That is, even if one had good estimates of patent values, they would account for little of the fluctuations in market value. Having numbers instead of values makes matters much worse, reducing this fraction even further. The contribution of patent numbers to the variance in their values is only on the order of 7 percent $[1/(1 + (3.6)^2)]$, and their contribution to the explanation of the variance in the unexpected changes in the market values of individual firms is much smaller (less than 0.1 percent).[16] One should not, therefore, use data on stock market fluctuations in this fashion to test detailed hypotheses about the information content of patent statistics. On the other hand, while the estimated variance components are rather small, they should not be interpreted as implying that the returns to inventive activity are small or that the topic we have been pursuing is not interesting, only that we have been looking for our particular needle in a very large haystack.

13.7 Spillovers and Other Uses of Patent Data

A major unresolved issue in the area of economics of technology is the identification and measurement of R&D spillovers, the benefits that one company or industry receives from the R&D activity of another. It is difficult to trace such spillovers without having strong a priori notions about who are the potential beneficiaries of whose research (see Griliches 1979, pp. 102–5 for additional discussion of these issues). One way to approach this problem is to use

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[15] There are two major problems in using this procedure to estimate the variance of the news in the economic value of patents held by the firm: The first is that the distribution estimated by Schankerman and Pakes is a distribution of the value of patent rights, which may vary less than proportionally with the true economic value of the associated invention to the firm. The second problem probably goes in the other direction: Some of the change in the firm's patent value this year may not be news, and thus may have already been incorporated into the market value at the beginning of the year. Allowing for some predictability of patent numbers would only reduce such fractions further, multiplying them essentially by $1 - R^2$ of the prediction equation. (See Griliches, Hall, and Pakes 1991 for a more detailed discussion of this and related issues.)

[16] An alternative approach to this question is developed in Griliches, Hall, and Pakes by modeling the components of variance in stock market value surprises explicitly as functions of current and past patenting and R&D activity, allowing one to estimate also the contribution of revisions in past patents' values to current changes in market value. Though the resulting estimates are rather imprecise, because they are based essentially on fourth moments of the data, they do imply that the variance in the news about the value of patents (current and past) could account for about 5 percent of the total variance in market value surprises, a number that may look low but is actually as high as any that have been found in other studies of market value revisions. Only about one-fifth of this, however, can be attributed to news associated with *current* patent applications.

the detailed information on patenting by type of patent (patent class) to cluster firms into common "technological activity" clusters and determine whether a firm's variables are related to the overall activity levels of its cluster.

In his thesis and several recent papers, Adam Jaffe (1983, 1985, 1986, 1988) has used firm level data on patenting by class of patent and on the distribution of sales by four-digit SIC to cluster firms into 21 distinct technological clusters and 20 industry (sales orientation) clusters. It turns out that these two criteria lead to different clusterings. Using the technological clusters, Jaffe constructed a measure of the total R&D "pool" available for spillovers (borrowing or stealing) in a cluster. He then looked at three "outcome" variables: R&D investment ratio for the firm (in 1976), patents received (average number applied for during 1975–77), and output growth, between 1972 and 1977. In each of these cases, his measure of the R&D pool contributed significantly and positively to the explanation of the firm level "outcome" variables even in the presence of industry dummies (based on sales clustering). Not surprisingly, perhaps, firms in technological clusters with large overall R&D "pools" invested more intensively in R&D than would be predicted just from their industrial (SIC) location. More interesting is the finding that firms received more patents per R&D dollar in clusters where more R&D was performed by others, again above and beyond any pure industry differences (based on a classification of their sales). Similarly, his analysis of firm productivity growth during the 1972–77 period showed that it was related positively to both the average R&D intensity of the individual firms and the change in the size of the R&D pool available to these firms. In terms of profits, or market value, there were, however, both positive and negative effects of neighboring firms' R&D. The net effect was positive for high R&D firms, but firms with R&D about one standard deviation below the mean were made worse off overall by the R&D of others. Here the idea of R&D spillovers is made operational by using the firm's patenting pattern to construct a measure of its location in "technological space" and showing that the R&D of others, weighted inversely to their distance from this location, has an observable impact on its own success. More recently, Jaffe (1989) has used regional data on patenting to investigate spillovers from academic research.

Patent documents also contain citations to other, previous patents. Following the growth of interest in citations in general and the development of computer software that allows the search for all subsequent citations of a particular patent (or article), there has been a growing interest in using citations counts as alternative "indexes" of differential quality. It should be noted here that patent citations differ from usual scientific citations to the work of others in that they are largely the contribution of patent examiners whose task is to delimit the reach of the new patent and note the context in which it is granted. In that sense, the "objectivity" of such citations is greater and may contribute to the validity of citation counts as indexes of relative importance. But in another sense, they are like citations added at the insistence of the editor; they may reflect the importance that is put in the field on particular papers but are not a valid indicator for channels of influence, for intellectual spillovers. On the other hand, they bring us closer to something that might be interpreted as measuring the social rather than just the private returns to these patents.

The use of patent citations as "indicators" is discussed, largely in a bibliometric style, by R. S. Campbell and A. L. Nieves (1979), Carpenter, Narin, and Woolf (1981), Carpenter and F. Narin (1983), and Narin, E. Noma, and R. Perry (1987) (see also the more general discussion of bibliometric evidence in Office of Technology Assessment 1986, chap. 3). An interesting economic application is to be found in M. Trajtenberg (1990) who shows that citation-weighted patent numbers are more closely correlated with his "output" measure, consumer surplus gains from the development and diffusion of CAT scanners (computed tomography), while unweighted patent counts are more closely related to "input," to R&D expenditures by the various firms in this field. (For another application of citation data see Lieberman 1987.) This way of using patent data is only in its beginnings and we are likely to see a much wider use of it in the future.

A number of studies have tried to "validate" patents as indicators of technical change by connecting them to counts of innovations, new chemical entities, and subsequent measures of profits or growth. One of the earliest and best studies of this kind (William Comanor and Scherer 1969) related pharmaceutical patents to the number of new chemical entities and all new products introduced by the different firms in subsequent years and found a closer relationship between patent applications (rather than grants) with all new products (rather than just the number of new chemical entities). I will not consider in detail a number of studies that found varying degrees of relationship between patents and "invention" or "innovation" counts, because the subjectivity and elasticity of such innovation count data make their results very difficult to interpret. For examples of such work see B. Achilladelis, A. Schwarzkopf, and M. Cines (1987), Basberg (1982), Kleinknecht (1982), and Walsh (1984). Scherer (1965a) shows a positive relationship between earlier patenting rates and subsequent profitability and sales growth differences in a cross-section of firms, but I know of no studies that relate "successfully" patenting rates or patenting stocks to subsequent *growth* of productivity at the firm level.

Patent data have been used by Pavitt and Soete and their associates to analyze the relative "competitiveness" of various countries, to construct "revealed technology advantage" indexes for various countries, and to describe and contrast the international location of inventive activity in different industries (Pavitt and Soete 1980, 1981; Pavitt 1982; Pavitt and Patel 1988; Soete 1987). Patents have been used by economic historians to study regional patterns of economic growth and the externalities of population size and agglomeration (Allen Kelley 1972; K. L. Sokoloff 1988; Sokoloff and B. Z. Khan 1989, among others). There have been also many other attempts to use patent data in different areas of economic analysis. It is not possible, unfortunately, to do justice to all of them here.

13.8 Aggregate Trends in Patenting and the Bureaucratic Cycle

Among the various explanations of the worldwide productivity slowdown in the 1970s, the exhaustion of inventive and technological opportunities remains one of the major suspects in the case. This suspicion was fed by one of the more visible statistical facts: The total number of patents granted peaked in the U.S. around 1970 and then declined through most of the 1970s (see Figure 13.1). Similar trends could also be observed in patenting worldwide, except in Japan (see Robert Evenson 1984; Englander, Evenson, and Hanazaki 1988, and Soete et al. 1989). These same data also fed the idea that the United States had lost its competitive inventive edge. If one looks at the data on patents granted to U.S. corporations they peaked in the mid-1960s and have not really recovered since (see Figure 13.2). A related notion is diminishing returns to inventive activity, to investments in R&D. Looking at Figure 13.2 one notices the much more rapid rate of growth in national R&D expenditures than in total patenting and the implicit suggestion of diminishing returns.

Two important aspects of these data are visible in Figure 13.1: Trends in patent grants do not always follow those of patent applications and there have been cycles before. An application for a patent is filed when the expected value of receiving the patent exceeds the cost of applying for it. The expected value of a patent equals the probability that it will be granted, times the expected economic value of the rights associated with the particular patented item or idea, minus the potentially negative effects arising from its disclosure. A patent is granted if it passes certain minimal standards of novelty and potential utility. These standards can change over time, both as a result of changes in perception of what is an innovation and as the result of changing "applications" pressure on a relatively fixed number of patent office workers. Moreover, a change in the resources of the patent office or in its efficiency will introduce changes in the lag structure of grants behind applications, and may produce a rather misleading picture of the underlying trends. In particular, the decline in the number of patents granted in the 1970s is almost entirely an artifact, induced by fluctuations in the Patent Office, culminating in the sharp dip in 1979 due to the absence of budget for printing the approved patents.[17]

This can be seen most easily in Figure 13.8 which plots the number of grants that would be predicted by a "constant" Patent Office policy and performance, that is, a 65 percent approval rate and a constant lag structure. The graph of such a "prediction" is essentially flat throughout the 1970s, reflecting the rough constancy of total applications during this period and implying a marked change in the lag structure of the granting process during the last 20 years. In the late 1960s it took more than three years for half of the eventual grants to

[17] The impact of changes in bureaucratic procedures on shorter-run aspects of these data is discussed in G. G. Brunk and G. Demack (1987), who point out that since 1968, the Patent Office has been issuing a fixed number of patents each week, with this number changing, from time to time, as the backlog varied.

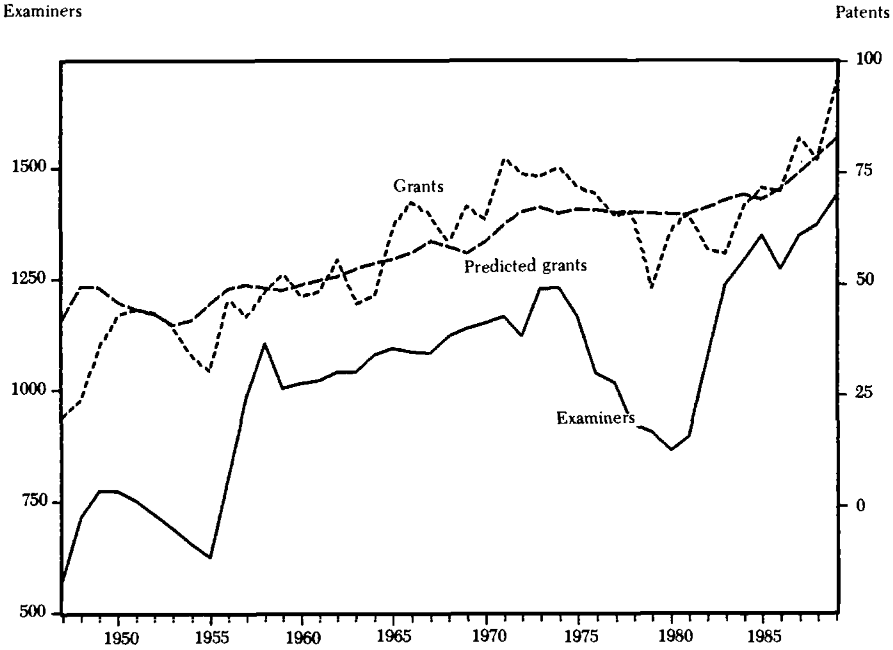

Fig. 13.8 Actual versus predicted patent grants and the number of patent examiners, 1947–1989

Source: Griliches (1989), figure 3, updated.

Note: Predicted grants (based on a "fixed" Patent Office policy) = .65(.1 $APPL_{-1}$ + .61 $APPL_{-2}$ + .25 $APPL_{-3}$ + .04 $APPL_{-4}$).

be issued. A campaign to reduce these lags and eliminate the accumulating backlog was begun in 1971 and brought down the fraction taking more than three years to about 10 percent by the late 1970s. But by the early 1980s the Patent Office ran into another budgetary crisis and the backlog began to grow again (see Griliches 1989, table 1).

Looking at shorter-run fluctuations in the total number of patents granted one can see that they are much more closely associated with the number of examiners than with the inflow of patent applications ("predicted grants" being just a scaled moving average of recent applications). It is obvious that the decline in patents granted in the 1970s came not from a decline in applications—they declined very little—but from the contraction in the resources of the Patent Office. This particular indicator of "technological decline" is, thus, nothing more than a bureaucratic mirage!

Another way of making this point is via the estimation of a Patent Office "production function," which looks at the number of patents granted as a function of two major "inputs": the internal resources available to it, the average number of patent examiners, and the "materials" it has to work with, lagged

Table 13.3 **The Patent Office "Production Function"**

	Coefficients (Standard Errors)				
	Log Total Grants		Log Domestic Grants		
Variables	1925–87	1945–87	1945–87		
Log average examiner	.916	.879	.938	.957	.899
	(.145)	(.129)	(.153)	(.146)	(.130)
Log predicted grants	.479	.419			
	(.188)	(.129)			
Time	−.026			−.010	
	(.008)			(.003)	
Time squared	.00025				
	(.00010)				
Log domestic predicted grants			.625	.400	.333
			(.325)	(.301)	(.311)
Log foreign predicted grants			−.195		
			(.071)		
Logit foreign applications ratio					−.102
					(.031)
$\bar{R}^2$	.890	.950	.788	.796	.800
SEE	.107	.115	.119	.117	.116
AR(1)	.427	.273	.286	.273	.273
	(.121)	(.153)	(.160)	(.158)	(.159)

Source: Griliches (1989), table 2.

Average examiner = [*examiners* (−1) + *examiners* (−2) + *examiners* (−3)]/3.

Predicted grants = .65[.1 *Appl* (−1) + .61 *Appl* (−2) + .25 *Appl* (−3) + .04 *Appl* (−4)].

Same formula for predicted domestic and foreign grants as a function of domestic and foreign applications.

AR(1) = first-order autoregressive serial correlation adjustment.

SEE = standard error of estimate (standard deviation of estimated residuals).

Logit foreign applications ratio: log[(*Fr Appl/Tot Appl*)]/[1 − (*Fr Appl/Tot Appl*)].

applications. Table 13.3 presents a number of such regressions for the 1925–87 and 1945–87 periods (examiner data are not available before 1920) and finds that the major determinant of the number of patents granted is the number of patent examiners employed by the Patent Office (averaged over the previous three years) with an estimated coefficient (elasticity) of approximately one. The supply of applications is important but it works largely through the examiner variable. Examiners are employed, in part, in response to application pressure and the state of the accumulating backlog. There is also a negative trend in the "efficiency" of patent examiners, perhaps as the result of the rising complexity of applications and the increasing size of the literature that needs to be searched.[18]

A parallel analysis of grants to domestic inventors yields similar results.

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[18] See Scherer et al. (1959, p. 134) for evidence of rising complexity.

Most of the variability in their numbers is again attributable to the number of examiners. But there is also evidence of a significant negative effect of the rising number of foreign applications, represented in Table 13.3 by the number of "predicted" grants to foreigners or the logit transformed ratio of foreign applications. Both versions of this variable indicate a "crowding out" of domestic patents by the rising tide of foreign applications and provide a substantive interpretation for the negative trend in this equation. This does not "solve," however, all of the mystery. In the case of domestic patents there has been also a decline in applications in the 1970s, which requires an interpretation of its own.

13.9 Aggregate Patenting and the Business Cycle

One explanation for the decline in the rate of domestic patent applications in the 1970s is the worldwide deterioration in economic conditions and expectations that occurred as the result of the two oil price shocks and the governmental efforts to contain the resulting inflationary forces (Griliches 1988). The notion that inventive activity is largely "demand" driven had its strongest proponent in Schmookler (1966), who showed that inventive activity (as measured by patents) was related to earlier movements in investment and output of the relevant industries. (See also the later summation of his position in Schmookler 1972, pp. 70–84.) His work can be, and has been, criticized on several levels. In the longer run, "supply" forces, in the form of new discoveries and the steady contribution of new scientific knowledge, surely have an important role to play (Nathan Rosenberg 1974). Moreover, by current econometric standards the evidence presented by Schmookler for his conclusions does not look all that strong (though it gains conviction by the cumulative force of the various bits and pieces examined, and by observing the working of a knowledgeable and first-rate mind grappling with the problem and coming to a considered judgment). Subsequent empirical work on this topic, by Scherer (1965a and 1982b), P. Stoneman (1979), Geoffrey Wyatt (1986), Derek Bosworth and Tony Westaway (1984), C. Papachristodoulou (1986), and Kleinknecht and B. Verspagen (1990), have either supported his original conclusions or weakened them, but no one has really overturned them.[19] In any case, at the level of annual fluctuations that we are looking at, demand forces are likely to be more important and easier to detect than the much slower "supply" forces whose effects take longer to accumulate.

Table 13.4 presents a number of different attempts to explain the total num-

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[19] A number of studies, following Stoneman, have regressed the log of patents on the log of R&D per patent, interpreting the latter variable as a measure of the "cost" of invention, and the resulting negative coefficient as an indication of the workings of "supply" forces. But the sign of this coefficient could reflect nothing more than the spuriousness of such a relationship, induced by the large transitory or measurement error component in patent numbers. On the latter possibility see Griliches, Hall, and Pakes (1991).

Table 13.4 **Determinants of Applications for U.S. Patents by U.S. Residents, 1953–87; Dependent Variable: Log of Domestic Patent Applications**

Variables	Regression Coefficients (Standard Errors) and Period					
	1953-87			1954-87		
Time	−.000	−.017	−.018	−.013	−.007	−.007
	(.001)	(.005)	(.004)	(.003)	(.004)	(.001)
DLNTDF			−.279	−.317	−.314	−.314
			(.097)	(.084)	(.074)	(.077)
DLNTDF(−1)			−.257	−.203	−.155	−.155
			(.098)	(.081)	(.084)	(.076)
LCRD(−1)		.338	.410	.203	.000	
		(.094)	(.075)	(.090)	(.125)	
LRUNBR(−1)				.064	.121	.121
				(.019)	(.032)	(.015)
LRRDDF					−.775	−.776
					(.352)	(.233)
SEE	.0507	.0425	.0326	.0281	.0264	.0259
$\bar{R}^2$	−.029	.256	.561	.674	.713	.724
D-W	.72	1.21	1.74	2.00	2.04	2.02

Source: Griliches (1989), table 6.

SEE = standard deviation of the estimated residuals.
D-W = Durbin-Watson statistic.
DLNTDF = the rate of growth in the national defense component of real GNP.
LCRD = logarithm of company-financed R&D expenditures in industry, deflated.
LRUNBR = logarithm of total "real" basic research expenditures in universities, deflated.
LRRDDF = logarithm of the ratio of the R&D to the implicit GNP deflators.

ber of domestic patent applications in the U.S. during the last 30 years or so. Because reasonably consistent R&D data at the national level do not exist before 1953, most of the analyses are based on the 1954–87 period.[20] There are a number of interesting findings in this table. (1) For the period as a whole (1953 to 1987) there was no significant decline in the number of patent applica-

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[20] Taking the longer-run view and looking at periods with no R&D data, one can reproduce the main outlines of Schmookler's results. For example, for the whole 1880–1987 period (88 years), one gets (in first differences of logarithms format):

$$\underset{(.009)}{gda = -.006} + \underset{(.030)}{.110}\, ggpdi + \underset{(.128)}{.299}\, ggnp(-1)$$

$$R = 0.15,\ SEE = 0.075,\ D\text{-}W = 1.87,$$

where the rate of growth in domestic patent applications (*gda*) is related positively to the current rate of growth in gross private domestic investment (*ggpdi*) and the lagged rate of growth in real GNP (*ggnp*). Because the post–World War II period exhibits much less variance, the results are much weaker there, but not all that different. During this later period we have, however, actual direct "input" measures, such as R&D expenditures and the number of scientists and engineers engaged in R&D, and they dominate the aggregate economy indexes such as GNP or GPDI.

tions in the U.S. by U.S. residents. Because there was a positive rate of growth in real R&D over this period, at least if one uses the standard deflators, any attribution of a positive influence to them will imply the finding of a negative time trend in the patents "production function." (2) Fluctuations in R&D do affect the number of patents applied for, but less than proportionately. Among the various possible measures of R&D, company expenditures on R&D "work best," as long as only one measure of R&D is to be included in the equation. Findings (1) and (2) together imply a negative trend in the "propensity to patent" or in the "efficiency" of patent "production" of about -1 to -2 percent per year. The estimated coefficient of the company R&D variable is quite high and significant, between 0.2 and 0.4, and is consistent with earlier findings based on micro data (see Section 13.4). (3) Changes in the size of the defense establishment, in the form of current and lagged changes in real gross national product devoted to national defense, have a large and significantly negative effect on the number of domestic patents applied for and perhaps also on actual levels of inventive activity. The estimated effect is large, a decline of 5 percent in domestic patenting as the result of a 10 percent increase in defense GNP, and it is quite robust to the introduction or deletion of other variables. This finding is consistent with both the view that defense expenditures pull resources away from inventive activity and with the view that they channel inventive activity into areas where patenting is either more difficult or less important. (4) There is evidence in these data of a positive contribution of basic research in universities to the overall level of domestic inventive activity as measured by the total number of domestic patent applications. (5) There is also some evidence that the rising real cost of R&D, in the form of the ratio of the R&D to GNP price deflators, has had a negative impact on patenting, either because it reflects also the rising cost of patenting relative to other economic activities, or because it adjusts in part for the "underdeflation" of the R&D variables by the same set of deflators. All of these conclusions are tentative. They are based on highly aggregated data, a rather short time period, and a highly multicollinear set of examined variables.[21] Looking at industry (2.5 digit) level data does not help much, nor does it change the results significantly (see Griliches 1989).[22]

These macro results do not really help to explain the longer-run trends. For the period as a whole, 1954 through 1987, there is no actual decline in patenting to explain and also no substantive change in the rate of growth of defense expenditures. But unless the R&D deflators are all wrong, the data do indicate

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21. The simple correlation of company R&D with time and real GNP is 0.99 and 0.98 respectively, and it is about 0.94 with either university basic research or total R&D in industry.

22. Attempts to extend these results by adding more "demand" side variables such as changes in real GNP, capacity utilization, or stock price indexes were not successful. Almost all of the systematic short-run variability in aggregate domestic patenting is picked up by fluctuations in the R&D and national defense variables. All of the other demand variables appear to be working via these variables.

a rather significant growth in both private company R&D expenditures in industry and basic R&D expenditures in universities at 5 and 8 percent per year respectively, which should have resulted in some increase in the observed rate of patenting. Thus, we are left more or less where we started, with a significant unexplained decline in U.S. patenting relative to the ongoing investment in R&D.

13.10 A Shrinking Yardstick?

Before we look at the longer-run trend in domestic patenting and discuss its interpretation as an indicator of inventive activity, it is worth stressing that from the point of view of the measurement of technical change in the U.S., using total factor productivity measures or related indexes, *domestic* patenting may not be the relevant magnitude. Total patents may be a better measure of shifts in "technology," in the "production possibilities frontier." Foreign inventions should have a similar impact on total factor productivity and therefore, from the point of view of measures of technological "opportunity" available to the U.S. economy, it may not matter whence the invention came. The level of domestic patenting may be more relevant, however, for studies of "competitiveness" and when thinking about rates of return to domestic R&D.

Figure 13.9 plots (on a common log scale) the long-term data on domestic patent applications, real GNP, and gross private domestic investment (in lieu of R&D data which are not really available before the 1950s).[23] Several interesting facts stand out in this chart: After growing at roughly the same rate as real GNP in the late nineteenth and early twentieth centuries, domestic patent applications peaked in the late 1920s and have not achieved such levels again. After a severe decline during the Great Depression and the early war years and a brief postwar recovery, they stayed essentially flat throughout the whole postwar period, while both GNP and total and corporate R&D expenditures were growing. These facts led Schmookler (1966, pp. 28–30) to declare such data not really comparable between the pre– and post–World War II periods. He gave three reasons for the "shortfall" in the more recent period: (1) the change in judicial and political climate in the late 1930s, which became much more hostile to corporate patenting and the enforcement of patent rights, reducing thereby the value of applying for one; (2) the growth in delays in processing patent applications at the Patent Office, which reduced the ultimate value of such protection; and (3) the rise of industries where there is less reliance on patents and more on secrecy and on first-mover advantage, and the realization by many corporations that they might be able to do without patenting. What Schmookler did not mention explicitly is the rise in the real wage

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[23] The domestic patent application numbers are extrapolated backward, before 1940, by the number of total patent applications, foreign applications constituting less than 10 percent of the total at that point.

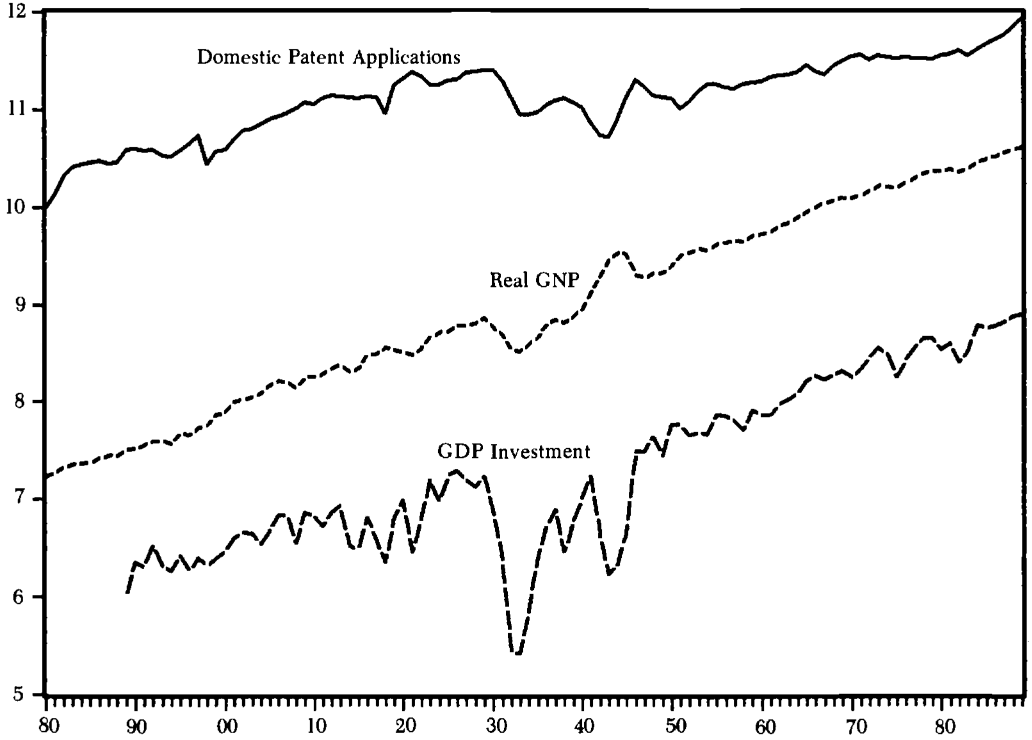

Fig. 13.9 Patent applications by U.S. residents and real GNP and investment, 1880–1989, log scale

Source: Griliches (1989), figure 4, updated.

Note: Domestic applications extrapolated back, before 1940, by the number of total applications.

and hence the rise in the opportunity cost of dealing with the patent system. This rise in real wages contributed to the significant decline in the number of patents issued to "independent" inventors and probably also to a higher threshold of potential value for corporations before they would file an application. If this is true, then the relative stagnation of domestic applications in the postwar period does not preclude the possibility that real inventive activity and its output were rising at the same time.

Schmookler's first two explanations appear less cogent today. (The judicial climate has actually reversed itself recently.) The third explanation, that the lack of growth in domestic patent applications is due to changes in the industrial mix, away from traditionally high patenting areas (such as chemicals) and toward the faster-growing, lower-patenting industries such as computers, has been disputed by Griliches (1989). He used "fixed" patent per R&D dollar intensities (from Bound et al. 1984 and Scherer 1984a) together with the industrial distribution of company R&D expenditures in 1957 and 1985 to compute a "predicted" average number of patents per R&D dollar, with a result that goes in the right direction but is rather small: a -3 percent adjustment for the whole 1957–76 period. It is small both because patenting intensities are not all that different across industries and because the industrial composition of R&D did not change drastically during this period.[24]

Another possible explanation is the overestimation of the growth in "real" R&D due to an underestimate by conventional R&D "deflators" of the growth in the real cost of doing science, in finding new drugs and new compounds, and in designing new chips. If the "real" cost of doing R&D has risen by about 3 to 4 percent more per year than is indicated by the conventional deflators, most of the observed decline in patenting per R&D dollar would be eliminated (Daniel Smith 1988).[25] It is rather difficult, however, to distinguish this from various other versions of the exhaustion of the scientific frontiers hypothesis. Why is the cost of real science rising faster than a reasonably weighted index of scientific salaries and a quality-adjusted price index of scientific instruments and equipment? Is it because the competition from other scientists within the country and abroad is driving up the resources necessary to produce a unit of visible advance in a field? Is this not just a reflection of diminishing returns to R&D investments when they are applied to a fixed or a slower-growing underlying scientific opportunities set, of crowding out and fishing out? (See also the discussion in Englander, Evenson, and Hanazaki 1988 on this.)

13.11 The Specter of Diminishing Returns

Aggregate patent numbers (applied and granted) have fluctuated greatly in the past. They have also grown more slowly in this century, much less so than

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[24] See Hall (1988) for similar results.

[25] "For an institution viewed as a whole, with a constant complement of young scientists, typical weighted growth rates per scientist (in the 'sophistication factor') might be 2–5 percent in constant-value terms per annum . . ." A. V. Cohen and L. N. Ivins (1967, p. 28).

investments in R&D, which has led scholarly observers to wonder repeatedly about the implied slackening in the growth rate of technical progress. In 1935, Robert K. Merton wrote: "In the U.S., however, the number of patents has scarcely kept pace with the growth of population since 1885—a fact which may lead us to suspect the possibility of a slackening in the rate of technologic advance generally" (p. 454). At the same time, S. C. Gilfillan (1935) was blaming the decline in patenting on the decline in the native ability of the American people, due to immigration and dysgenics, because "the stupid have been breeding at a much higher rate" (pp. 218–19). In 1952, Alfred B. Stafford wondered "Is the Rate of Invention Declining?" as he observed a declining trend in patenting, from 1916 through 1947, in two-thirds of all the patent classes, and worried about diminishing returns on one hand and the increasing complexity of invention on the other[26] (see also Schmookler 1954). The same point was taken up by Scherer et al. in 1959: ". . . the sharp decline in patenting during the depressed 1930's can be attributed to unfavorable economic conditions, while the slump during World War II is explained by the historical tendency for patenting to decline during wartime. But no such ready explanation is available for the continued record of sluggishness during the booming postwar period" (p. 130). He then attributed some of this decline, as did also Schmookler (1966) later on, to a change in the judicial climate and especially to the increase in compulsory licensing decrees. But that does not seem to explain all of the decline, or its persistence into the 1970s. And this type of worry continues to this day, as can be seen in Baily and Chakrabarti (1988), Scherer (1986), and this paper itself. One can always worry that the world is coming to an end. Someday it undoubtedly will, but it does not look as if the end is already upon us, at least not yet.

What are the facts, so far as they can be discerned? There has been no absolute decline in the rate of patenting in the U.S. Total patent grants and applications are running about 30 percent above the early 1960s, and U.S. domestic patent applications have also recovered to the levels attained in the 1960s. The question then is, do we need a growing rate of invention (if patent numbers do indeed measure it) to sustain a steady positive rate of growth in total factor productivity? Does the faster growth in real R&D expenditures indicate diminishing returns to R&D or an improvement in the quality of patented inventions? And could the, we hope temporary, 11 percent decline in the average number of domestic patent applications, between its peak in 1968–71 and its trough in 1977–83, have been responsible for the productivity slowdown in the 1970s or have significant productivity growth implications for the future?

To the extent that an invention either reduces the cost of production or develops entirely new products, it has an aspect of increasing returns to it. The same invention could produce the same proportional effect, in different size markets

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[26] Stafford (1952) is a marvelous example of how easy it is to make wrong predictions about the future. See also the sharp and confused exchanges between Gilfillan, Schmookler, and Kunik in *Technology and Culture* (Gilfillan 1960).

or economies. The public good nature of most inventions and the "multiplicative" aspect of their impact do not require their number to grow just to sustain a positive rate of productivity growth. On the other hand, economies do not grow just by replication and expansion; they also get more complex, proliferate different products and activities, and develop in different geographical and economic environments. To that extent, the "reach" of any particular invention does not expand at the same rate as the growth of the overall economy, but only at the rate of growth of its "own" market. Therefore, I would expect that the "required" number of inventions for a steady positive rate of growth in productivity has also to grow, but at a rate that need not be as fast as that of the economy as a whole.

The preceding paragraph deals with the fundamentally unobservable quantum of invention or an advance in knowledge. It is clear, from the previous discussion and the earlier references, that its relationship to observed patent numbers is unlikely to have stayed constant over time. The important question, however, is what does an observed decline in patent numbers imply about the underlying stream of inventions and their ultimate effect on productivity. If the decline occurs because of a rise in the real cost of patenting, or even a decline in the expected value of the marginal patent, this may still have very little effect on the aggregate contribution of values of the inventions associated with these patents. The evidence discussed in Section 13.5 shows that the vast majority of patents are worth very little and that the bulk of the private and social total product of the inventive system is based on a relatively small number of very valuable patents. If the patent value were known to the inventor in advance then a rise in the cost of patenting or a decline in the return from inventing would only deter the marginal, low-value inventive activity, and would leave the total aggregate return effectively unchanged. Inventors are unlikely, however, to know the value of their inventions in advance. At the other extreme, one could assume that all of the estimated dispersion in patent values is "within," that all of it represents the uncertainty that faces each individual inventor. Then, a decline in patent numbers would imply a parallel decline in total inventive activity and results.[27] Inventors do, undoubtedly, face great uncertainty about the ultimate value of their inventions, as is emphasized and documented by Pakes (1986), but probably not as extensive as would be implied by the estimated cross-sectional dispersion in patent values. The truth, I believe, is somewhere in the middle, but closer to the first case, with some definite knowledge about the potential importance of the particular invention. In that case, and this is also what can be read into the numbers reported in Schankerman and Pakes (1986), a decline in patenting would be associated with an increase in the average "value" of a patent, and a much smaller impact, if any, on the aggregate social output of this activity.

Even if there were a real decline in inventive output associated with the

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[27] This is one way to read the evidence presented in Edwin Mansfield (1986) that major U.S. corporations have not reduced the fraction of their inventions that they patent.

observed decline in patent numbers, it is unlikely that we could discern its effects in the conventional productivity numbers. There are at least three reasons for this. First, not all of productivity growth is due to invention and only some fraction of the latter arises from patented inventions. If one takes 1.5 to 2.0 percent as the approximate growth rate per year in total factor productivity, at least half of it is likely to be due to the growth in the quality of the labor force, economies of scale, and various reallocations of capital between assets and industries. Moreover, it is unlikely that patented inventions could account for more than half of all the relevant advances in knowledge. This leaves us with at most a quarter of total productivity growth, and an unknown fraction of its fluctuations, to be attributed to patented invention.

Second, the effects of an invention on productivity appear with a long and variable lag and it is doubtful that the available data and current econometric techniques could identify them clearly. Moreover, the aggregation over many inventions and many lag structures is likely to smooth them out further, beyond recognition.

Third, the great variability in the magnitude and importance of the various inventions adds another source of variance here.[28] Given the great skewness in the value distributions one cannot take much comfort from the relatively large samples, or rather, population numbers (a point already noticed in the past by Nordhaus 1969 and others). To the extent that one does observe correlations between patent numbers and contemporaneous productivity numbers, the causality is most likely running the other way, from productivity as a measure of the economic environment to patents as a measure of inventive "effort" rather than from the impact of inventive "output" on subsequent productivity.

Thus, the question of diminishing returns to R&D and the implicit forecast of a declining productivity growth rate remains unresolved. If the relationship of patent numbers to inventive output has been changing then they cannot be used to make a judgment about this. The other evidence on this topic is also equivocal. A priori, one would expect to hit diminishing returns in any narrowly defined field, at least until the field or the product area is redefined anew by some other major breakthrough. Kuznets used detailed patent data to make this point already in 1930 (pp. 54–58). This also follows from the various theoretical models of the R&D process such as Evenson and Kislev (1975, ch. 8) and others. On the other hand, inventive effort moves from one "fishing" ground to another, and new fishing grounds open up as the result of basic R&D and other sources of discovery. Hence, in the longer run there is less evidence of exhaustion of opportunities, and studies that have tried to look for declines in the rates of return to R&D have found very little evidence of such a decline (see Griliches 1986 and Sveikauskas 1988, among others). The same conflict

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[28] See Griliches (1989, p. 316) for a "back of an envelope" calculation which concludes that if about one-third of the 10 percent decline in patent applications (between the late 1960s and 1970s) were to translate itself into a decline in real innovative output, it would take us over seven years, not counting any lags, to detect it with any statistical "confidence" even if there were no other sources of variation in productivity. And in the meantime, the trend might have reversed itself.

appears in the various estimates of the "patent production function" discussed in Section 13.4. Time-series estimates, which presumably measure returns to movements primarily along already established trajectories, all tend to come out with relatively low elasticities of patents received with respect to R&D invested, on the order of 0.2 to 0.45. On the other hand, cross-sectional studies, which presumably better represent the optimal migration of R&D resources across fields and the finding of new niches, yield elasticity estimates much closer to unity.

The assumption of diminishing returns is already contained in most R&D-based models of productivity and productivity growth. In such models, with the stock of knowledge capital proxied by a "stock" of accumulated past R&D expenditures, the estimated elasticities tend to be rather small, on the order of 0.06 to 0.2 (e.g., Mansfield 1984 and Griliches 1986). This, by the way, is not all that different from the time-series-based patent R&D coefficients estimates in Section 13.9. If productivity is a measure of knowledge accretion and patents are a proxy index for it, then there may be no paradox here, after all. This is what is also implied by Figure 13.10, which plots (on a common logarithmic scale) the index (level) of multifactor productivity in the private business sector of the U.S. economy (as computed by the BLS) together with a measure of the total "stock" of patent applications in the U.S. and the parallel concept of the stock of total R&D expenditures (both based on a 15 percent depreciation rate). Note the remarkably parallel behavior of the productivity series and the total patent stock series and the faster growth rate, at least during the earlier part of the period, of the total R&D stock series. The relationship would be poorer for the patent stock variable if only domestic patent applications were counted; it would have turned down significantly by the mid-1980s. This is a bit of evidence for my view that the relevant indicator for measures of technical change is total patents, not just domestic patents.

In the past I looked at such charts and thought that something was wrong with the productivity numbers. But if we are to believe the patent numbers, perhaps they are not so wrong after all. For reasons discussed above, I do think that over longer periods of time patent numbers are an imperfect index of inventive output whose relationship to the underlying "frontier shift" has been declining over time. More will have to be learned, however, before we can feel certain about such inferences. Thus, the patent numbers leave us where we began, with a suggestive, but possibly misleading puzzle.

13.12 Concluding Comments

In this survey I have described a number of recent studies, many of them spurred on by the growing availability of machine readable data files and on-line data bases, whose common denominator is the use of patent statistics to illuminate the process of innovation and technical change. A number of interesting and important findings have emerged from this work and also, as is

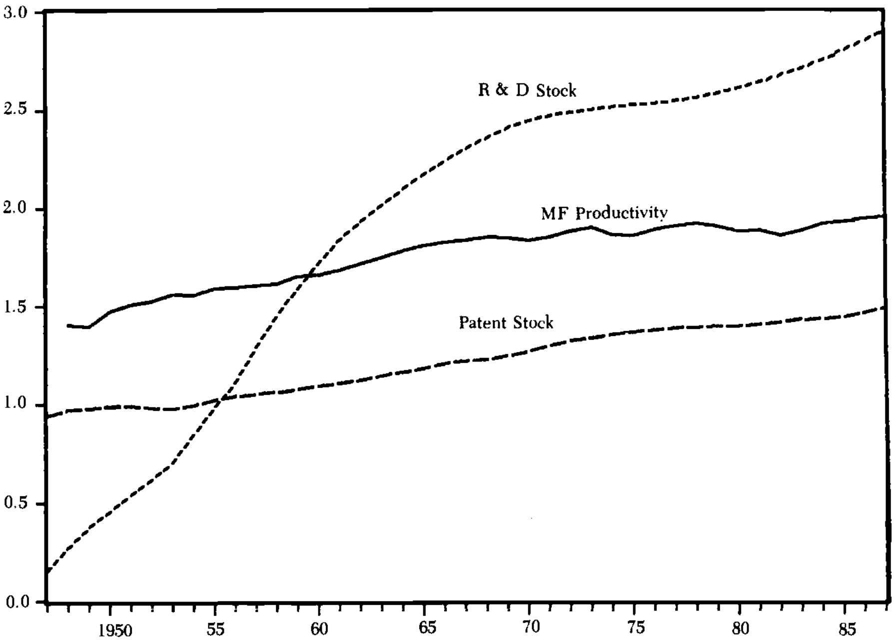

Fig. 13.10 Multifactor productivity in the private business economy and patent and R&D capital "stocks," log scale

Source: Griliches (1989), figure 6.

Note: R&D and patent stocks computed from aggregate data using a 15 percent declining balance depreciation formula and estimated initial conditions.

common in empirical work, quite a bit of frustration with our inability to really answer the "big" questions.

Among the major findings was the discovery of a strong relationship between patent numbers and R&D expenditures in the cross-sectional dimension, implying that patents are a good indicator of differences in inventive activity across different firms. While the propensity to patent differs significantly across industries, the relationship between R&D and patents is close to proportional, especially for firms above a minimal size. Small firms do receive a significantly higher number of patents per R&D dollar but this can be explained by their being a much more highly selected group. There is also a statistically significant relationship between R&D and patents in the within-firm time-series dimension, but it is weaker there. The bulk of the effect is contemporaneous, implying possibly also some reverse causality: successful research leading to both patents and to the commitment of additional funds for the further development of the resulting ideas.

The practical implication of these findings is that in the absence of detailed R&D data, the much more plentiful patent data can be used instead as an indicator of both inventive input and output. Care should be taken, however, not to overinterpret small and even sizable differences in patent numbers, especially in the time dimension. Analyses of survey responses by patent owners, the modeling of the renewal pattern of patents in Europe, and attempts to relate market values and changes in the stock market rates of return all conclude with very high estimates of both the variance and skewness in the distribution of patent values. These findings, especially the large amount of skewness in this distribution, lead to rather pessimistic implications for the use of patent counts as indicators of short-run changes in the output of R&D.

At the aggregate level the interesting finding is that the appearance of an absolute decline in inventive activity was largely a statistical mirage, caused by a bureaucratic rather than an economic or technological cycle. The question about the causes of the relative decline in patenting relative to the growth in R&D expenditures cannot be answered conclusively, though I remain rather sanguine on this matter. There is good reason to think that the relationship between inventive output and the number of patents has changed over time, that the yardstick shrank. Some evidence on this comes from patent renewals data pointing to a rising average "quality" of patents. Also, R&D numbers may be overestimating the real growth in inventive input. Moreover, it is not obvious that we need a growing number of inventions to sustain our current rates of growth, or that we should worry too much about the rising rate of foreign inventions. We are likely to be their ultimate beneficiaries.

In spite of all the difficulties, patent statistics remain a unique resource for the analysis of the process of technical change. Nothing else even comes close in the quantity of available data, accessibility, and the potential industrial, organizational, and technological detail. Moreover, there are other ways of using them besides simply counting them. It is possible to use a firm's distribution of patenting by field to infer its position in "technological space" and to use this information, in turn, to study how the results of R&D spill over from one firm to another, illuminating thereby also the process of strategic rivalry that the firm finds itself in. As U.S. patent renewal information becomes available at the individual patent and firm level, one will be able to use it together with data on patent citations to construct more relevant "quality-weighted" inventive "output" measures. Even without going that far, the currently available patent data can be used to study longer-run interfirm differences in levels of inventive activity and as a substitute for R&D data where they are not available in the desired detail. We should not be cursing the darkness, but rather, we should keep on lighting candles.

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Note: A number of important references are included even if they are not cited in the text.

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