COWLES FOUNDATION FOR RESEARCH IN ECONOMICS

AT YALE UNIVERSITY

Box 2125, Yale Station
New Haven, Connecticut 06520

COWLES FOUNDATION DISCUSSION PAPER NO. 862

APPROPRIATING THE RETURNS FROM INDUSTRIAL R & D

by

Richard C. Levin
Alvin K. Klevorick
Richard R. Nelson
Sidney G. Winter

February 1988

Appropriating the Returns from Industrial R & D

Richard C. Levin
Alvin K. Klevorick
Richard R. Nelson
Sidney G. Winter

Revised February 1988

This paper was prepared for a meeting of the Brookings Panel on Economic Activity, December 3-4, 1987. It will be published in a forthcoming issue of the <u>Brookings Papers on Economic Activity</u>.

Appropriating the Returns from Industrial R & D*

I. Introduction

To have the incentive to undertake research and development, a firm must be able to appropriate returns sufficient to make the investment worthwhile. The benefits consumers derive from an innovation, however, are increased if competitors are able to imitate and improve upon the innovation to assure its availability on favorable terms. Patent law seeks to resolve this tension between incentives for innovation and widespread diffusion of benefits. A patent confers, in theory, perfect appropriability (monopoly of the invention) for a limited period of time in return for a public disclosure that assures, again in theory, widespread diffusion of benefits upon the patent's expiration.

Previous investigations of the working of the patent system suggest that patents do not always work in practice as they do in theory.[1] On the one hand, appropriability is not perfect. Many patents can be "invented around;" others provide little protection because legal requirements for proof of validity or infringement are stringent. On the other hand, public disclosure does not always assure ultimate diffusion of an invention on competitive terms. For example, investments to establish the brand name of a patented product may outlive the patent itself.[2]

There is also some indication that patents are not always necessary to assure the effective appropriation of returns from innovation. Studies of the aircraft and semiconductor industries, for example, have noted that gaining lead time and exploiting learning curve advantages are the primary methods of appropriation.[3] Other studies have emphasized the importance of complementary investments in marketing and service to enhance the appropriability of R&D.[4]

Existing evidence on the nature and strength of appropriability conditions, and on the working of the patent system in particular, is scattered and unsystematic. Because imperfect appropriability may lead to underinvestment in new technology, and because technological progress is a primary source of economic growth, it would be useful to have a more comprehensive empirical understanding of appropriability. In particular, it would be desirable to identify those industries and technologies in which patents are effective in the sense of preventing competitive imitation of a new process or product. It would also be desirable to know where patents can be effectively used to secure income from licensees. Where patents are not effective, it would be useful to determine both why they are not and whether any other mechanisms permit innovators to capture and protect the returns from R & D investment. The results of such an inquiry could be of considerable value for economists studying innovation and for policy makers concerned with the technological performance of the economy.

In this paper, we describe the results of an inquiry into the nature of appropriability conditions in over one hundred manufacturing industries, and we discuss how this information has been and might be used to cast light on important issues in the economics of innovation and public policy. Our data, derived from a survey of high-level R&D executives, are informed opinions about the nature of an industry's technological and economic environment rather than quantitative measures of inputs and outputs.

Our use of semantic scales to assess the "effectiveness" of alternative means of appropriation, for example, introduces considerable measurement error, but it is doubtful that more readily quantifiable proxies would serve as well. Remarkable progress has been made toward developing a methodology to estimate the economic value of patents.[5] But data suitable for this purpose are as yet unavailable in the United States, and the European data lack sufficiently reliable detail to support inferences about inter-industry differences in patent values. Our judgment was that asking knowledgeable respondents about the effectiveness of patents and alternative means of appropriation was at least as likely to produce useful answers as asking for "quantitative" estimates of the economic value of a typical patent.

We have taken considerable care to establish the robustness of our findings in the presence of possibly substantial measurement error, but ultimately the value of our data will depend on their contribution to better empirical understanding of technological change and more discriminating discussion of public policy. To view the empirical contribution of the data from the simplest perspective, consider their potential for improving the quality of research that uses patent counts to measure innovative activity.[6] This line of inquiry has shown, among other results, that there is substantial variation across industries in the average number of patents generated per dollar of R & D investment.[7] Our findings on inter-industry differences in the effectiveness of patents may contribute to an explanation of this variation in the apparent productivity of R & D.

More fundamentally, large and persistent inter-industry differences in R & D investment and innovative performance have resisted satisfactory explanation, in part for lack of data that adequately represent the theoretically important concepts of appropriability and technological opportunity. Promising but ultimately unsatisfactory results have been obtained in exploratory work that used crude proxy variables[8] and econometric ingenuity[9] to capture the influence of appropriability and opportunity conditions. Our desire to provide a stronger observational basis for this line of inquiry was a prominent motive for our survey research and helped to shape its design.

Finally, the gathering of better information on the nature and strength of appropriability is particularly timely in view of the prominence of intellectual property on the current policy agenda. Several recent initiatives have questioned the adequacy of the laws and institutional arrangements that protect intellectual property. One impetus for change has been the need to clarify and perhaps strengthen the system of property rights at various new frontiers of technology. Thus, for example, recent legislation has adapted copyright law to protect the rights of the creator of new computer software, a new legal framework has been constructed to protect intellectual property embodied in semiconductor chip designs, and important court decisions and administrative actions have shaped the development of a property rights system in biotechnology.[10]

Another spur to change has been the need to resolve conflicts between the aims of social regulation and the exercise of intellectual property rights. For example, the Drug Price Competition and Patent Life Restoration Act of 1984 extended pharmaceutical patent lives to compensate for the impact of regulatory requirements on the introduction of new drugs.

Intellectual property also appears prominently in the crowd of policy issues milling under the banner of "competitiveness." Recent annual reports of the United States Trade Representative have focused on the difficulties that U.S. manufacturers encounter in protecting their intellectual property rights in foreign markets. The trade bill passed in 1987 by the House of Representatives contains several provisions that increase the scope of protection and the opportunities for relief available to U.S. manufacturers confronted with imports that infringe their intellectual property rights.[11] Proposed antitrust legislation, motivated by a concern that courts have kept inventors from reaping rewards that the patent laws are intended to provide, stipulates that patent license agreements and similar contracts relating to use of intellectual property "shall not be deemed illegal per se under any of the antitrust laws."[12]

When this activity in the intellectual property arena is intended to rectify obvious inadequacies in existing institutions, the case for reform appears strong and straightforward. It is easy to deplore the blatant copying of innovative integrated circuit designs, the import of "knock off" copies of trademarked or patented U.S. products, and the flagrant piracy of copyrighted literary texts, audio and video cassettes. But reforms may yield unintended consequences. In its simplest form, this concern translates into wariness about Trojan horses: provisions brought into the law by the rhetorical tug of "competitiveness" and "intellectual property" may harbor instruments of protectionism and price fixing. Other possibilities for producing unintended consequences are subtler, but no less important. For example, to the extent that appropriability conditions differ widely across industries, a seemingly uniform adjustment of intellectual property, antitrust, or trade law may have a vastly different impact on some industries than on others.

Moreover, it should not be taken for granted that more appropriability is better. Much contemporary policy discussion seems to be based on a simplistic model: better protection necessarily leads to more innovation, which yields, in turn, better economic performance -- higher standards of living, more "competitiveness," and so on. Either link in this simple chain can fail.

When better protection does yield more innovation, it may accomplish this result at an excessive cost in terms of the incremental resources devoted to producing the innovation: the larger prize may merely encourage duplicative private effort to capture it.[13] Alternatively, better protection may exacerbate pre-existing distortions in the allocation of innovative effort and induce innovation of the wrong kind.[14] Or better protection may buy innovation at an excessive price in terms of further delaying access to the innovation on competitive terms.[15]

The premise that stronger protection will always enhance innovation is also open to challenge. Unimpeded diffusion of existing technology has a beneficial short run impact not only on consumers but also on those who would improve that technology with innovations of their own. Where technological advance is a cumulative, interactive process involving many innovators, strong protection of individual achievements may slow the general advance. This would not occur in a hypothetical world of zero transaction costs, in which efficient contracts to share information would be made. In reality, however, markets for rights to information are subject to major transactional hazards, and strong protection of a key innovation may preclude competitors from making socially beneficial incremental innovations. The semiconductor industry of the 1950s and 1960s provides an excellent example of rapid progress in a cumulative technology that might have been impossible under a regime that strongly protected intellectual property.[16]

In the next section of the paper, we discuss our survey instrument, the construction of our sample, and certain methodological issues concerning the interpretation of our data. Sections III through VII are devoted, in turn, to our findings concerning the effectiveness of patents and other means of appropriating the returns from R & D, the characterization of appropriability conditions, limits on the effectiveness of patents, channels of intra-industry spillovers of technological knowledge, and the cost and time required to duplicate a rival's innovations. We summarize in Section VIII the results of related work that employs the survey data to re-examine some central questions in the empirical literature on R & D. In the final section, we discuss how our findings might contribute to a more discriminating discussion of patent law, antitrust law, and trade policy.

II. Questionnaire Design and Survey Methods

A. Contents of the Questionnaire

In shaping the content of our questionnaire, we derived useful guidance from the conceptual literature on technological change,[17] the prior empirical literature on the economic impact of the patent system,[18] the work of Mansfield and his associates on imitation costs,[19] and numerous case studies. The questionnaire was aimed at high-level R&D managers with knowledge of both the relevant technology and market conditions. To check the interpretability of the questions, and the likely validity and reliability of the responses, we pre-tested the questionnaire with twelve such managers representing a diverse array of businesses.[20]

To understand how appropriability differs across industries, we asked each respondent to report the typical experience or central tendencies within a particular line of business. Respondents were thus treated as informed observers of a line of business, rather than as representatives of a single firm.[21] This approach led inevitably to heterogeneity in the responses of firms within a line of business. We discuss below the extent and sources of such heterogeneity.

The questionnaire contained four parts. Parts I and II explored aspects of appropriability; Parts III and IV probed aspects of technological opportunity and perceptions about technological advance. Questions in Part I examined the effectiveness of alternative means of protecting the competitive advantages of R&D, the reasons for the effectiveness or ineffectiveness of patents in a line of business, and the means of acquiring knowledge of a competitor's technology. Part II asked about the cost and time required to imitate innovations of rivals. We distinguished process from product innovations, major from typical innovations, and patented from unpatented innovations. The questions in this part are similar to those asked by Mansfield, Schwartz, and Wagner,[22] but they differ in two respects. We asked about an industry's typical experience, whereas Mansfield et al. asked about particular innovations, and our coverage of industries is much broader.

Part III explored the links between an industry's technology and external sources of opportunity. We asked about the importance of scientific research in general and of university-based research in particular. We also explored the extent to which inter-industry spillovers are an important source of technological opportunity. Part IV asked some broad questions about the pace and character of technological advance. One objective was to look at "natural trajectories" of the sort described by Nelson and Winter.[23] Table 1 summarizes the principal topics covered in our survey questionnaire.

|TABLE 1 HERE|

In this paper we focus on an analysis of the responses to the questions in Parts I and II of the questionnaire. Data derived from responses to questions in Parts III and IV have been used in the econometric work of Levin et al., Cohen et al., and Levin and Reiss,[24] and some findings concerning the importance of science and other external sources of technological knowledge have been discussed by Nelson.[25]

B. Sample Construction

As a sampling frame, we used the lines of business (LBs) defined by the Federal Trade Commission. In the manufacturing sector, these chiefly correspond to four-digit SIC industries, although some FTC LBs are defined as groups of four-digit or even three-digit industries. The compelling consideration favoring use of FTC LBs was that this is the most disaggregated level at which data on R&D expenditures are available. An additional consideration was that Scherer's technology flow matrix,[26] which classifies patents by industry of origin and industry of use, was also constructed at this level of aggregation.

The Appendix provides details on the construction of our sample and the rate of response. Ultimately, we received responses from 650 individuals representing 130 lines of business. The 130 LBs are listed in Table A-2 in the Appendix, where it is indicated that there are eighteen industries for which we have ten or more responses and twenty-seven industries for which we have five to nine responses. Our sample is reasonably representative of the population of R & D-performing business units, though the exclusion of firms without publicly-traded securities undoubtedly means that small, start-up ventures, important sources of innovation, are underrepresented. The number of respondents in a line of business is positively correlated with the LB's R & D spending (rho = 0.38, t = 4.52), sales volume (rho = 0.24, t = 2.99), and R & D intensity (rho = 0.37, t = 4.50). The number of respondents does not, however, rise in strict proportion to the level of industry R & D or sales. The rate of response within a line of business, however, is not significantly correlated with industry R & D spending, sales, or R & D intensity.

C. Methodological Issues

Given our interest in identifying inter-industry differences in the appropriability of R & D, it is reassuring that analysis of variance confirms the presence of significant inter-industry variation in the responses to most questionnaire items.[27] There remains, however, substantial intra-industry variation in the responses.

There are several potential sources of intra-industry heterogeneity in the responses to a particular question. First, the lines of business as defined by the FTC may be objectively heterogeneous in relevant technological dimensions. For example, if two firms classified as manufacturers of "industrial inorganic chemicals" produce different products using quite different technologies, they might differ markedly in their perception of the effectiveness of patents or the time required for imitation in their "industry." We checked the importance of this source of heterogeneity by asking respondents to identify a major process and a major product innovation within their industries during the past 10-15 years. For the industries with ten or more respondents, we found a remarkable degree of convergence in the identified innovations; in most of these industries, more than half the respondents agreed on at least one such major innovation. We believe it unlikely that overly aggregated industry definition is a major source of intra-industry heterogeneity.[28]

A second source of heterogeneity in responses is that a respondent's perception of the central tendencies within an industry may be affected by his firm's policies or strategies. Respondents within a line of business may thus have different perceptions of the common technological environment that they were asked to characterize. A two-way analysis of variance of the responses to questions about the effectiveness of patents, for example, revealed that both firm and industry effects are statistically significant. A representative multi-industry firm, however, tends to be involved in technologically related industries, and thus what appear to be firm effects in the data may simply reflect the correlation in responses from related industries.

A third, and probably the most important, source of intra-industry heterogeneity is the inherently subjective nature of the semantic scales used in the survey. Most answers are reported on a seven-point Likert scale. For instance, the effectiveness of patents in preventing duplication is evaluated on a scale ranging from "not at all effective" to "very effective." There is no natural or objective "anchor" for such evaluative ratings. Individuals may perceive the same environment but simply use the scale differently. Some might systematically favor high scores; others might concentrate responses in the center of the scale; yet others might use extreme values with high frequency.

The numerous techniques available to control for inter-rater differences in means and variances generally require abandonment of one or more dimensions along which the data might be informative. For example, we are interested in inter-industry comparisons of answers to a single question; controlling for inter-rater fixed effects would vitiate such comparisons, since we would expect a respondent's mean score over all questions to depend upon his industry. Standardizing the variance of each respondent's answers raises similar problems, since the distribution of "correct" responses across questionnaire items is unknown and it almost certainly differs systematically across industries. Rather than impose an arbitrary standardization, therefore, we examine the results for each group of questions using a variety of techniques and perspectives to assess the robustness of our principal conclusions. There is undeniably much noise in these data, but several important signals are robust to alternative weightings of the observations, to alternative partitions of the sample, and to the use of alternative summary statistics.[29]

We sidestep an additional methodological difficulty by treating ratings along a seven-point semantic continuum as if they were interval data. The data are, of course, more properly regarded as ordinal in character. It would be straightforward to treat the data as ordinal if we were interested only in inter-industry comparisons of responses to a single question. We seek, however, to make inter-question comparisons as well (e.g., are patents more or less effective than secrecy in protecting process innovations from duplication?), and we therefore treat the data as if they were interval in character.[30]

One additional methodological concern is whether our level of industry aggregation is appropriate for the problems we are studying. The FTC line of business level was chosen to facilitate merging the data with disaggregated R & D data and Scherer's classification of patents by industries of origin and use. Our analysis indicates, however, that most of the interesting inter-industry distinctions that we perceive across 130 LBs defined at the FTC level are robust to an aggregation of the data into the twenty-five industry groups used by the National Science Foundation in its annual survey of R & D spending and employment patterns.

III. Patents and Other Means of Appropriation

Table 2 displays the pattern of responses to questions concerning the effectiveness of alternative means of capturing and protecting the competitive advantages of new or improved production processes and products. Respondents rated each method of appropriation for both processes and products on a seven-point Likert scale.

The first two columns of Table 2 report the mean response, over the entire sample of 650 respondents, to each of the questions, as well as the standard error of each estimated mean. These statistics, of course, give equal weight to each respondent and consequently weigh each industry in proportion to its number of respondents. The overall pattern across questions, however, is robust to the use of alternative summary statistics, such as the mean of industry means, or the median of industry means. This is apparent from inspection of the third and fourth columns of Table 2, which summarize the distribution of industry mean responses to each question. Each pair of numbers represents the range of industry means from the upper bound of the lowest quintile to the lower bound of the highest quintile of industries: 20 percent of the 130 industries in our sample had mean responses at or below the bottom of the range indicated for each question, and 20 percent had mean responses at or above the top of the range. Mean responses for the remaining 60 percent (or seventy-eight industries) fell within the reported range.

|TABLE 2 HERE|

The picture presented by Table 2 is quite striking. For new processes (columns 1 and 3), patents were rated on average the least effective of the listed mechanisms of appropriation. Four-fifths of the surveyed lines of business scored the effectiveness of lead time and learning curve advantages on new processes in excess of 4.3 on a seven-point scale. By contrast, only one-fifth of the surveyed lines of business rated process patent effectiveness in excess of 4.0. Secrecy, though not on average as effective as lead time and learning advantages, was somewhat more effective than patents in protecting processes.

Comparing columns 2 and 4 with columns 1 and 3, it is clear that product patents were typically viewed as more effective than process patents, and secrecy was viewed as less effective in protecting products than processes. Overall, for products, lead time, learning curves, and sales or service efforts were regarded as substantially more effective than patents. Four-fifths of the sample businesses rated the effectiveness of sales and service efforts above 5.0, but only one-fifth considered product patents this effective.[31]

The tendency to regard secrecy as more effective than process patents but less effective than product patents probably reflects the greater ease and desirability of maintaining secrecy about process technology. Indeed, in some instances firms refrain from patenting processes to avoid disclosing either the fact or the details of a process innovation.[32] On the other hand, firms have every incentive to advertise widely the advantages of new or improved products and to get the products into the hands of customers, thereby facilitating direct observation of the product and the technology it embodies. It is thus likely to be both difficult and undesirable to maintain secrecy about product technology.

It is also interesting that respondents tended to regard "patents to prevent duplication" as more effective than "patents to secure royalty income." This finding is consistent with the view that licensing arrangements are beset with transactional difficulties, as might be expected in a situation where information is asymmetrically distributed.

Viewing the results at the level of specific industries, it is remarkable that only three of 130 LBs rated process patents above five on a seven-point scale of effectiveness in preventing duplication. Two of these were concrete and primary copper; the other LB had only a single respondent.[33] Only five of 130 industries rated product patents to prevent duplication above six. Two of these were singletons; the other three LBs were drugs, pesticides, and industrial organic chemicals. Twenty other LBs rated product patents between five and six. Focusing on those LBs with more than two responses, almost all these industries giving patent protection high marks fall neatly into two groups: chemical products or close relatives (inorganic chemicals, plastic materials, synthetic fibers, synthetic rubber, and glass) or relatively uncomplicated mechanical equipment (air and gas compressors, power driven hand tools, and oilfield machinery). The only anomalies are roasted coffee and products of steel rolling and finishing mills.

Some additional industry-level detail is displayed in Table 3, which reports, for the eighteen lines of business with ten or more respondents, the mean rating given for the effectiveness of patents in preventing duplication. These eighteen industries tend to be substantially more research intensive than the sample average, yet the pattern of interindustry variation is very similar to that within the full sample. In every instance but one, petroleum refining, product patents were regarded as more effective than process patents. Only four chemical industries (drugs, plastic materials, inorganic chemicals, and organic chemicals) and petroleum refining rated process patent effectiveness above four on a seven-point scale, and only these same four chemical industries and steel mills rated product patents above five.[34]

|TABLE 3 HERE|

The data on these eighteen most heavily sampled industries help to establish the robustness of our conclusion about the limited effectiveness of patents as a means of appropriation. In none of these industries did a majority of respondents rate patents -- either to prevent duplication or to secure royalty income -- as more effective than the most highly rated of the other four means of appropriating returns from new processes, although in drugs and petroleum refining a majority regarded process patents as at least the equal of the most effective alternative mechanism of appropriation. In only one industry, drugs, were product patents regarded by a majority of respondents as strictly more effective than other means of appropriation.[35] In three other industries -- organic chemicals, plastic materials, and steel mill products -- a majority of respondents rated patents as no less effective than the best alternative.

The exclusion from our sample of firms that offer no publicly-traded securities may bias our findings concerning the limited effectiveness of patents. For small, start-up ventures, patents may be a relatively effective means of appropriating R & D returns, at least in part because some other means, such as investment in complementary sales and service efforts, may be infeasible for them. A small, technologically-oriented firm's patent portfolio may be its most marketable asset. Although our respondents were asked to describe the typical experience of firms in their industries, they may well have overlooked aspects of appropriability that are particularly relevant for start-up firms.

The most probable explanation for the robust finding that patents are particularly effective in chemical industries is that comparatively clear standards can be applied to assess a chemical patent's validity and to defend against infringement. The uniqueness of a specific molecule is more easily demonstrated than the "novelty" of, for example, a new component of a complex electrical or mechanical system. Similarly, it is easy to determine whether an allegedly infringing molecule is physically identical to a patented molecule; it is more difficult to determine whether comparable components of two complex systems "do the same work in substantially the same way." To the extent that very simple mechanical inventions approximate molecules in their discreteness and easy diffentiability from other inventions, it is understandable that industries producing relatively uncomplicated machinery rank just after chemical industries in the perceived effectiveness of patent protection.

The perceived ineffectiveness of patents as means of appropriation in most industries raises the question of why firms use them. Further work is needed here, but we offer some speculations informed by the comments of our pre-test subjects and by several survey respondents at a conference we held to report on our preliminary findings. These R & D executives identified at least two motives for patenting that have little connection with appropriating the returns from investment. One is to measure the performance of R & D employees, which is a non-trivial problem because R & D workers are typically engaged in "team" production. Legal standards for identifying "inventors" on a patent application are, however, reasonably rigorous. The second motive is to gain access to certain foreign markets. Some developing countries require, as a condition of entry, that U.S. firms license technology to a host-country firm. According to some of our respondents, some patents are filed primarily to permit such licensing.[36]

IV. Characterizing Appropriability Conditions

Thus far we have focused on the overall strength of various mechanisms of appropriation and inter-industry variation in the effectiveness of patents. The patterns of covariation in the responses, however, suggest that inter-industry differences in appropriability conditions might be summarized by a limited number of "factors." Moreover, the very clear indications that patents are effective in only a small number of industries suggest that it might be fruitful to classify industries into a small number of "clusters," each distinguishable by a primary means of appropriation and perhaps by the overall ease of appropriating returns. Such parsimonious representation of our results could prove useful in empirical work examining the links between appropriability conditions and measures of R & D, innovation, and productivity growth.

Correlations among responses to our questions concerning the effectiveness of alternative means of appropriation reveal some interesting patterns.[37] For both processes and products, when patents are effective in preventing competitors from duplicating, they tend also to be effective in securing royalty income. But neither variety of patent effectiveness is strongly correlated with the effectiveness of other means of appropriation. For processes, there is a strong connection among three other mechanisms: lead time, learning curve advantages, and secrecy. In the case of products, superior sales and service efforts were strongly linked to lead time and learning advantages, though not to secrecy.

The pattern of correlation suggests that the mechanisms of appropriation may effectively reduce to two dimensions: one associated with the use of patents, the other related to secrecy, lead time, and learning curve advantages. For product innovations, sales and service efforts may be involved in the second of these dimensions. We investigated this possibility by reducing the data to principal components and by employing a variety of factor-analytic techniques. Principal factor analysis and several methods of rotation did little to alter the picture presented by the principal components, which are displayed in Table 4.[38]

The first two columns of Table 4 show the weights associated with the first two principal components when the six questions relating to process appropriability are analyzed separately from the six questions relating to product appropriablity. The next two columns report the results of a principal components analysis on the entire set of twelve questions. With both approaches, the first principal component gives near-zero weight to the two patent-related methods of appropriation and gives heavy weight to the non-patent mechanisms. The weighting is reversed for the second principal component. Thus, the first two principal components (and, in the factor analysis, the first two factors) are readily interpreted, respectively, as non-patent and patent-related dimensions of appropriability. Despite this clear interpretation, the data do not reduce very satisfactorily to just two dimensions. As Table 4 indicates, when the process and product questions are analyzed separately, the first two components explain only sixty percent of the variance in the responses to six questions, and when the twelve questions are combined, two components explain only fifty percent of the variance.

|TABLE 4 HERE|

Our interpretation that means of appropriation can be grouped into patent and non-patent mechanisms is nonetheless reinforced by a cluster analysis that classified industries on the basis of their mean responses to the questions concerning these mechanisms. For both process and product appropriability measures, the best clustering results were achieved by dividing the industries into three groups, as shown in Table 5. In both cases, the results can be given a similar interpretation. Industries assigned to Cluster 1 tend to have relatively low scores for all mechanisms of appropriation. Within this cluster, sales and service effort is the most highly rated mechanism, and, in fact, it is regarded as reasonably effective in capturing the returns from new products. Industries in Cluster 2 rated lead time and learning curves as relatively effective, but patents were not viewed as particularly effective. Secrecy is important in appropriating process returns in this cluster, and sales and service efforts complement lead time and learning advantages for products. For both products and processes, Cluster 3 is the only one in which patents appear effective, but on average the effectiveness of lead time and learning is no lower for these industries than for those in Cluster 2. The relatively few industries in which patents were rated as more effective than other mechanisms are all in the third cluster.

|TABLE 5 HERE|

The cluster analysis suggests that there is a group of industries in which no appropriation mechanism is particularly effective. An alternative approach to identifying settings with low appropriability is to consider the maximum score an industry assigned to any of the six mechanisms on the questionnaire. Only eleven of 130 LBs failed to rate at least one means of appropriating returns from product innovation above five on our seven-point scale. The industries in this group with more than two responses are all drawn from the food products and metalworking sectors: milk, meat products, iron and steel foundries, boiler shops, and screw machine products (nuts, bolts, and screws). Many more industries appear to lack an effective means of appropriating the returns from process innovation. More than one-quarter of the sample industries (thirty-four of 130) rated no means of appropriating process returns above five. This group contains all the industries (except milk) that ranked low on product appropriability, but it is otherwise a pretty diverse lot. The heaviest concentration of industries represented in this group is in SIC 34 and 35, the fabricated metals and machinery sectors. But several chemical industries are represented here, including the three LBs in which product patents are viewed as most effective -- organic chemicals, pesticides, and drugs.

The urge to find patterns in the data should not be carried too far. The associations among mechanisms of appropriation revealed by the correlation, principal components, and cluster analyses are suggestive, but there is substantial heterogeneity in the underlying data. As noted, the first two principal components, though readily interpretable, explain an unsatisfactory fraction of the overall variance. A similar lack of "goodness-of-fit" characterizes the cluster analyses of process and product appropriability. Despite the fairly clear interpretation that can be given to each cluster, the within-cluster variance is almost twice the between-cluster variance.

V. Limits on the Effectiveness of Patents

To understand why patent protection might be weak in some industries, we asked respondents to rate the importance of several possible limits on patent effectiveness. Table 6 summarizes the responses.

|TABLE 6 HERE|

For both process and product patents, the ability of competitors to "invent around" was regarded as the most important constraint on effectiveness. Three-fifths of the responding businesses rated the importance of "inventing around" above five on a seven-point scale for both processes and products; only one other constraint -- the fact that new processes are not readily patentable -- was rated this important by more than one-fifth of the surveyed businesses. Table 6 also indicates that limitations on patents are generally more severe for processes than for products, which is consistent with our finding that product patents tend to be more effective than process patents. In particular, the lack of "patentability" is more serious for processes than for products, and so is the disclosure of information through patent documents.[39]

The responses concerning limits on patent effectiveness can be used to suggest how our survey data might illuminate and focus policy discussion. In recent years, there has been considerable interest in making patent protection more effective. One initiative has been to make less stringent the legal requirements for a valid patent claim.[40] Another has been to vacate court decrees compelling licensing. Our data identify industries in which stringent requirements for patent validity or compulsory licensing are perceived as important limits on the utility of patents in appropriating returns to invention.

Respondents in twenty-two lines of business, drawn most heavily from the food processing and fabricated metals sectors, viewed the likely inability to withstand challenges to validity as a substantial constraint on the effectiveness of process patents (scoring the importance of this constraint above five on a seven-point scale); in fourteen of these LBs, the mean response was six or more. There is considerable overlap between this group and the nineteen LBs citing invalidity as a constraint on the effectiveness of product patents (again assigning invalidity a score above five). Further investigation would be required to determine just why firms in the food products and fabricated metals sectors appear to have problems establishing valid patent claims. These are mature industries; opportunities may be limited, and, possibly, "novelty" may be difficult to achieve or simply difficult to prove.

Compulsory licensing was rarely judged a significant limit on the effectiveness of patents. Only one LB (a singleton) rated this constraint above five on the semantic scale for products, and only six LBs cited compulsory licensing of process patents as a limit of comparable importance. Two of these LBs were not singletons -- metal containers and electron tubes. Compulsory licensing decrees are thus perceived as important in only a small subset of the industries that Scherer indicates are subject to such decrees.[41] The overall lack of impact of compulsory licensing is consistent with Scherer's finding that such requirements did not discourage R & D spending.

The choice between a patent and secrecy may be influenced by the extent to which the disclosures made in the patent document facilitate inventing around the patent. Our data provide some support for this view. The effectiveness of secrecy is positively correlated with the extent to which disclosures limit the effectiveness of patents. The link is stronger for product patents than for process patents. But there are very few industries in which patent disclosures represent a substantial limitation on the effectiveness of patents. Only four of 130 LBs rated product patent disclosures as high as six on a seven-point scale, and only sixteen LBs regarded process disclosures as a comparably important constraint on patent effectiveness. In only one LB with five or more respondents -- metal-cutting machine tools -- did disclosures constrain so substantially the effectiveness of both process and product patents.

VI. Channels of Intra-industry Information Spillover

To the extent that a rival can learn easily about an innovator's technology, the incentive to invest in R&D is attenuated, since the inventor appropriates a smaller fraction of the potential private benefits. But to the extent that learning is easy, wasteful duplication or near duplication of R & D effort by rival firms may be avoided. Also, knowledge of an innovator's new technology may complement rival R & D effort by enhancing its productivity. Nelson and Winter, Spence, and Levin and Reiss[42] have developed models that begin to disentangle these offsetting effects, called by Spence the "incentive" and "efficiency" effects of inter-firm spillovers. A sharper characterization of inter-industry differences in the nature and strength of the mechanisms by which firms learn about their competitors' technology should advance these modelling efforts.

Table 7 summarizes the responses to questions concerning the effectiveness of alternative learning mechanisms. On the whole, there is little difference between the pattern of responses for processes and for products, except that, as one would expect, reverse engineering is markedly more effective in yielding information about product technology. On average, doing independent R&D was rated as the most effective means of learning about rival technology.[43] This may appear to be wasteful duplication, but it need not be. One pre-test subject said that R & D effort devoted to determining what a competitor has done may have strong complementarities with a firm's own research program in areas not directly imitative of the innovating competitor. Licensing was also rated, on average, an important way of gaining access to a rival's new technology, as was reverse engineering of products.

|TABLE 7 HERE|

Inspection of the correlations among both individual and industry mean responses reveals that mechanisms relying on interpersonal communication (publications and technical meetings, informal conversations, and hiring away employees) are strongly intercorrelated. Learning by means of licensing technology is uncorrelated with nearly all other learning mechanisms, except disclosure through patent documents. There are two possible interpretations of this last connection. Potential licensees may learn about the opportunity to license through patent documents, or the documents may prove useful in employing new technology once it is licensed. We cannot tell whether the "announcement effect" or the "complementary information" effect of disclosures predominates.[44]

The pattern of correlation suggests that we might expect to find three or four clusters of industries -- distinguished in turn by an emphasis on learning through licensing, interpersonal channels, and either reverse engineering, independent R&D, or both. The results obtained from cluster analysis were not entirely satisfactory.[45] Nonetheless, we present in Table 8 the results of grouping the LBs into three clusters on the basis of responses to the set of questions on channels of spillover.

|TABLE 8 HERE|

For both new processes and new products, the largest group of industries typically relies on licensing and independent R&D to learn about competitive technology. For LBs in this cluster, interpersonal channels are relatively unimportant, and reverse engineering is important for products. For both processes and products, there is a second cluster of industries in which interpersonal channels of spillover are most important. But, in the case of learning about new products, only ten LBs are classified in this cluster, and in the case of learning about new processes, other channels -- independent R & D and reverse engineering -- are nearly as valuable as interpersonal channels. In the case of processes, a third cluster appears to find all mechanisms of learning about competitors' innovations relatively unproductive. For products, the third group of LBs finds all mechanisms of learning about competitors' technology moderately effective.

VII. Cost and Time Required for Imitation

As part of our investigation of appropriability, we asked respondents to indicate the typical levels of cost and time it would take to duplicate several categories of innovations if they were developed by a competitor. For each type of innovation, respondents were asked to identify (within a range) the cost of duplication as a percentage of the innovator's R & D cost. Intervals measured in months or years were used to classify the time typically required to imitate each type of innovation. In light of evidence that there exists a time-cost tradeoff in certain industries,[46] we asked respondents to estimate the cost and time required "to have a significant impact on the market."

Tables 9 and 10 display frequency distributions of industry median responses.[47] The dispersion of industry medians suggests substantial inter-industry variation in both the cost and time required to duplicate all categories of innovation. If, however, individual responses to the questions on imitation cost are coded on a six-point interval scale, there is sufficient intra-industry variation to render inter-industry differences insignificant at the 0.01 level. Inter-industry differences in the time required for duplication are, by contrast, significant at the 0.01 level in every instance except the time required to duplicate a typical, patented new process.

|TABLES 9 AND 10 HERE|

Several conclusions are apparent from inspection of Tables 9 and 10. First, duplication of major innovations tends to cost more and take longer than duplication of typical innovations. (In a sense, this confirms that respondents correctly interpreted the distinction between typical and major innovations.) Second, for a given category of innovation, the cost and time required to duplicate are distributed very similarly for products and processes. Products tend to be, on average, slightly cheaper and quicker to duplicate than processes, though this generalization does not hold for major, patented innovations.

Finally, and most interesting, patents tend, on average, to raise imitation cost and time for each category of innovation. These increases in cost and time can be regarded as alternative indicators of the relative effectiveness of patents in different industries.

To explore this point further, we coded the individual responses to the imitation cost and time questions on a six-point interval scale, calculated the individual and industry mean increases in cost and time associated with the presence of patents, and correlated these, respectively, with individual and industry mean responses to our questions on the effectiveness of patents to prevent duplication. For each category of innovation, the reported effectiveness of patents is positively correlated with the increase in duplication cost and time associated with patents, although the correlations tend to be stronger for products than for processes. We also found some evidence, at the individual respondent level, that patent effectiveness is associated with the absolute level of duplication cost for patented processes and products. We found a much stronger association, however, between reported patent effectiveness and the amount of time required to duplicate both patented process and product innovations.

These broad-brush patterns of association conceal some striking anomalies. For particular categories of innovation, at least two and as many as fourteen industries reported that patents actually reduced the cost or time required for duplication. A partial explanation of this finding is that a disproportionate number of these industries also reported that disclosure of information through patent documents was a significant limitation on patent effectiveness.

A second anomaly is that, despite the positive correlation between patent effectiveness and the cost of imitating patented products, there are several industries in which patents are relatively ineffective and duplication costs are nonetheless very high, whether or not the innovation is patented. Among these are guided missiles and several types of industrial machinery (food products machinery, electric welding apparatus, and speed changers, drives, and gears). In these instances, the relative complexity of the products presumably makes reverse engineering inherently costly despite relatively weak patent protection.

It is interesting to compare our findings with those obtained by Mansfield, Schwartz, and Wagner, who studied the effects of patents on imitation cost in three industries.[48] They concluded that, on average, patents raised imitation costs by thirty percentage points in drugs, by twenty percentage points in chemicals, and by seven percentage points in electronics. To render our data comparable, we evaluated each respondent's answer at the mean of the relevant range,[49] and we computed crude industry average imitation costs for each type of innovation.

Our results for drugs, chemicals, and electronics products are consistent with those of Mansfield, Schwartz, and Wagner. We find that patents raise imitation costs by about forty percentage points for both major and typical new drugs, by about thirty percentage points for major new chemical products, and by twenty-five percentage points for typical chemical products. In electronics, our results differ somewhat for semiconductors, computers, and communications equipment, but the range is seven to fifteen percentage points for major products and seven to ten percentage points for typical products.[50]

Although the cost and time required for duplication are related to the effectiveness of patents, they do not seem to be linked strongly to any other mechanism of appropriability. In particular, most imitation time and cost measures are uncorrelated with lead-time and learning-curve advantages in appropriating returns on both processes and products, and where such correlations are statistically significant (at the individual respondent level), the correlation coefficient is invariably below 0.15. These results make sense upon reflection. Lead time and learning advantages may permit appropriation of returns even where duplication is relatively quick and inexpensive. "Effective" patents, however, presumably require considerable time and expense to be "invented around."

Finally, most of our respondents believe only a small number of firms are capable of effectively duplicating new processes and products in their lines of business. As seen in Table 11, the median and modal number of firms judged capable of duplicating a major process or product innovation was three to five. The median and modal number of firms regarded as capable of duplicating a typical process or product innovation was six to ten. The data reveal only the slightest tendency toward a smaller number of capable duplicators for processes than for products.

|TABLE 11 HERE|

VIII. Using the Survey Data to Explain R & D and Innovation

In this section, we summarize how data derived from our survey have been employed to understand better the sources of inter-industry differences in R & D spending and the rate of technological advance. In the first such effort, Levin, Cohen, and Mowery (hereafter LCM) used several survey-based measures to explain variation in the published Federal Trade Commission data on industry-level R & D spending as a percentage of sales.[51] They also sought to explain inter-industry differences in the rate at which new processes and new products were introduced during the 1970s, as reported by our survey respondents.[52] In a subsequent paper, Cohen, Levin, and Mowery (hereafter CLM) studied the extent to which the same survey-based measures explain the powerful industry effects in the confidential FTC data on R & D intensity at the level of the business unit.[53]

The first paper focused on the Schumpeterian hypothesis that R & D intensity and innovation rates are significantly influenced by the level of industry concentration. One common rationale for this hypothesis is that industry concentration enhances the potential for appropriation of R & D returns. A different view is that concentration, in the long run, tends to be a consequence of industry evolution in a regime of abundant technological opportunity and a high degree of uncertainty associated with investment in R & D. Both these perspectives suggest that there is not a simple, causal relationship between concentration per se and R & D. Concentration may be statistically significant in simple regression specifications because it reflects the influence of the unobserved appropriability and opportunity conditions that directly affect R & D spending and the rate of innovation.

In OLS and 2SLS specifications that included only the four-firm concentration ratio and its square as regressors, LCM replicated with the industry-level FTC data the familiar inverted-U relationship between concentration and R & D intensity, and they found a strong relationship of the same form between concentration and the rate of innovation.[54] Adding two-digit industry fixed effects weakened slightly the effect of concentration on R & D, but the innovation-rate equation was unaffected.

The results changed dramatically with the addition of measures of appropriability and technological opportunity derived from our survey.[55] Whether or not two-digit industry fixed effects were included, the coefficients on concentration and its square fell by an order of magnitude in the R & D equation, and the effect of concentration was no longer statistically significant at the 0.05 level in either the R & D intensity or the innovation-rate equation. The vector of survey-based opportunity variables was significant at the 0.05 level in all specifications, and the opportunity and appropriability variables were jointly significant. The appropriability variables, however, were not individually significant in the R & D equation, although the rate of innovation was positively related to the effectiveness of an industry's most effective means of appropriation.[56]

The CLM paper used the disaggregated FTC data at the level of the business unit to investigate the Schumpeterian hypothesis linking size and R & D intensity. CLM found that, when either fixed industry effects (at the LB level) or survey-based industry characteristics were taken into account, firm size had a very small and statistically insignificant effect on R & D intensity. Business unit size did have a significant effect on the probability of engaging in R & D, but there was no perceptible tendency for R & D intensity to increase with business unit size within the group of R & D performers. Size effects, however, explained only two-tenths of one percent of the variance in R & D intensity, while LB-level industry effects explained half of this variance.

CLM found that industry-level measures of appropriability, opportunity, and demand conditions were consistently significant in OLS, GLS, and Tobit regressions explaining business unit R & D intensity. Moreover, these industry characteristics explained approximately half of the variance in R & D intensity explained by fixed industry effects. When attention was focused on those LBs for which there were at least three survey respondents, measured industry characteristics explained 56 percent of the between-industry variation in R & D intensity. Within particular two-digit industries (chemicals, machinery, and electrical equipment), measured characteristics explained 78 to 86 percent of the variance explained by fixed effects.

The results obtained in the LCM and CLM papers indicate that survey-based measures can contribute substantially to an explanation of inter-industry differences in R & D intensity and innovative performance. Measures derived from our survey, despite their imperfections, have also been found useful for a variety of other purposes.[57]

IX. Remarks on Policy

Our findings suggest some general principles relevant to policies that affect the incentives to engage in innovative activity. We conclude by discussing these general principles, and we briefly consider their application in the context of two illustrative examples.

A first principle is that the patent system and related intellectual property institutions should be understood as social structures that enhance the appropriability of returns from innovation. They are not the only, nor necessarily the primary, barriers that prevent general access to what would otherwise be pure public goods. Lead time accrues naturally to the innovator, even in the absence of any deliberate effort to enhance its protective effect. Secrecy, learning advantages, and sales and service efforts can provide additional protection, though they require the innovator's deliberate effort. The survey confirms that these other mechanisms of appropriation are typically more important than the patent system. Hence, in examining a proposed adjustment of the patent system or related institutions, it is important to recognize that the incremental effect of the policy change depends on the protection other mechanisms provide.

The survey results confirm also that there is substantial inter-industry variation in the level of appropriability and in the mechanisms that provide it. From this follows our second major principle, which is that the incremental effects of policy changes should be assessed at the industry level. For example, in the aircraft industry, where other mechanisms provide considerable appropriability, lengthening the life of patents would tend to have little effect on innovation incentives at the margin. In the drug industry, the effect of a longer lifetime would tend to matter more.[58]

Finally, it is important to keep in mind that improving the protection of intellectual property is not necessarily socially beneficial. Empirical work to date has indicated a positive cross-sectional relationship between strong appropriability, as measured by variables constructed from our survey, and innovative performance. But the social cost-benefit calculation is not straightforward. Stronger appropriability will not yield more innovation in all contexts, and, where it does, innovation may come at excessive cost.

To illustrate how our survey results and general perspective might inform policy discussion, consider the proposal (S. 438, H.R. 557) that patent license agreements and other contracts relating to the use of intellectual property "shall not be deemed illegal per se under any of the antitrust laws." One consequence would be to eliminate the per se illegality of tying arrangements where the tying product is covered by a patent or otherwise protected as intellectual property.[59] Our findings suggest some issues a court should consider in evaluating such a tying arrangement under the rule of reason.

When the rule of reason is applied to tying cases, a relevant consideration is the firm's market power in the market for the tying good. Courts have often presumed that intellectual property protection is itself evidence for such power. To the other good reasons for rejecting such a presumption,[60] we add that the mere existence of a patent or other legal protection says nothing about its efficacy in a competitive context. As the survey results show, the effectiveness of protection varies widely across industries. Thus, in deciding a case, a court should inquire into the actual competitive significance of intellectual property protection in the particular market.

Suppose, for example, that a pharmaceutical company were to tie hospital sales of supplies or equipment to its sale of a patented drug. Since patent protection of drugs is generally strong and effective, and a drug is often uniquely suited for particular purposes, skepticism about the reasonableness of the tie-in would be in order. The arrangement could not plausibly be regarded as a straightforward means of appropriating returns to which the firm was entitled as owner of the patent; given the typical effectiveness of drug patents, the price of the drug should suffice for that purpose. There might be other benign explanations for the tie; for example, if the supplies or equipment were complementary in use to the drug, the arrangement might be explicable as an attempt to control the quality of treatment. But if no such alternative rationale were supported by the evidence, the tie would seem to be an unreasonable restraint of trade.

By contrast, consider a producer of a patented product in an industry where no mechanism of appropriability functions particularly well -- plywood, for example, where patents, secrecy, lead time, and learning advantages are all rated no higher than four on a seven-point scale of effectiveness. In this case, the low level of appropriability in general and of patents in particular should weigh against any presumption that a patent confers market power. We would argue further that the patentee in such an industry should be entitled to some scope for ingenuity in constructing arrangements that maximize the return to the patent, provided that these arrangements are not open to antitrust objections on grounds independent of the role played by the patent.

The intellectual property provisions of the Omnibus Trade and Competitiveness Reform Act also serve to illustrate the relevance of our survey results. One provision requires the

United States Trade Representative to identify countries that have been particularly insensitive, as a matter of law or _de facto_ policy, to the need for protection of intellectual property and to initiate unfair-trade-practice (Section 301) investigations against them.[61] This provision of the trade bill would complement the Administration's diplomatic efforts to strengthen intellectual property rights throughout the world and particularly in countries that permit firms to copy patented or copyrighted products from the U.S.

Since the impact of legal protection of intellectual property depends on the strength of other appropriability mechanisms and varies widely across industries, focused efforts to solve problems in specific markets would be more prudent than a broad attempt to upgrade protection. There is little point in expending diplomatic capital to compel foreign countries to pass or enforce laws that, in most industries, would have minimal impact on the competitive process. By constrast, in those specific industries, such as pharmaceuticals -- where patent protection is effective, where other means of appropriation are poor substitutes, and where foreign governments often restrict, officially or tacitly, the ability of U.S. firms to exploit patents -- a more persuasive case could be made for the U.S. to seek adjustment in the behavior of its trading partners.

APPENDIX

Details of Sample Construction

Review of the FTC data indicated that several LBs did not report any R&D activity, and several other LBs were aggregated to prevent violating confidentiality rules. Anticipating difficulty in finding knowledgeable respondents in industries without formal R & D activity, and wishing to avoid industry categories that included technologically disparate products, we eliminated from our sampling frame all LBs without reported R&D as well as those judged overly heterogeneous.

The industries eliminated on grounds of heterogeneity were either the FTC's aggregations of technologically disparate LBs or LBs corresponding to SIC industries with four-digit codes ending with "9." Such industries are residual categories within the relevant three-digit groups; their titles usually contain the words "miscellaneous, not elsewhere classified."

Confidentiality requirements prohibited us from using the FTC data as a means of identifying the firms that conduct R & D in each line of business. Instead, we used the Business Week annual R & D survey to identify all publicly traded firms that reported R & D expenses in excess of either 1 percent of sales or thirty-five million dollars. This constitutes a nearly comprehensive list of significant R&D-performing private firms. There were 746 such firms in 1981, when our survey design efforts commenced.

We used the information in Dun and Bradstreet's Million

Dollar Directory to assign each of the Business Week firms to its major lines of business. Dun and Bradstreet's does not provide a complete list of each firm's lines of business, but it indicates as many as six four-digit SICs for each firm, in rough order of sales. Since some firms operate in non-manufacturing industries, in manufacturing industries absent from our sample, or in two or more industries that map into only one FTC LB, we had substantially fewer than 746 x 6 observations. Within our sample lines of business, we found a total of 1,928 business units operated by 688 firms.

A major survey-design problem was how to obtain responses for multiple business units within the same firm. Of our 688 firms, 470 participated in more than one of our sample LBs. We initially attempted to identify relevant respondents using the reference volume, Industrial Research Laboratories of the United States. But our pre-test subjects told us that over half the people in such a sample were inappropriate. Some had been assigned to the wrong line of business; others had been promoted or had left the relevant division or the firm.

We, therefore, adopted a two-stage approach in which each firm's senior R&D vice president or chief executive officer was asked to furnish the names of employees with the knowledge to complete the questionnaire for specific lines of business. We sent first round requests to 470 firms representing 1710 business units. There was attrition of 332 business units from this sample for three reasons: the firm did not do R&D in the specified line of business, the industry definition did not fit any of its activities, or a respondent could not be located. From this adjusted sample frame of 1378 business units in firms with multiple units, we received names of respondents for 716. We sent questionnaires to each of these potential respondents as well as to representatives of the 218 firms operating in only one line of business. At this stage, there was some further attrition in the sample. Ultimately, we received 650 completed questionnaires, from an overall adjusted sample frame of 1562 -- an overall response rate of 41.6 percent. Table A-1 summarizes this information.

|TABLES A-1 AND A-2 HERE|

*. We are grateful for the generous support of the National Science Foundation and especially for the patient encouragement offered by Rolf Piekarz of the NSF's Division of Policy Research and Analysis. We also appreciate the comments and suggestions were offered by numerous colleagues, participants at the Brookings conference, our formal discussants, and the editors of this volume.

This project would have been impossible but for the assistance and enthusiasm of the industrial research community. In addition to our 650 respondents, we thank the R & D executives who took the time to help us pre-test the survey instrument -- especially Ralph Gomory, Bruce Hannay, and Lowell Steele, who served on our advisory panel.

Donald DeLuca, Wendy Horowitz, and other members of the Roper Center for Survey Research smoothly managed the complex logistics of our survey with consistent thoughtfulness and attention to detail. Robert W. Wilson assisted us by interviewing many of our pre-test subjects. At various stages in the project, we received valuable research assistance from Margaret Blair, Marc Chupka, Emily Lawrance, Constance Helfat, Andrew Joskow, Kathleen Rodenrys, Somi Seong, Andrea Shepard, and Hal Van Gieson.

1. F. M. Scherer et al., Patents and the Corporation, 2nd ed. (privately published, 1959), and C. T. Taylor and Z. A. Silberston, The Economic Impact of the Patent System: A Study of the British Experience (Cambridge University Press, 1973).

2. See, for example, Meir Statman, "The Effect of Patent Expiration on the Market Position of Drugs," in Robert B. Helms, ed., Drugs and Health (American Enterprise Institute, 1981), pp. 140-151.

3. The importance of lead time and learning curve advantages is documented in Almarin Phillips' account of competition in civilian aircraft manufacture and in John Tilton's study of the semiconductor industry. See Phillips, Technology and Market Structure: A Study of the Aircraft Industry (Lexington, 1971); and Tilton, International Diffusion of Technology: The Case of Semiconductors (Brookings, 1971).

4. A good example is the work of Marie-Therese Flaherty, "Field Research on the Link between Technological Innovation and Growth: Evidence from the International Semiconductor Industry," Working Paper 84-83 (Graduate School of Business Administration, Harvard University, no date).

5. See especially Ariel Pakes, "Patents as Options: Some Estimates of the Value of Holding European Patent Stocks," Econometrica, vol. 54 (July 1986), pp. 755-784.

6. For a summary of the best of this work, see the report of Zvi Griliches, Ariel Pakes, and Bronwyn Hall, "The Value of Patents as Indicators of Inventive Activity," Working Paper No. 2083 (National Bureau of Economic Research, November 1986). For a variety of other perspectives on the usefulness of patent data,

see the recent special issue of Research Policy, vol. 16 (August 1987).

7. See F. M. Scherer, "The Propensity to Patent," International Journal of Industrial Organization, vol. 1 (March 1983), pp. 107-128, and John Bound, C. Cummins, Zvi Griliches, Bronwyn Hall, and Adam Jaffee, "Who Does R & D and Who Patents?" in Zvi Griliches, ed., R & D, Patents and Productivity (University of Chicago Press, 1984).

8. Richard C. Levin, "Toward an Empirical Model of Schumpeterian Competetion," Working Paper Series A, No. 43 (Yale School of Organization and Management, 1981), and Richard C. Levin and Peter C. Reiss, "Tests of a Schumpeterian Model of R & D and Market Structure," in Zvi Griliches, ed., R & D, Patents and Productivity (University of Chicago Press, 1984), pp. 175-204.

9. Ariel Pakes and Mark Schankerman, "An Exploration into the Determinants of Research Intensity," in Zvi Griliches, ed., R & D, Patents and Productivity (University of Chicago Press, 1984), pp. 209-232.

10. The following documents reflect, in turn, the various developments mentioned in the text: Computer Software Act of 1980; Semiconductor Chip Protection Act of 1984; Diamond v. Chakrabarty, 447 U.S. 305 (1980), holding that plant and animal life is patentable under U.S. patent law; D.J. Quigg, memorandum of April 7, 1987, explaining the policies of the U.S. Patent and

Trademark Office concerning applications to patent life forms.

11. These provisions are contained in H.R. 3, the Omnibus Trade and Competitiveness Reform Act, which is under consideration by the conference committee at the time of this writing.

12. H.R. 557 and S. 438, 100th Congress, 1st Session.

13. This is the "free access" externality, first emphasized in the context of innovation by Yoram Barzel and subsequently explored in many models of "patent races." See Barzel, "Optimal Timing of Innovations," Review of Economics and Statistics, vol. 50 (1968), pp. 348-355. For a survey of the "patent race" literature, see Jennifer Reinganum, "The Timing of Innovation: Research, Development and Diffusion," in Richard Schmalensee and Robert Willig, ed., Handbook of Industrial Organization (North-Holland, forthcoming 1988).

14. See Richard R. Nelson, "Assessing Private Enterprise: an Exegesis of Tangled Doctrine," Bell Journal of Economics, vol. 11 (Spring 1981), pp. 93-111.

15. This possibility arises if, for example, a patent life is extended beyond the optimal duration. See William D. Nordhaus, Invention, Growth, and Welfare (MIT Press, 1969).

16. See Richard C. Levin, "The Semiconductor Industry," in Richard R. Nelson, Government and Technical Progress: A Cross-Industry Analysis (Pergamon Press, 1982), pp. 9-100.

17. Among the sources of ideas reflected in the questions we asked are Paul David, Technical Choice, Innovation and Economic Growth: Essays on American and British Experience in the Nineteenth Century (Cambridge University Press, 1975); Richard R. Nelson and Sidney G. Winter, "In Search of Useful Theory of Innovation," Research Policy, vol. 6 (Winter 1977), pp. 36-76; Nathan Rosenberg, "Science, Invention, and Economic Growth," Economic Journal, vol. 84 (March 1974), pp. 90-108; and Devandra Sahal, Patterns of Technological Innovation (Addison-Wesley, 1981).

18. Scherer et al., Patents and the Corporation; Taylor and Silberston, The Economic Impact of the Patent System.

19. Edwin Mansfield, M. Schwartz, and S. Wagner, "Imitation Costs and Patents: An Empirical Study," Economic Journal, vol. 91 (December 1981), pp. 907-918.

20. Our pre-test subjects had experience in the following industries: communications equipment, industrial inorganic chemicals, metal cutting machine tools, shoe machinery, household electrical appliances, processed foods, computing equipment, semiconductors, copper smelting and refining, radio and TV sets, and industrial organic chemicals.

Each pre-test subject was sent the questionnaire in advance, and he was asked to complete it for a specific line of business. At the same time, he was asked to keep in mind the suitability of the questions for other lines of business with which he was familiar. After completing the questionnaire, the cooperating executive was interviewed face-to-face or by telephone. Interviews typically lasted one-half hour or more. Each question was discussed with the aim of eliminating sources of ambiguity wherever possible.

21. Industry representatives advised us that repondents were more likely to cooperate if asked to report on characteristics of their industry than if placed in a position of possibly divulging practices and policies of their own firms.

22. Mansfield, Schwartz, and Wagner, "Imitation Costs and Patents."

23. Nelson and Winter, "In Search of Useful Theory."

24. Richard C. Levin, Wesley M. Cohen, and David C. Mowery, "R & D Appropriability, Opportunity, and Market Strucure," American Economic Review, vol. 75 (May 1985), pp. 20-24; Cohen, Levin, and Mowery, "Firm Size and R & D Intensity: A Re-examination" Journal of Industrial Economics, vol. 35 (June 1987), pp.543-565; Levin and Reiss, "Cost-Reducing and Demand-Creating R & D with Spillovers" (Stanford University, 1986).

25. Richard R. Nelson, "Institutions Supporting Technical Advance in Industry," American Economic Review, vol. 76 (May 1986), pp. 186-189.

26. F. M. Scherer, "Inter-industry Technology Flows in the United States," Research Policy, vol. 11 (August 1982), pp. 227-245.

27. Inter-industry differences are significant at the 0.05 level for approximately 60 percent of the questions in Parts I and II of our questionnaire. If a higher level of aggregation is used to measure industry effects, such as the level at which the National Science Foundation reports R & D spending (a hybrid of two- and three-digit level industries), inter-industry differences are significant at the 0.05 level for 70 percent of the questions.

28. "Objective" heterogeneity, as anthropologists have long insisted, is, however, in the eye of the beholder. One R & D manager, asked to inform us about the "air and gas compressor" industry, telephoned to inquire whether we were interested in "large, medium, or small" compressors. In his view, the technologies were "fundamentally different." We asked him to note on his questionnaire where the answers to our questions differed across these size categories. The booklet he returned contained no such notation.

29. One notable consequence arising from the "measurement error" in the data is that industry mean responses from LBs with only one or two responses tend to be disproportionately located near the extrema of the distribution of LB mean responses to any given question. Most conclusions based on the full sample of 130 LBs, and virtually all those emphasized in this paper, are replicated in the smaller sample of seventy-five LBs with more than two survey respondents.

30. We designed our questionnaire to insure that cross-question comparisons would arise naturally in the minds of the respondents. The questionnaire items are arranged in blocks, with each item in a block rated on the same semantic scale.

31. This view of the efficacy of sales and service efforts is consistent with the emphasis given to investment in "co-specialized assets" as a means of appropriation in the recent work of David Teece, "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy," Research Policy, vol. 15 (December 1986), pp. 285-305.

32. See Ignatius Horstmann, Glenn MacDonald, and Alan Slivinski, "Patents as Information Transfer Mechanisms: To Patent or (Maybe) Not to Patent," Journal of Political Economy, vol. 93 (October 1985), pp. 837-858, for a theoretical treatment of the tradeoff between patenting and maintaining secrecy about a process innovation.

33. To preserve the confidentiality of the information provided by individual respondents, we do not identify any industry in which there was only one response. Hereafter, we refer to such cases as "singletons."

34. The same pattern appears when the survey data are aggregated up to the level (roughly 2-1/2 digit) at which the National Science Foundation reports detailed data on the level and composition of research and development expenditures. Of the twenty-five industries into which the manufacturing sector is

divided, only industrial chemicals, drugs, and petroleum refining rated process patents above four, and only industrial chemicals and drugs rated product patents above five.

35. Our results are reinforced by a recent finding of Edwin Mansfield that only in the drug industry, among the twelve broadly defined industries he studied, were patents regarded as essential to the development and commercial introduction of a majority of inventions. Chemicals were the only other industry that reported patents to be essential for the development and introduction of as many as 30 percent of inventions. See Mansfield, "Patents and Innovation: An Empirical Study," Management Science, vol. 32 (February 1986), pp. 173-181.

36. Yet another motive for patenting is discussed in the literature: gaining strategic advantage in interfirm negotiation. In the semiconductor industry, because of the cumulative nature of the technology, it is difficult to participate (legally) in the industry without access to the patents of numerous firms. In consequence, there is widespread cross-licensing of patents. Established firms, however, rarely license a new entrant until the entrant has established a significant position in the market. As a defense against infringement suits, a prudent new entrant will establish a patent portfolio of its own, thus compelling established firms to negotiate cross-license agreements. See Erich von Hippel, "Appropriability of Innovation Benefit as a Predictor of the

Locus of Innovation," Research Policy, volume 11 (January 1982), pp. 95-115, and Richard C. Levin, "The Semiconductor Industry," pp. 80-81.

37. Simple correlation coefficients were calculated using the the individual respondent as the unit of observation and using industry mean responses as the unit of observation. Correlations among industry means for the entire sample of 130 lines of business are qualitatively very similar to those obtained if the sample of LBs is restricted to those with more than two responses. These and other correlation matrices discussed in this paper are available from the authors upon request.

38. The results reported in Table 4 are based upon a principal components analysis undertaken at the level of individual responses. An analysis at the level of industry mean responses produced substantively identical results.

39. Additional evidence of the internal consistency of our survey results is provided by the pattern of negative correlation between responses concerning the various limits on patent effectiveness and responses concerning the effectiveness of patents. For both processes and products, using either individual respondents or industry means as the unit of observation, all such correlation coefficients are negative, except in the case of compulsory licensing. Most of these correlations are significant at the 0.01 level.

40. For example, Public Law 98-622, passed in 1984, modified the previous requirement that each co-inventor listed in a patent application had to be a co-inventor on every claim of the patent. The new law allows inventors to apply jointly even if they did not physically work together, did not make the same level of contribution, or did not contribute individually to the subject matter of each claim. For a thorough discussion, see Patrick Kelley, "Recent Changes in the Patent Law which Affect Inventorship and the Ownership of Patents" (Unpublished manuscript, 1985).

41. F. M. Scherer, The Economic Effects of Compulsory Patent Licensing (New York University Graduate School of Business Administration, 1977).

42. Richard R. Nelson and Sidney G. Winter, "The Schumpeterian Trade-off Revisited," American Economic Review, vol. 92 (March 1982), pp. 114-132; A.Michael Spence, "Cost Reduction, Competition, and Industry Performance," Econometrica, vol. 52 (January 1984), pp. 101-121; Levin and Reiss, "Tests of a Schumpeterian Model," and "Demand-Creating and Cost-Reducing R & D."

43. Wesley Cohen and Daniel Levinthal have studied the incentives to engage in R & D that is directed toward developing "absorptive capacity," the ability to make use of technology developed by others. See Cohen and Levinthal, "Innovation and Learning: The Two Faces of R & D," (Carnegie-Mellon University,

March 1987).

44. The correlations between the effectiveness of particular learning mechanisms and the effectiveness of alternative methods of appropriation are both interesting and internally consistent. In particular, when patent protection is effective, learning tends to take place primarily through licensing and patent disclosures. The effectiveness of patents is essentially uncorrelated with the effectiveness of interpersonal channels of learning and of independent R & D, and it is negatively correlated with the effectiveness of reverse engineering.

45. With three clusters, the ratio of variance between clusters to variance within clusters was low, but attempts to find more than three clusters were thwarted by the persistent appearance of "clusters" containing only one or two lines of business.

46. Edwin Mansfield, Industrial Research and Technological Innovation (W.W. Norton, 1968).

47. Qualitatively identical results and interpretations are obtained from frequency distributions of individual responses and from the distribution of industry means.

48. Mansfield, Schwartz, and Wagner, "Imitation Costs and Patents."

49. The ranges are shown in the headings of Table 9. The fifth and sixth column headings are not readily quantified. To permit the comparison discussed in the text, we assigned these

categories the values of 112.5 percent and 137.5 percent, respectively, thereby maintaining a constant spacing of 25 percentage points between each pair of categories.

50. Our results concerning the time to duplicate a rival's new products or processes are also roughly consistent with some recent findings of Edwin Mansfield. In all but one of ten industries he surveyed, the median respondent indicated that six to twelve months typically elapsed before the nature and operation of a new product were known to a firm's rivals. Effective duplication, as we have defined it, should take as long or longer, and examination of Table 10 reveals that it typically does. The median and modal industries require one to three years to duplicate a major innovation or a typical patented innovation. A typical unpatented innovation, however, is more often duplicated within six to twelve months. See Mansfield, "How Rapidly Does New Industrial Technology Leak Out?" Journal of Industrial Economics, vol. 34 (December 1985), pp. 217-224.

51. The ratio of company-financed R & D to sales (R & D intensity) varies considerably across industries defined at the FTC line of business level of aggregation. In the 1976 data used by Levin, Cohen, and Mowery, R & D intensity ranges from 0.08 percent to 8.5 percent; both the mean and standard deviation are 1.7 percent. See Levin, Cohen, and Mowery, "R & D Appropriability, Opportunity, and Market Structure."

52. Respondents were asked to identify, on a seven-point Likert scale (ranging from "very slowly" to "very rapidly"), the rate at which new processes and new products had been introduced in their industries since 1970. Industry mean responses are highly correlated with total factor productivity growth, and the plausibility of the responses is reinforced by the identity of the highest and lowest industries in the sample. Excluding singletons, the LBs reporting the slowest rates of product introduction were concrete, cement, boiler shops, milk, gypsum, primary copper, grain mill products, and sawmills. The LBs reporting the most rapid rates of product introduction were electrical equipment for internal combustion engines, radio and TV sets, computers, semiconductors, communications equipment, photographic equipment and supplies, engineering and scientific instruments, and guided missiles.

In their study, LCM used as a dependent variable the average of each industry's reported rates of process and product introduction.

53. Cohen, Levin, and Mowery, "Firm Size and R & D Intensity."

54. All coefficients in the R & D and innovation-rate equations were statistically significant at the 0.01 level.

55. To represent appropriability conditions, LCM used two survey-based measures: (1) the maximum of the mean scores an industry's respondents assigned to the effectiveness of the six methods of appropriation and (2) the time required to effectively

duplicate a patented, major product innovation. To represent opportunity conditions, LCM used a measure of an industry's closeness to science, as well as variables summarizing the importance of four other external sources of knowledge to an industry's technological advance: material suppliers, equipment suppliers, users of the industry's products, and government agencies and research labs.

56. It may seem anomalous that the effectiveness of appropriation is positively related to innovation but not to R & D, but recall that the relationship is observed at the level of the industry. Better appropriability may discourage R & D directed toward imitation to an extent that more than compensates for its stimulus to innovative R & D. Such a reallocation of effort would be entirely consistent with the observed positive relationship between appropriability and the rate of innovation.

57. Levin and Reiss have recently used survey-based measures of appropriability and opportunity in a simultaneous equation model of R & D spending and market structure that builds upon their earlier work in Griliches' 1984 NBER volume. Cohen and Levinthal use survey-based variables in their work on R & D as investment in absorptive capacity (see footnote 42 supra). Iain Cockburn and Zvi Griliches are studying the usefulness of our survey measures in estimating the value of patents from stock market data. Meryl Finkel, in her 1986 Harvard dissertation,

explored the effect of our appropriability variables on the investment decisions of multinational corporations. Franco Malerba is using the survey data to explain inter-industry differences in the extent and effectiveness of learning mechanisms.

58. For a calculation of the impact of the Drug Price Competition and Patent Life Restoration Act of 1984, see Henry Grabowski and John Vernon, "Longer Patents for Lower Imitation Barriers: The 1984 Drug Act," American Economic Review, vol. 76 (May 1986), pp. 195-198.

59. We focus on this particular consequence of the proposed legislation and set aside two major considerations regarding the merits of the legislation in its present form. First, without amendment, the legislation is likely to severely undercut the per se treatment of price fixing. Second, it might be more appropriate to consider eliminating per se treatment of all tying arrangements, rather than just those involving intellectual property. On this point, see the concurring opinion in Jefferson Parish v. Hyde 466 U.S. 2 (1984).

60. See E. W. Kitch, "Patents: Monopolies or Property Rights," in J. Palmer, ed., The Economics of Patents and Copyrights (JAI Press, 1986), pp. 31-47, and the associated commentary of F. M. Scherer, pp. 51. Digidyne Corp. v. Data General Corp., 743 F. 2nd 1336 (9th Cir. 1984) is an example of an application of per se doctrine in a context where the intellectual property

(software) does not convincingly convey market power.

61. The Trade Representative may, at his discretion, escape this requirement by a finding that such an investigation would not be in the national interest.

TABLE 1

Principal Topics Covered by the Questionnaire

A. Appropriability

1. Means of protecting the competitive advantages of R&D.
2. Limits on the effectiveness of patents.
3. Means of acquiring technical knowledge developed by competitors.
4. Cost and time required for imitation.

B. Technological Opportunity

1. The relevance of basic and applied science.
2. Impact of university-based research.
3. Other sources of contribution to technology.
4. Natural trajectories of technical advance.
5. Perceived rates and expectations of technical advance.

TABLE 2

Effectiveness of Alternative Means of Protecting the Competitive Advantages of New or Improved Processes and Products (1=not at all effective; 7=very effective)

Method of Appropriation	Overall Sample Means (std. errors) (1) Processes	(2) Products	Distribution of Industry Means* (3) Processes	(4) Products
1. Patents to Prevent Duplication	3.52 (0.06)	4.33 (0.07)	2.6–4.0+	3.0–5.0+
2. Patents to Secure Royalty Income	3.31 (0.06)	3.75 (0.07)	2.3–4.0+	2.7–4.8+
3. Secrecy	4.31 (0.07)	3.57 (0.06)	3.3–5.0	2.7–4.1
4. Lead Time	5.11 (0.05)	5.41 (0.05)	4.3–5.9+	4.8–6.0+
5. Moving Quickly Down the Learning Curve	5.02 (0.05)	5.09 (0.05)	4.5–5.7	4.4–5.8
6. Superior Sales or Service Efforts	4.55 (0.07)	5.59 (0.05)	3.7–5.5	5.0–6.1

* Range of industry means from the upper bound of lowest quintile of industries to the lower bound of the highest quintile of industries.

+ Interindustry differences in means significant at the .01 level.

TABLE 3

Effectiveness of Patents in Industries with Ten or More Survey Responses

Line of Business	Process	Products
	Mean Score on 1-7 Scale (std. errors)	
Pulp, Paper, and Paperboard	2.6 (0.3)	3.3 (0.4)
Cosmetics	2.9 (0.3)	4.1 (0.4)
Inorganic Chemicals	4.6 (0.4)	5.2 (0.3)
Organic Chemicals	4.1 (0.3)	6.1 (0.2)
Drugs	4.9 (0.3)	6.5 (0.1)
Plastic Materials	4.6 (0.3)	5.4 (0.3)
Plastic Products	3.2 (0.3)	4.9 (0.3)
Petroleum Refining	4.9 (0.4)	4.3 (0.4)
Steel Mill Products	3.5 (0.7)	5.1 (0.6)
Pumps and Pumping Equipment	3.2 (0.4)	4.4 (0.5)
Motor, Generators, and Controls	2.7 (0.3)	3.5 (0.5)
Computers	3.3 (0.4)	3.4 (0.4)
Communications Equipment	3.1 (0.3)	3.6 (0.3)
Semiconductors	3.2 (0.4)	4.5 (0.4)
Motor Vehicle Parts	3.7 (0.4)	4.5 (0.4)
Aircraft and Parts	3.1 (0.5)	3.8 (0.4)
Measuring Devices	3.6 (0.3)	3.9 (0.3)
Medical Instruments	3.2 (0.4)	4.7 (0.4)
Full Sample	3.5 (0.06)	4.3 (0.07)

TABLE 4

Principal Components Analysis of Methods of Appropriation

	Processes/products separately		Processes/products together	
	Coefficients of:		Coefficients of:	
	1st principal	2nd comp.	1st principal	2nd comp.
Method of Appropriation				
<u>New Processes</u>				
1. Patents to prevent duplication	0.04	0.86	0.01	0.73
2. Patents to secure royalties	0.12	0.86	0.08	0.78
3. Secrecy	0.59	-0.12	0.54	0.04
4. Lead time	0.84	-0.09	0.79	-0.04
5. Moving down the learning curve	0.84	-0.05	0.80	-0.04
6. Sales and service efforts	0.51	0.11	0.45	-0.06
Cumulative Variance Explained	0.34	0.59	n/a	n/a
<u>New Products</u>				
1. Patents to prevent duplication	0.06	0.87	0.06	0.73
2. Patents to secure royalties	0.06	0.87	0.07	0.80
3. Secrecy	0.51	0.01	0.51	0.06
4. Lead time	0.84	0.00	0.79	-0.03
5. Moving down the learning curve	0.84	-0.07	0.82	-0.04
6. Sales and service efforts	0.69	-0.09	0.62	-0.11
Cumulative Variance Explained	0.36	0.61	0.31	0.50

TABLE 5

Cluster Analysis of Mechanisms of Appropriation

New Processes	Cluster Number 1	2	3
Number of LBs in cluster	38	67	25
Mean score in each cluster:			
1. Patents to prevent duplication	3.1	3.0	4.7
2. Patents to secure royalties	2.9	2.9	4.8
3. Secrecy	2.8	4.6	4.7
4. Lead time	4.2	5.4	5.6
5. Learning curves	4.3	5.3	5.1
6. Superior sales or service	4.7	4.5	4.9

New Products	Cluster Number 1	2	3
Number of LBS in cluster	20	68	42
Mean score in each cluster:			
1. Patents to precent duplication	3.1	3.8	5.3
2. Patents to secure royalties	3.2	3.1	5.0
3. Secrecy	2.6	3.5	4.0
4. Lead time	4.0	5.6	5.7
5. Learning curves	4.2	5.3	5.2
6. Superior sales or service	5.2	5.7	5.6

TABLE 6

Limits on the Effectiveness of Patents on New or Improved Processes and Products (1=not an important limit; 7=very important)

Limit on Effectiveness	Overall Sample Means (std. errors) (1) Processes	(2) Products	Distribution of Industry Means* (3) Processes	(4) Products
1. New Processes not readily patentable	4.32 (0.07)	3.75 (0.07)	3.6-5.4+	2.8-4.8
2. Patents unlikely to be valid if challenged	4.18 (0.06)	3.92 (0.07)	3.5-5.0+	3.0-5.0+
3. Firms do not enforce patents	4.29 (0.06)	3.84 (0.07)	3.5-5.0+	3.0-4.8+
4. Competitors legally "invent around" patents	5.49 (0.05)	5.09 (0.06)	4.9-6.0	4.4-5.9++
5. Technology moving so fast that patents are irrelevant	3.40 (0.07)	3.34 (0.07)	2.0-4.3++	2.0-4.0++
6. Patent documents disclose too much information	4.19 (0.07)	3.65 (0.07)	3.2-5.0	2.8-4.5+
7. Licensing required by court decisions	2.96 (0.06)	2.79 (0.06)	2.0-3.8	2.0-3.3
8. Firms participate in cross-licensing agreements with competitors	3.08 (0.06)	2.93 (0.06)	2.2-3.9++	2.1-3.9++

* Range of industry means from the upper bound of the lowest quintile of industries to the lower bound of the highest quintile of industries.

++ Interindustry differences significant at the .01 level.

\+ Interindustry differences significant at the .10 level.

TABLE 7

Effectiveness of Alternative Methods of Learning about New Processes and Products
(1=not at all effective; 7=very effective)

Method of Learning	Overall Sample Means (std. errors) (1) Processes	(2) Products	Distribution of Industry Means* (3) Processes	(4) Products
1. Licensing Technology	4.58 (0.07)	4.62 (0.07)	3.4-5.6++	3.5-5.5++
2. Patent Disclosures	3.88 (0.05)	4.01 (0.06)	3.0-4.6++	3.0-4.8++
3. Publications or Technical Meetings	4.07 (0.05)	4.07 (0.05)	3.4-4.7	3.3-4.6+
4. Conversations with Employees of Innovating Firm	3.64 (0.06)	3.64 (0.06)	2.9-4.7+	2.9-4.5+
5. Hiring R&D Employees from Innovating Firm	4.02 (0.07)	4.08 (0.07)	2.7-5.0++	2.8-5.0++
6. Reverse Engineering of Product	4.07 (0.07)	4.83 (0.06)	3.0-5.0++	4.0-5.7+
7. Independent R&D	4.76 (0.06)	5.00 (0.05)	4.0-5.5	4.4-5.6++

* Range of industry means from the upper bound of lowest quintile of industries to the lower bound of the highest quintile of industries.
++ Interindustry differences in means significant at the .01 level.
\+ Interindustry differences in means significant at the .05 level.

TABLE 8

Cluster Analysis of Channels of Spillover

New Processes	Cluster Number 1	2	3
Number of LBs in cluster	68	43	19
Mean score in each cluster:			
1. Licensing technology	5.0	4.3	2.5
2. Patent disclosures	4.0	4.0	3.2
3. Publications or technical meetings	3.8	4.6	3.9
4. Conversations with employees of innovating firm	3.2	4.8	3.0
5. Hiring R&D employees from innovating firm	3.7	5.1	2.4
6. Reverse engineering of product	3.8	4.6	4.0
7. Undertake independent R&D	5.0	4.6	4.3

New Products	Cluster Number 1	2	3
Number of LBs in cluster	68	10	52
Mean score in each cluster:			
1. Licensing technology	4.7	2.5	4.5
2. Patent disclosures	3.9	2.9	4.3
3. Publications or technical meetings	3.7	5.1	4.3
4. Conversations with employees of innovating firm	3.0	4.6	4.5
5. Hiring R&D employees from innovating firm	3.2	4.4	4.9
6. Reverse engineering of product	4.7	3.0	5.2
7. Undertake independent R&D	5.1	3.7	5.0

TABLE 9

Cost of Effectively Duplicating an Innovation
(Frequency Distribution of Median Responses for 127 Lines of Business)

Type of Innovation	Less Than 25%	25% to 50%	51% to 75%	76% to 100%	More Than 100% Not Possible	Timely Duplication
	Cost of Duplication as a Percentage of Innovator's R&D Cost					
New Process						
1. Major, patented new process	1	5	19	66	26	10
2. Major, unpatented new process	5	10	55	49	6	2
3. Typical, patented new process	2	15	61	41	6	2
4. Typical, unpatented new process	8	43	58	14	4	0
New Product						
5. Major, patented new product	1	4	17	63	30	12
6. Major, unpatented new product	5	13	58	40	7	4
7. Typical, patented new product	2	18	64	32	9	2
8. Typical, unpatented new product	9	58	40	15	5	0

TABLE 10

Time Required to Effectively Duplicate an Innovation
(Frequency Distribution of Median Responses for 129 Lines of Business)

Type of Innovation	Time Required to Effectively Duplicate an Innovation: Less Than 6 Months	6 Months to 1 Year	1 to 3 Years	3 to 5 Years	More Than 5 Years	Timely Duplication Not Possible
New Process						
1. Major, patented new process	0	4	72	37	9	7
2. Major, unpatented new process	2	20	84	17	2	4
3. Typical, patented new process	0	40	73	13	0	3
4. Typical, unpatented new process	8	66	47	6	1	1
New Product						
5. Major, patented new product	2	6	64	40	8	9
6. Major, unpatented new product	3	22	89	12	1	2
7. Typical, patented new product	5	39	72	6	4	3
8. Typical, unpatented new product	18	67	39	4	1	0

TABLE 11

Number of Firms Capable of Duplicating an Innovation

(Frequency Distribution of Median Responses for 129 Lines of Business)

Type of Innovation	Number of Firms Capable of Duplication				
	None	1 or 2	3 to 5	6 to 10	More than 10
1. A major new or improved process	2	32	75	18	2
2. A typical new or improved process	1	7	41	58	22
3. A major new or improved product	2	25	73	25	4
4. A typical new or improved product	1	5	33	63	26

TABLE A-1

Survey Response Rates

Firms with Multiple Business Units		
Round 1:	Requests for participation	1710
	Adjusted sample frame	1378
	Agreed to participate	716
	Response rate	52.0%
Round 2:	Questionnaires sent	716
	Adjusted sample frame	693
	Completed questionnaires	560
	Response rate	80.8%
	Compound response rate	41.3%
Firms with Single Business Unit		
	Questionnaires sent	218
	Adjusted sample frame	207
	Completed questionnaires	90
	Response rate	43.5%
Overall Response		
	Adjusted sample frame	1562
	Completed questionnaires	650
	Response rate	41.6%

TABLE A-2

Lines of Business Responding to the Survey

*Response code: A = 10 or more responses
B = 5 to 9 responses
blank = fewer than 5 responses

SIC CODE(S)	LINE OF BUSINESS	RESPONSES*
2011,2013	Meat Products	
2026	Fluid Milk	
2021,2022,2023,2024	Dairy Products Except Milk	
2032	Canned Specialties	
2037,2038	Frozen Foods	
2033,2034,2035	Processed Fruits and Vegetables	B
2043	Breakfast Cereals	
2048	Animal Feed	
2041,2044,2045	Grain Mill Products	
2046	Wet Corn Milling	
2051	Bakery Products	
2061,2062,2063	Sugar	
2065	Confectionery Products	
2066	Chocolate and Cocoa Products	
207	Fats and Oils	B
2082,2083	Malt and Malt Beverages	
2086,2087	Soft Drinks and Flavorings	
2095	Roasted Coffee	
21	Tobacco Products	
241,242	Logging and Sawmills	
243	Millwork, Veneer and Plywood	
252	Office Furniture	
254	Partitions, Shelving and Fixtures	
261,262,263	Pulp, Paper and Paperboard Mills	A
2641,2642,2643	Converted Paper Products	B
265	Paperboard Containers and Boxes	B
266	Building Paper and Board Mill	
275	Commercial Printing	
2813	Industrial Gases	
2816	Inorganic Pigments	
2812,2819	Industrial Inorganic Chemicals	A
2821	Plastics Materials and Resins	A
2822	Synthetic Rubber	
2823,2824	Synthetic Fibers	B
283	Drugs	A
2844	Perfumes, Cosmetics and Toilet Preparations	A
2841,2842,2843	Soaps, Detergents, and Cleaning Preparations	B
285	Paints and Allied Products	
286	Industrial Organic Chemicals	A
2873,2874,2875	Fertilizers	
2879	Pesticides and Agricultural Chemicals	B

TABLE A-2 (Cont'd.)

SIC CODE(S)	LINE OF BUSINESS	RESPONSES*
2892	Explosives	
291	Petroleum Refining	A
301	Tires and Inner Tubes	B
307	Plastic Products	A
3229,323	Glass and Glass Products	
324	Cement	
325	Structural Clay Products	
3261,3264	Pottery and Related Products	
3271,3272,3273,3274	Concrete and Related Products	
3275	Gypsum Products	
3291	Abrasive Products	
3292	Asbestos Products	
3296	Mineral Wool and Related Products	
331	Steelworks, Rolling and Finishing Mills	A
332	Iron and Steel Foundries	B
3331	Primary Copper Smelting and Refining	
3332	Primary Lead Smelting and Refining	
3333	Primary Zinc Smelting and Refining	
3334,3353,3354,3355	Primary Aluminum Smelting and Refining	B
3339	Primary Smelting and Refining of Nonferrous Metals	
334	Secondary Smelting and Refining of Nonferrous Metals	
3351,3356	Rolling, Drawing and Extruding of Nonferrous Metals	
3357	Drawing and Insulating of Nonferrous Wire	
336	Nonferrous Metal Castings	
3411,3412	Metal Cans and Containers	
3421	Cutlery	
3423,3425	Hand Tools	
3431,3432,3433	Heating Equipment and Plumbing Fixtures	
3441	Fabricated Structural Metal	
3442	Metal Doors, Sash, Frames and Trim	
3443	Fabricated Plate Work (Boiler Shops)	
345	Screw Machine Products, Bolts, Nuts and Screws	
3462,3463	Metal Forgings	B
348	Ordnance and Accessories	
3494	Valves and Pipe Fittings	B
3511	Turbines and Turbine Generator Sets	
3519	Internal Combustion Engines	B
3523	Farm Machinery and Equipment	B
3531	Construction Machinery and Equipment	B
3532	Mining Machinery and Equipment	B
3533	Oilfield Machinery and Equipment	B

TABLE A-2 (Cont'd.)

SIC CODE(S)	LINE OF BUSINESS	RESPONSES*
3535	Conveyors and Conveying Equipment	
3536	Hoists, Industrial Cranes and Monorail Systems	
3537	Industrial Trucks, Tractors, Trailers and Stackers	B
3541	Machine Tools, Metal Cutting Types	B
3545	Machine Tool Accessories and Measuring Devices	B
3546	Power Driven Hand Tools	
3551	Food Products Machinery	
3552	Textile Machinery	
3554	Paper Industries Machinery	
3555	Printing Trades Machinery and Equipment	
3561	Pumps and Pumping Equipment	A
3562	Ball and Roller Bearings	
3563	Air and Gas Compressors	
3564	Blowers and Exhaust and Ventilation Fans	B
3566	Speed Changers, Industrial High Speed Drives and Gears	
3567	Industrial Process Furnaces and Ovens	
3573	Electronic Computing Equipment	A
3576	Scales and Balances, Except Laboratory	
3585	Refrigeration and Heating Equipment	B
3612	Power, Distribution and Specialty Transformers	B
3613	Switchgear and Switchboard Apparatus	B

TABLE A-2 (Cont'd.)

SIC CODE(S)	LINE OF BUSINESS	RESPONSES*
3621,3622	Motors, Generators and Industrial Controls	A
3623	Electric Welding Apparatus	
3632	Household Refrigerators and Freezers	
3645,3646	Lighting Fixtures and Equipment	
3651	Radio and TV Receiving Sets	
3652	Phonograph Records and Prerecorded Magnetic Tape	
3661,3662	Communications Equipment	A
3671,3672,3673	Electron Tubes	
3674	Semiconductors and Related Devices	A
3691,3692	Primary and Storage Batteries	
3694	Electrical Equipment for Internal Combustion Engines	
3711,3713	Motor Vehicles	
3714	Motor Vehicle Parts and Accessories	A
3721,3728	Aircraft and Parts, Except Engines	A
3724	Aircraft Engines and Engine Parts	
373	Ship and Boat Building and Repairing	
374	Railroad Equipment	
376	Complete Guided Missles	B
381	Engineering and Scientific Instruments	B
382	Measuring and Controlling Devices	A
383	Optical Instruments and Lenses	
3843	Dental Equipment and Supplies	
3841,3842	Surgical and Medical Instruments, Appliances and Supplies	A
3861	Photographic Equipment and Supplies	
3949	Sporting and Athletic Goods	
3942,3944	Dolls, Games and Toys	
395	Pens, Pencils, and Other Office and Artists' Materials	