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THE VALUE OF PATENTS AS INDICATORS OF INVENTIVE ACTIVITY

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ABSTRACT

This paper summarizes a number of studies which use patent data to examine different aspects of technological change. It describes our firm level data set construction effort; reports on the relationship between R&D expenditures and the level of patenting; analyzes the relationship between patents, R&D, and the stock market value of firms; reports on the estimation of the value of patent rights based on European patent renewal data; and describes the use of patent data to estimate the importance of R&D spillovers. It concludes that patent data represent a valuable resource for the analysis of technological change. They can be used to study longer-run interfirm differences in inventive activity and as a substitute for R&D data where they are not available in the desired detail. It is possible also to use a firm's distribution of patenting by field to infer its position in "technological space" and use it in turn to study how R&D spills over from one firm to another. Moreover, patent renewal data, which are also becoming available in the U.S., allow one to construct more relevant "quality weighted" inventive "output" measures.

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The Value of Patents as Indicators of Inventive Activity

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1. Introduction

In this paper we present an overview of a series of studies pursued at the NBER during the last decade which used patent statistics to study different aspects of the economics of technological change. It consists of five substantive sections: A description of our firm level data; a report on the relationship between R&D expenditures and the level of patenting; a report on the relationship between patents, the stock market value of firms, and their R&D expenditures; a summary of work on the estimation of the value of patent rights based on patent renewal data; and a description of the use of patent data to estimate the importance of R&D spillovers. A brief set of conclusions closes the paper.

2. The NBER-R&D Data Base and the Growth of U.S. Firms in the 1970s

A major achievement of the NBER project has been the development and construction of a large data set covering the economic and technological performance of most of publicly traded U.S. manufacturing companies from the early 1960s through the early 1980s. It is the result of a detailed match of publicly available sales, employment, investment, R&D, and balance sheet information from the Compustat tapes (based on company 10-K filings with the SEC) with data acquired from the U.S. Patent Office on patents issued to all organizations between 1969 and 1982. Three major tasks had to be accomplished to make these data useable: (1) The Patent Office data on the number of patents granted to various organizations had to be matched with our list of manufacturing corporations. (2) The balance sheet items in the Compustat record had to be converted from historical to either current replacement or constant dollar prices. And (3) detailed sales price indexes had to be imported into these files to allow the computation of output and productivity measures for these companies.

To assemble our data set we started with the population of firms listed in the 1978 Compustat Industrial Tape, to which we added those firms that still existed in 1976 from the Research Tape, firms in the Compustat Over-the-Counter tape and firms in the Compustat Full Coverage tape. This yielded an approximate total of 2700 manufacturing firms in 1976. (See Cummins et al, 1985 and Bound, et al, 1984 for a description of this sample and the Appendix for more detail on on the match procedures). We then matched to this firm data set the detailed information on patents granted from the Office of Technology Assessment and Forecast (OTAF) tapes and found that approximately two-thirds of these firms received at least one patent between 1969 and 1982.

A preliminary analysis of aggregate trends in these data revealed changing lags due to fluctuations in the delays at the Patent Office in processing the applications. Because patents are recorded by date granted while we are interested, primarily, in patent counts by date of application, such delays have implications for the completeness of our series in the later years.

Table 1 provides a distribution of U.S. patents by date granted and by date applied for and shows both the degree of completeness of the data at any point of time and the fluctuations in the lag between the application

Table 1

The Distribution of Patents Applied for by Year of Application, 1970-1982, and Time to Year of Grant

Year of Application	Percent Granted Years Later 0	1	2	3	4	5+	Total in Current Panel**
1969	0	11	66	20	2	1	100
1970	0	18	62	17	2	1	100
1971	0	17	61	18	2	2	100
1972	0	28	57	11	2	2	100
1973	0	37	50	10	2	1	100
1974	1	42	48	6	2	1	100
1975	1	42	46	8	1	2	100
1976	2	42	47	6	2	2	100
1977	1	42	41	12	2	2	99
1978	1	24	57	15	2	1	99
1979	0	22	60	15	2	1	97
1980[e]	0	22	53	20	3	2	75
1981[e]	0	17	50	27	*	*	17
1982[e]	0	15	52	*	*	*	0

1969-70 based on a sample of 100,000 patents from the 1969-79 OTAF tape on patents granted. 1971-1982 based on the complete 1984 OTAF tape.

*Not computable

**Based on the 1982 OTAF tape. 1984 information not incorporated yet.

[e]Estimated.

Table 2

Statistics for the 1976 Cross Section: Trimmed Data

Industry	NFIRMS	AVEPLANT	AVESALES	AVEEMP	NRNDFIRM	AVERND	AVERATIO	NPATFIRM	AVEPAT
Food & kindred products	182	178.7	585.7	8.9	62	5.4	0.005	46	5.8
Textile & apparel	188	55.2	137.8	4.3	49	1.9	0.018	33	5.9
Chemicals, excl. drugs	121	503.2	693.6	9.1	92	18.6	0.021	67	39.0
Drugs & medical inst.	112	116.6	301.7	6.8	96	14.4	0.045	64	28.2
Petroleum refining & ex.	54	3200.1	4622.8	20.0	26	34.9	0.005	25	72.0
Rubber & misc. plastics	98	122.4	214.8	5.3	59	5.9	0.016	35	12.2
Stone, clay & glass	81	186.1	243.6	5.3	31	7.0	0.019	26	22.4
Primary metals	103	499.6	488.5	8.6	39	7.7	0.013	44	14.6
Fabric. metal products	196	57.8	131.0	2.6	102	1.8	0.011	77	5.4
Engines, farm & const. equip.	64	186.9	457.3	8.8	51	10.2	0.016	42	25.7
Office, comp. & acctg. eq.	106	288.2	352.9	8.3	94	21.6	0.061	42	39.0
Other machinery, not elec.	199	40.8	116.1	2.8	149	2.3	0.021	111	5.8
Elec. equip. & supplies	105	155.0	405.5	10.7	77	11.2	0.023	56	34.3
Communication equipment	258	31.8	89.9	2.5	199	3.4	0.040	110	13.3
Motor veh. & transport eq.	105	464.2	1233.6	22.2	59	49.2	0.012	48	25.0
Aircraft and aerospace	37	237.4	754.1	15.6	26	32.7	0.042	17	39.0
Professional & sci. equip.	139	73.4	130.5	3.3	118	8.0	0.051	65	16.0
Lumber, wood, and paper	163	204.2	260.4	4.7	64	2.8	0.007	49	6.9
Misc. consumer goods	100	81.6	232.5	5.2	44	1.8	0.013	41	5.2
Conglomerates	23	1174.3	2202.3	50.1	13	43.3	0.014	20	37.3
Misc. manuf., n.e.c.	148	36.3	89.3	2.1	29	0.7	0.027	16	2.1
All firms	2582	230.9	417.2	6.8	1479	10.5	0.027	1034	19.1

Note:
NFIRMS = Total number of firms in industry.
AVEPLANT = Average gross plant in millions of dollars.
AVESALES = Average sales in millions of dollars.
AVEEMP = Average employment in thousands.

NRNDFIRM = Number of firms with nonzero R & D.
AVERND = Average R & D expenditure in millions of dollars for firms with nonzero R & D.
AVERATIO = Average R & D to sales ratio for firms with nonzero R & D.
NPATFIRM = Number of firms with nonzero patents.
AVEPAT = Average number of patents for firms with nonzero patents.

From: Bound et al (1984)

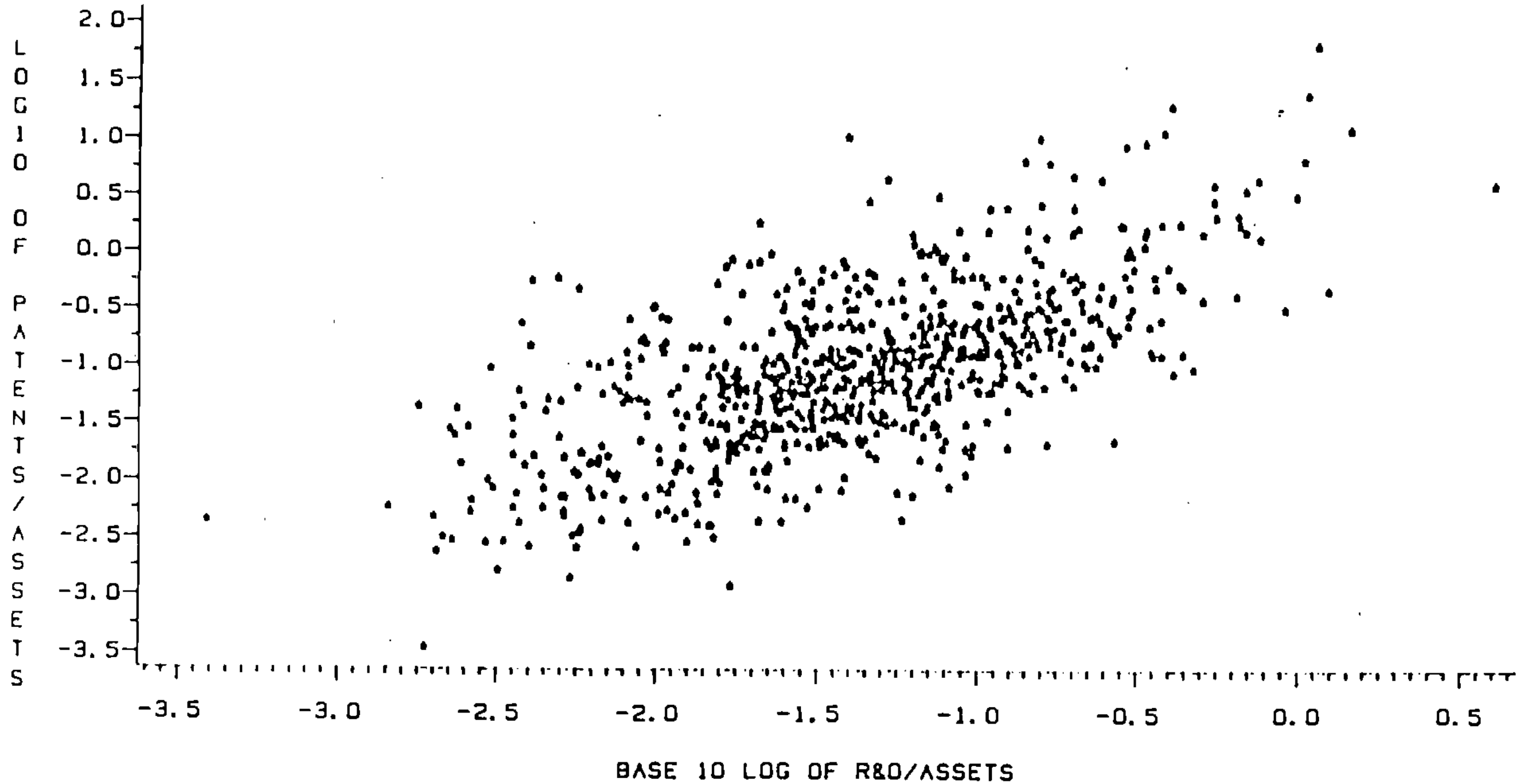
any point of time and the fluctuations in the lag between the application and granting dates. About 97 percent of all patent applications which will be ultimately granted are granted within the first four years of the application date (but only about 70 to 80 percent are granted within the first three years). Hence, our sample of patents by date of application extends effectively only through 1979.

In Bound et al (1984) we looked primarily at the cross-sectional aspect of these data. We found that about two-thirds of our sample were granted at least one patent between 1965 and 1979 and that the smaller firms (less than ten million dollars in sales) account for a slightly larger fraction of patents than of R&D or sales. The industries with a higher than average ratio of patents to R&D were the chemical, drug, petroleum, engine, farm and construction machinery, electrical equipment, and aircraft industries. Although technology based, firms in the communications equipment and computer industries patent less than the average of firms doing the same amount of R&D. (See Table 2.)

Turning to the scale question, we found very little evidence that larger firms or firms doing more R&D were more productive in patenting (Figure 1). The answer to this question is clouded by conflicting results from alternative specifications of the relationship of patenting to R&D and by the sheer diversity of the firms in our sample. For the larger firms in our sample patenting is approximately proportional to R&D. The smallest firms do seem to show somewhat more patenting per R&D dollar but they are a far more selected group, owing to the way we chose the sample. (A small firm has to be in some sense more than usually successful to be listed on one of the stock exchanges.)

FIGURE ONE

LOG OF PATENTS/ASSETS VS LOG OF R&D/ASSETS*



*Patents/Assets in number per million dollars.

From: Bound et al (1984).

To look at time series aspects of our data, we have focused on a subsample of manufacturing firms (excluding foreign-owned firms and wholly-owned subsidiaries) which (1) existed in 1976 and (2) had at least three years worth of good data on our major variables of interest: sales, book value, and market value. This yielded a subset of about 1900 firms for which we have constructed detailed market value data and revalued their physical assets in current prices. About 1600 of them have data on sales, market value, and book value of plant for the eight year period 1972-1980. They accounted for about one trillion dollars of sales in 1976 and employed approximately sixteen million workers. Although we sacrifice the pre-1972 history of R&D for some of these firms in enlarging the sample, this sample is more representative of the whole of U.S. manufacturing and we have the complete patenting history since about 1967 for these firms. They account for about fifteen billion dollars of R&D in 1976 (approximately 88 percent of the total of company-financed R&D reported by the National Science Foundation) and received about nineteen thousand patents. These are the basic data that were used subsequently by us in various analyses of market value, R&D, patenting, and productivity. They were recently updated to 1981-1982 and the Quarterly Compustat Tape was used to recompute market values and the stock market rate of return for the fiscal rather than the calendar year to make these variables more comparable to the other data in the record.

Table 3 gives some more information on this panel. If we want consistent and continuous data from 1972 through 1980, we have relatively "clean" data on 968 firms, 525 of which were performing R&D consistently while 235 reported no R&D effort throughout this period. Two things stand

Table 3 : Average Growth Rates in the U.S., 1973-80 at the Company and Industry Level

Industry	Number of Firms			Growth Rates (percent per year): Employment				Deflated Sales per Employee			
	Total Sample	Non R&D	R&D Sample	Total Industry	Firms Total Sample	Firms Non R&D	R&D Sample	Total Industry	Firms Total Sample	Firms Non R&D	R&D Sample
Total	968	235	525	0.7	1.3	0.2	1.9	0.4	1.2	0.8	1.6
1. Food, etc.	63	22	22	-0.2	2.0	2.0	1.2	2.3	2.0	2.0	2.2
2. Chemicals & Rubber	91	6	71	0.7	1.2	---	1.4	-0.2	0.9	---	0.7
3. Drugs	52	3	44	1.0	3.5	---	4.0	1.5	0.3	---	0.4
4. Metals	135	50	50	-0.5	0.4	-.05	0.2	-1.3	-0.8	-1.9	0.1
5. Machinery	113	10	82	2.3	2.8	-0.1	2.7	-0.4	-0.0	-0.6	0.2
6. Electrical Equipment	140	10	106	2.2	2.6	0.9	2.4	5.1	4.3	5.1	4.4
7. Transport Equipment	63	10	34	-0.5	0.4	---	0.4	-0.9	-0.1	---	0.3
8. Instruments	46	0	39	---	5.2	---	4.7	---	2.6	---	3.0
9. Other	265	124	77	0.6	-0.1	0.5	0.0	0.0	1.2	1.6	1.2
a. Stone, Clay &	39	11	15	---	-1.5	-0.1	-1.4	---	0.5	-0.1	1.1
b. Lumber, Wood &	93	49	27	---	1.5	2.4	1.0	---	0.3	-0.4	0.9
c. Misc. Consumer Goods	60	27	23	---	0.5	1.1	-0.8	---	0.9	1.1	0.8

Averages not shown for samples with 10 or less firms.
See Griliches-Mairesse (1983, 1985) for sources and methodology.

out from this table: (1) The R&D firms both grew faster throughout this period, in terms of employment, and had a higher growth in productivity, deflated sales per employee, than non-R&D firms. And (2), there is much variation across industries in this experience. Employment in R&D performing firms grew at about two percent per year while non-R&D firms were almost not growing at all (0.2 percent per year).

If one looks at the same numbers industry by industry, the results are less clear. Only in three out of the eight industries where comparisons can be made, was the growth in average employment unequivocally higher for R&D firms. Nevertheless, this implication is confirmed by a more detailed look at the growth in employment of individual firms during the 1976-79 period by Bronwyn Hall (1985). For a larger sample of 1524 firms she finds that employment growth is related positively and significantly to R&D intensity (the logarithm of R&D expenditures per employee in 1976) with a coefficient of 0.018 (0.03) and moreover, that the effect of an R&D dollar on employment growth is higher than of a similar conventional investment in physical assets. Inclusion of 20 industry dummy variables and an adjustment for selective mortality between 1976 and 1979 leave these conclusions unchanged.

Another interesting aspect of Table 3 is its indication that the overall industry growth rates (of both employment and productivity) are lower than the average rates experienced by the firms in our sample. In part this reflects the selectivity of our sample. To be present in 1976 a firm, other things equal, must have been growing faster before 1976. To survive to 1980 also required above average growth. These issues of selective mortality have been investigated by Addanki (1986) and Hall

(1985). Addanki shows that firms that exited between 1976 and 1984 were small on average and less R&D intensive, though with slightly more patents per R&D dollar. The major difference between the numbers at the aggregate and the firm levels arises from differences in weighting. Because the firm level averages are unweighted, they are dominated by the small firms which survived throughout the whole period. They did indeed grow faster (see Hall, 1985). The average firm in the sample was, therefore, during this period growing faster than the corres-ponding industry total.

The data sets we have constructed contain a large number of interesting variables only some of which have been explored in our own work. The major available variables are: Gross and net value of plant in historical, constant, and current prices, total sales in current and constant prices, operating income, dividends, market value of the firm, number of employees, investment and R&D expenditures in current and constant prices, inventories, advertising and pension expense, number of patents received by date of grant and date of application, stock market rate of return (calendar and fiscal year), and the various relevant price indexes used in the construction of the "constant price" series. These data are a major research asset which is also available for use by others.

3. Patents and R&D

Much of our work was devoted to using the assembled patent data to study the R&D process and its contribution to economic growth. This is one way of assessing the usefulness of such statistics as indicators of inventive activity. Our work in this area can be divided, roughly, into four categories: (1) Charac-terizing the cross-sectional and time series

(2) Using patent renewal data to infer the distribution of patent right values, obtain a measure of their quality and estimate their rate of obsolescence. (3) Using stock market valuation data and data on R&D and patents to study the effectiveness of patents as an indicator of inventive activity. And, (4), using patent statistics in constructing and validating measures of R&D spillovers.

Our first papers in this area were based on an earlier, smaller (but longer) sample of firms. Pakes and Griliches (1980, 1984a) estimate something like a patent production function, focusing especially on the degree of correlation between patent applications and past R&D expenditures and on the lag structure of this relationship. Their main finding is a statistically significant relationship between R&D expenditures and patent applications. This relationship is very strong in the cross-sectional dimension. It is weaker but still significant in the within-firm time-series dimension (Table 4). Not only do firms that spend more on R&D receive more patents, but also when a firm changes its R&D expenditures, parallel changes occur in its level of patenting. The bulk of the relationship in the within-firm dimension between R&D and patent applications appears to be close to contemporaneous. The lag effects are significant but relatively small and not well estimated (Table 5). The significant coefficient for R&D five years back indicates, however, the probability of a long unseen "tail" to the effect of past R&D on the level of patenting. Pakes and Griliches interpret their estimates as implying that patents are a fairly good indicator of differences in inventive activity across firms, but that short-term fluctuations in their numbers within firms have a large noise component in them. They also find that,

Table 4
Patents and R&D: Selected statistics associated with estimating the equation: [a]

$$\ln P_{it} = \sum_{j=0}^{5} \beta_j \ln R_{it-j} + u_{it}, \qquad N = 121, \quad T = 8, \quad NT = 968.$$

	Total	Between	Within
Variance in $\ln P$	2.41	2.24	0.17
Variance in $\ln R$	1.72	1.68	0.04
$\overline{R}^2_{\ln P}(\Sigma\beta \ln R)$	0.66	0.69	0.33 (0.23)
Lowest, median and highest R^2 across 7 industry groupings	0.74, 0.82, 0.95	0.77, 0.87, 0.97	0.11, 0.28, 0.49 (0.06, 0.16, 0.47)

[a] The values in parentheses are based on partialling out time trends from both $\ln P$ and $\ln R$. 'Between' results are based on 8 year averages of all the variables across the 121 firms. 'Within' results are based on the annual deviations from each firm's own average $\ln P$ and $\ln R$. The industry groupings are Chemicals except Drugs, Drugs, Machinery except Office and Computers, Office and Computers, Electronic Components and Communications Equipment, Instruments, and Other. $\overline{R}^2$ – adjusted partial squared multiple correlation coefficients. Adjusted for degrees of freedom and the included common trend (in the total and within dimensions).

From: Pakes and Griliches (1980)

Table 5
Patents and R&D: Distributed lag estimates in the within dimension (N = 121, degree of freedom = 837). [a]

Coefficient of		
$\ln R_0$	0.56	(0.07)
$\ln R_{-1}$	−0.10	(0.09)
$\ln R_{-2}$	0.05	(0.09)
$\ln R_{-3}$	−0.04	(0.09)
$\ln R_{-4}$	−0.05	(0.10)
$\ln R_{-5}$	0.19	(0.08)
Sum	0.61	(0.08)

[a] Standard errors in parentheses.

From: Pakes and Griliches (1980)

except for drug firms, there has been a consistent, negative trend in the number of patents applied for and granted relative to R&D expenditures during their period of observation, 1968-1975.

In analyzing the relationship between patents and R&D we encountered a number of serious substantive and econometric problems. The first and, at least in retrospect, most important problem is that the size or value of the "output" associated with a particular patent varies enormously over different patents. We shall come back to this problem below and present some estimates of its magnitude and its consequences for our work. The second is that patents do not represent all of the output of R&D. Only a fraction of it is patentable or patented. Moreover, this fraction may vary considerably over industry, firm, and time. We tried to control for such differences in the firms' propensity to patent by using covariance (fixed-effects) techniques, estimating conditionally on the overall patenting performance of the firm, or treating them as unobservables in a multi-equation context. We also included year effects as a partial solution to the problem of the changing effectiveness of patents as a tool of appropriability over time.

Two other problems required the development of new econometric tools: (1) Our large panel is rather short because public reporting of R&D expenditures became prevalent only after 1972. Thus we have only about six to eight years worth of data and this may be too short a time period to elicit a good estimate of the R&D to patents lag structure. And (2), the dependent variable, patent counts, is an integer with many zeroes and is subject to significant heteroskedasticity due to the wide size range of our firms. In Pakes and Griliches (1984b) we suggest a specific procedure for dealing with the first problem: truncation bias in the estimation of distributed lag models in short panels. It is based on an explicit modelling of the unseen pre-1972 R&D history. The integer dependent variable problem was attacked in Hausman, Hall, and Griliches (1984) by extending, developing, and estimating a Poisson-type stochastic specification for our data. (This methodology was also applied in Bound et al, 1984.) The heteroskedasticity and integer problem was also approached via consistent non-linear estimation with robust standard errors.

Our most recent paper on the relationship between patents and R&D (Hall, Griliches, Hausman, 1986) updates the earlier Pakes-Griliches and Hausman-Hall-Griliches work on the Patents and R&D relationship using a more recent and larger (but shorter) sample of firms. It uses patenting data for 642 firms for the five years 1975-1979, and associated R&D data for the eight years 1972-1979, and reaches one positive, one mixed, and two essentially negative conclusions: (1) There is a strong, largely contemporaneous relationship between R&D expenditures and patenting with an estimated elasticity of about 0.3, which does not disappear when one controls for the size of the firm, its permanent patenting policy, or even the effects of its R&D history. (2) There does appear to be a small effect of past R&D history on current patenting, on the order of 0.1-0.2, but given the large randomness in patenting from year to year and the relative shortness and stability of the R&D series, it is not possible to pinpoint the exact magnitude or the timing of this effect. (3) There does not seem to be any significant feedback from past patenting successes to future R&D expenditure changes above and beyond their contemporaneous correlation. This too may, however, reflect the high noise ratio in our patent data rather than the true absence of such a relationship. (4) An interesting finding that emerged from this study, and also Pakes' (1985) earlier work, has nothing to say about patenting, although it provides one reason why it is difficult to measure this relationship within firms over time: The pattern of R&D investment within a firm is essentially a random walk (or more precisely, a martingale) with a relatively low error variance (Table 6). In other words, R&D budgets over this short horizon (eight years) are roughly constant (in constant dollars) and therefore must be determined by considerations other than short run patenting successes. (5) More generally, the small number of patents taken out by most of the firms and their intrinsically high variability from year to year makes the use of patent counts as an indicator of inventive activity in the time dimension suspect, especially for small firms. Moreover, the rough constancy of R&D over time makes it rather difficult to make strong inferences about them. This does not mean that there is no interesting information in these data, only that one should not take small annual variations in small numbers too seriously, a point to which we shall return below.

4. Patents, R&D, and Stock Market Values

The second set of studies involving patents and related variables are connected by their use of stock market values or the stock market rate of return as indicators of the success of inventive activity and as the driving force behind the investments in it. The use of stock market values as an output indicator has one major advantage. Because the public-good characteristics of inventive output make it extremely difficult to market, returns to innovation are earned mostly by embodying it in a tangible good

Table 6

A: Time Series Analysis of Log R&D[1]

642 Firms

Lag	Autocorrelations	Partial Autocorrelations	F-test for Equality of the Autocovariances[3]
0	1.0	---	1.54
1	0.987 (0.051)	0.992 (0.002)	1.81
2	0.991 (0.051)	0.054 (0.035)	0.76
3	0.974 (0.051)	-0.009 (0.034)	2.51
4	0.964 (0.051)	0.017 (0.034)	2.75
5	0.960 (0.051)	-0.036 (0.032)	1.22
6	0.959 (0.052)	0.006 (0.032)	0.92
7	0.959 (0.052)	0.055 (0.123)	---

B: Estimates of Autoregressive Equations for Log R&D: 1975-1979[2]

Equation	(1)	(2)	(3)	(4)	(5)
Log R_{-1}	0.995(0.003)	0.923(0.040)	0.923(0.039)	0.915(0.040)	0.917(0.040)
Log R_{-2}		0.074(0.039)	0.082(0.053)	0.067(0.040)	0.069(0.040)
Log R_{-3}			-0.009(0.034)		
Log P_0				0.028(0.009)	
Log P_{-1}				0.002(0.011)	0.015(0.009)
Log P_{-2}				-0.012(0.009)	-0.002(0.009)
Standard Error	0.292	0.291	0.291	0.290	0.291

Notes:

1. R&D expenditures are in millions of 1972 dollars. The deflator is described in Cummins et al, (1985).
2. All equations contain a separate intercept for each year.
3. These are tests of the stationarity assumption. We have eight estimates of the variance, seven for the first order covariance, six for the second, and so forth. We have added 1/3 to the patents variable before taking the logarithm due to the presence of some zeroes.

From: Hall et al (1986).

or service that is then sold or traded for other information that can be so embodied. There are, therefore, no direct measures of the value of inventions, while indirect measures of current benefits (such as profits or productivity) are likely to react to the output of the firm's research laboratories only slowly and erratically. On the other hand, under simplifying assumptions, changes in the stock market value of the firm should reflect (possibly with error) changes in the expected discounted present value of the firm's entire uncertain net cash flow stream. Thus, if an event does occur that causes the market to reevaluate the accumulated output of the firm's research laboratories, its full effect on stock market values ought to be recorded immediately. This, of course, need not be equal to the effect that will eventually materialize. The fact that we are measuring expectations rather than realizations, however, does have its advantages. In particular, since expectations are a major determinant of research expenditures the use of stock market values should allow one to check whether the interpretations given to the parameter estimates is consistent with the observed behavior of these series.

Pakes (1985) uses an investment model and modern time series analysis technique to interpret the dynamic relationship between patents, R&D, and the stock market rate of return. In this model, events occur which affect the market value of a firm's R&D program and what one estimates are the reduced form relationships between the percentage increase in this value and current and subsequent changes in the firm's R&D expenditures, its patent applications, and the market rate of return on its stock. His empirical results indicate that about five percent of the variance in the stock market rate of return is caused by the events which change both R&D

and patent applications. This leads to a significant correlation between movements in the stock market rate of return and unpredictable changes in both patents and R&D expenditures, changes which could not be predicted from past values of patents and R&D (See Table 7). Moreover, the parameter values indicate that these changes in patents and R&D are associated with large movements in stock market values. On average, an "unexpected" increase in one patent is associated with an increase in the firm's market value of $810,000, while an unexpected increase of $100 of R&D expenditures is, again, on average, associated with a $1,870 increase in the value of the firm. The R&D expenditure series appear to be almost error free in this context. Patents, however, contain a significant noise component (a component whose variance is not related to either the R&D or the stock market rate of return series). This noise component accounts for only a small fraction of the large differences in the number of patent applications of different firms (about 25%), but plays a much larger role among the smaller fluctuations that occur in the patent applications of a given firm over time (about 95%). Similarily, the effect of unexpected increases in patents on market value is highly variable. Nevertheless, there is still some information in the time-series dimension. If we were to observe, for example, a sudden large burst in the patent applications of a given firm, we could be quite sure that events have occurred to cause a large change in the market value of its R&D program; but smaller changes in the patent applications of a given firm are not likely to be very informative. This statement must be modified somewhat when we consider long-term differences in the patents of a given firm (say differences over a 5- or 10-year interval), since a larger fraction of their variance is

Table 7

R&D, Patents, and the Stock Market Rate of Return.

COEFFICIENT OF:	R & D EQUATION (r_t) Recursive (1)	Autoregressive (2)	Constrained (3)	PATENT EQUATION (p_t) Recursive (4)	Autoregressive (5)	Constrained (6)
r_t	n.i.	n.i.	n.i.	.60	n.i.	.60
				(.11)		(.11)
r_{t-1}	.89	.90	.92	−.21	.34	−.21
	(.05)	(.05)	(.05)	(.15)	(.12)	(.15)
r_{t-2}	−.06	−.10	−.04	−.13	−.20	−.15
	(.07)	(.07)	(.07)	(.17)	(.17)	(.16)
r_{t-3}	.21	.24	.14	0	.16	.04
	(.07)	(.08)	(.08)	(.18)	(.18)	(.17)
r_{t-4}	−.03	−.02	−.03	−.13	−.14	−.15
	(.05)	(.06)	(.05)	(.13)	(.14)	(.12)
p_{t-1}	0	0	n.i.	.45	.45	.45
	(.02)	(.02)		(.05)	(.05)	(.05)
p_{t-2}	.03	.03	n.i.	.30	.32	.30
	(.02)	(.02)		(.05)	(.05)	(.05)
p_{t-3}	−.05	−.04	n.i.	0	−.02	0
	(.03)	(.03)		(.06)	(.06)	(.06)
p_{t-4}	0	0	n.i.	.14	.14	.14
	(.02)	(.02)		(.05)	(.05)	(0.5)
q_t	.13	n.i.	.13	0	n.i.	n.i.
	(.02)		(.02)	(.06)		
q_{t-1}	.05	.05	n.i.	−.02	.01	n.i.
	(.03)	(.03)		(.07)	(.07)	
q_{t-2}	.08	.08	n.i.	−.04	.01	n.i.
	(.03)	(.03)		(.07)	(.07)	
q_{t-3}	.04	.05	n.i.	.05	.08	n.i.
	(.03)	(.03)		(.07)	(.07)	
q_{t-4}	−.02	−.02	n.i.	−.01	−.02	n.i.
	(.02)	(.02)		(.05)	(.04)	
σ^2	.035	.036	.035	.203	.215	.201
Test statistics:*						
T_1	2,196.52	2,205.88		14.09†	9.92	
T_2	1.91	1.52		358.75	335.62	
T_3	7.54†	3.29		.21†	.40	

Notes: Standard errors are in parentheses. r - log R&D, p - log Patents, q - one period rate of return on the common stock. T_1, T_2, and T_3 are the observed values of the T-test statistic for the joint significance of, respectively, the R&D variables, and the 1-period rate of return. The critical values are 2.39 and 3.36 at 5 and 1 percent, respectively, except at n.+

+Critical values are 2.23 and 3.06 at 5 and 1 percent, respectively.

From: Pakes (1985)

caused by events that lead the market to reevaluate the firm's inventive output during these periods.

The timing of the response of patents and R&D to events which change the value of a firm's R&D effort is quite similar. One gets the impression from the estimates that such events cause a chain reaction, inducing an increase in R&D expenditures far into the future, and that firms patent around the links of this chain almost as quickly as they are completed, resulting in a rather close relationship between R&D expenditures and the number of patents applied for. Perhaps surprisingly, he finds no evidence that independent changes in the number of patents applied for (independent of current and earlier R&D expenditures) produce significant effects on the market's valuation of the firm (this is reflected by a lack of an independent effect of lagged p r in the R&D equation and of q on p in the patent equation in Table 7). The data cannot differentiate between different kinds of events that change a firm's R&D level.

In a related paper Mairesse and Siu (1984) analyze the time-series interrelationship between changes in the market value of the firm, sales, R&D, and physical investment using what they call the extended accelerator model. This paper follows the Pakes paper both in approach and in the use of essentially the same data. It differs by not focusing on patents, instead adding sales and investment to the list of the series whose interrelationship is to be examined. They find that a relatively simple "causal" model fits their data: "innovations" in both market value and sales "cause" subsequent R&D and investment changes without further feedback from R&D or investment to either the stock market rate of returns or sales. There is little evidence of a strong feedback relationship between physical and R&D investment, though there is some evidence of contemporaneous interaction. An interesting conclusion of their paper is that independent changes in sales explain a significant fraction of the changs in R&D (and physical investment) above and beyond what is already explained by changes in the market value of the firm and by lagged movements in R&D itself, implying that by using different variables one might be able to separate out the effects of different kinds of shocks in the R&D process. This finding could, of course, be just a reflection of a substantial noise (error) level in the observed fluctuations of the stock market rate of return, in the sense that not all of the changes in the market value of a firm are relevant to investment decisions.

Ben-Zion (1984) examines the cross-sectional determinants of market value, following an approach similar to that outlined in Griliches (1981). It differs by not allowing for specific firm constants and by including other variables, such as earnings and physical investment, in the same equation. He also finds that R&D and patents are significant in explaining the variability of market value (relative to the book value of its assets), in addition to such other variables as earnings. His most interest-ing finding, from our point of view, is the relative importance of total patents taken out in the industry as a whole on the firm's own market value. In his interpretation, patents applied for indicate new technological opportunities in the industry, and these overall opportunities may be more important than a firm's own recent accomplishments, though here again this could arise just from the high error rate in the firm's own patent counts as an indicator of its own inventive potential.

This set of papers clearly opens up an interesting research area but still leaves many issues unresolved. Like the proverbial research on the characteristics of an elephant, different papers approach this topic from slightly different points of view. Pakes analyzes movements in patents, R&D, and market value; Mairesse and Siu investigate the relationship between R&D, investment, sales, and market value; while Ben-Zion (in his change regressions) looks at R&D, earnings, and market value.

In principle, one would like to use modern time series techniques together with some of the testable implications of recent investment theory to separate out the timing in the relationships between these variables and to consider disturbances processes that intercede between them. One of the conclusions of the Pakes paper, however, was that to separate out successfully the effects of different kinds of events on inventive activity will require a larger model and more indicator variables than were used heretofore. Especially distressing was his inability to distinguish between demand shocks, where demand shocks are loosely defined as events which cause increases in patenting only through the R&D expenditures they induce, and technological or supply shocks which may have a direct effect on patents as well as an indirect effect via induced R&D demand. A model capable of distinguishing between these shocks requires the addition of variables which react differently to such events. A prototype of such a model is outlined in Griliches, Hall and Pakes (1986), where the results of a replication of some of Pakes (1985) computations for a larger sample and an expan-sion of his equation system to add equations for sales, employment, and investment are also reported. They indicate that the addition of the latter variables is helpful, in the sense that fluctuations in their growth rates are related to fluctuations in both the growth rate of R&D and the stock market rate of return and hence should help in identifying the relationships we are interested in. On the other hand, the expansion of the sample to include many small firms with low levels of patenting, deteriorates significantly the informational content of this variable, raising its noise to signal ratio, and making it hard to discern a feedback from the independent variability in patenting to any of the other variables. Thus, at the moment, it does not look as if the data can sustain a model with two separate factors ("market" and "technological" innovations), even though in principle such a model should be identifiable in this kind of data and with this number of variables.

The difficulties in implementing such models arise to a large extent from the large "noise" component in patents as indicators of R&D output in the short-run within-firm dimension. While we were aware of the problem from the beginning, it was the work of Pakes and Schankerman (1984), which we turn to next, and their estimates of the dispersion of patent values which alerted us to its actual magnitude. Using their numbers Griliches, Hall, and Pakes (1986) estimate that though unexpected changes in the present value of R&D output can account only for about one percent of the variation in the stock market value of a firm from year to year and that the proportion that is accountable by unexpected changes in the number of patents is even smaller (less than 0.1 percent). Thus, it is not surprising that it is difficult to use patent data to separate out demand from supply shocks and follow these effects over time.

5. Patent Renewal Data

In many countries and recently also in the U.S., holders of patents must pay an annual renewal fee in order to keep their patents in force. If the renewal fee is not paid in any single year the patent is permanently cancelled. Assuming that renewal decisions are based on economic criteria, agents will only renew their patents if the value of holding them over an additional year exceeds the cost of such renewal. Observations on the proportion of patents that are renewed at alternative ages, together with the relevant renewal fee schedules, will then contain information on the distribution of the holding values of patents, and on the evolution of this distribution function over the lifespan of the patents. Since patent rights are seldom marketed, this is one of the few sources of information on their value. In a series of papers Pakes and Schankerman (1984), Pakes (1986), and Schankerman and Pakes (1986) present and estimate models which allow them to recover the distribution of returns from holding patents at each age over their lifespan. Since the renewal decision is based on the value of patent protection to the patentee, the procedure used in these articles directly estimates the private value of the benefits derived from the patent laws. Estimates of the distribution of these benefits at an economy-wide level of aggregation, and of movements in them over the post-1950 period are also obtained.

In addition, these patent renewal models imply that ideas for which patent protection is more valuable will tend to be protected by payment of renewal fees for longer periods of time. This suggests using the patent renewal data to construct an index of the average value, or quality, of the ideas embodied in patents, and then using this index to supplement the quantity-based patent count data in constructing more comprehensive and accurate measures of the value of patented output. There are two reasons why an index of the value of patented ideas should prove useful. First, the average value of patented inventions may differ among groups of patentees or over time periods, so that differences in the number of patents among groups or time periods will provide systematically biased estimates of differences in their value. Second, both small sample case studies and larger sample econometric evidence indicate that the distribution of the value of patented ideas is very dispersed and highly skewed (see below for details). This implies that the "noise to signal" ratio in the patent count variable as a measure of the value of patented ideas is large. Provided that differently valued patents are renewed for different lengths of time, the renewal data allow us to construct an indicator of the value of patented output with a lower noise to signal ratio than that of the patent count index alone. We illustrate these two uses of the renewal data below.

In Pakes (1986) patent holders are allowed to be uncertain about the sequence of returns that will accrue to the patent if it is to be kept in force. This uncertainty is introducted to allow for the fact that agents often apply for patents at an early stage in the innovation process, a stage in which the agent is still exploring alternative opportunities for earning returns from the information embodied in the patented idea. Early patenting arises in part from the incentive structure created by the patent system, since, if the agent does not patent the information available to him, somebody else might. This incentive is reinforced by the fact that the renewal fees in all countries studied are quite small during the early years of a patent's life.

A patent holder who pays the renewal fee obtains both the current returns that accrue to the patent over the coming period, and the option to pay the renewal fee and maintain the patent in force in the following period should he desire to do so. An agent who acts optimally will pay the renewal fee only if the sum of the current returns plus the value of this option exceeds the renewal fee. It is assumed that the agent values the option at the expected discounted value of future net returns (current returns minus renewal fees), taking account of the fact that an optimal policy will be followed in each future period, and conditional on the information currently at the disposal of the agent. An optimal sequential policy for the agent has the form of an optimal renewal (or stopping) rule; a rule determining whether to pay the renewal fee at each age. The proportion of patents which drop out at age a corresponds to the proportion of patents which do not satisfy the renewal criteria at that age but did so at age a-1. The drop out proportions predicted by the model are a function of the model's parameter values and of the renewal fee schedule. The data gives us the actual proportion of drop outs. The estimation problem consists, roughly speaking, of finding those values of the model's parameters which make the drop out proportions implied by the model as "close" as possible to those we actually observe.

The empirical results from the Pakes (1986) paper indicate that patents are applied for at an early stage in the inventive process, a stage in which there is still substantial uncertainty concerning both the returns that will be earned from holding the patents, and the returns that will accrue to the patented ideas. Gradually the patentors uncover more information about the actual value of their patents. Most turn out to be of little value, but the rare "winner" justifies the investments that were made in developing them. His estimates imply also that most of the uncertainty with respect to the value of a patent is resolved during the first three or four years of its life. Using this result, Schankerman and Pakes (1986) employ a simpler but more detailed model to examine changes in the distribution of patent values over time and the correlates of these changes. The substantive results from these papers imply that the average value of a patent right is quite small, about $7,000 in the population of patent applications in France and the UK. In Germany, where only about 35 percent of all patent applications are granted (about 93% and 83% were granted in France and the UK respectively), the average value of a patent right among grants was about $17,000. The distribution of these values, however, is very dispersed and skewed. One percent of patent applications in France and the UK had values in excess of $70,000 while in Germany one percent of patents granted had values in excess of $120,000. Moreover, half of all the estimated value of patent rights accrues to between five and ten percent of all the patents. The annual returns to patent protection decay rather quickly over time, with rates of obsolescence on the order of 10 to 20 percent per year. Since about 35,000 patent were applied for per year in France and the UK and about 60,000 in Germany, these figures imply that though the aggregate value of patent rights is quite large, it is only on the order of ten to fifteen percent of the total national expenditures on R&D. While these returns (which are the result of the proprietary right created by the patent laws) may, depending on the response elasticity of R&D investments to such incentives, stimulate a large amount of R&D investment, it is clear that other means of appropriating the benefits of R&D must be quite important.

Even though the total number of patent applications fell during the 1970s, one should not take this decline in numbers as implying, necessarily, the exhaustion of technological opportunities. Schankerman and Pakes find that although the numbers of patents per scientist and engineer fell sharply, their estimated "quality-adjusted" total value of patent rights per scientist and engineer was remarkably stable over the period examined by them (Table 8). One final point. Disaggregated patent renewal data are gathered by the International Patent Documentation Center (INPADOC). These data would allow one to investigate the returns to patent protection separately by technical field of the patent and by the nationality and type of patentor (e.g., individuals and small business enterprises vs large corporate entities). Issues related to which sectors of a particular economy, and which economies, derive disproportionate benefits from the patent laws lie at the heart of most discussions of cost and benefits of alternative patent systems (see Scherer, 1965, Chapter 16, and the literature cited there.) Moreover, inter-sectoral differences in the patenting and R&D processes are central to the literature on market structure, industrial policy, and technical progress. Thus, future studies using these data could be very interesting and should be encouraged.

6. The Spillover Effects of R&D

One of the major unresolved issues in this area of research is the identification and measurement of R&D spillovers, the benefits that one company or industry receives from the R&D activity of another. It is difficult to trace such spillovers without having strong a priori notions

Table 8: Estimated Indices of Quantity, Quality, and Total Value of Cohorts of Patents at Five-Year Intervals Between 1955 and 1975[a]

Year \ Index	United Kingdom				France				Germany			
	PA	P5	$\bar{V}$	V	PA	P5	$\bar{V}$	V	PA	P5	$\bar{V}$	V
1955	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1960	1.24	1.35	0.80	1.08	1.26	1.39	1.14	1.59	1.04	1.08	1.01	1.10
1965	1.56	1.67	0.86	1.42	1.67	1.78	1.49	2.64	1.21	1.04	0.99	1.03
1970	1.72	1.78	0.84	1.49	1.67	1.83	1.68	3.08	1.21	1.01	1.32	1.33
1975	1.45	1.58	1.40	2.18	1.55	1.65	1.86	3.06	1.10	0.99	1.93	1.91

[a]PA and P5 are indices of the number of patents applied for and the number of patents which survive until age 5, respectively. $\bar{V}$ and V are indices of the mean and total of the estimated discounted present value of patent protection from age five for the patents surviving until age five. The index numbers refer to the cohorts applied for in the year row.

From: Schankerman and Pakes (1986)

about who are the potential beneficiaries of whose research. One of the ways we have been trying to approach this problem is by using the detailed information on patenting by type of patent (patent class) to cluster firms into common "technological activity" clusters and looking whether a firm's variables are related to the overall activity levels of its cluster.

In his thesis and several recent papers, Adam Jaffe (1983, 1984, 1985, 1986) has used firm level data on patenting by class of patent and on the distribution of sales by 4-digit SIC to cluster 500+ of our panel firms into 21 distinct technological clusters and 20 industry (sales orientation) clusters. It turns out that these two clustering criteria lead to different clusterings. Using the technological clusters Jaffe constructed a measure of the total R&D "pool" available for spillovers (borrowing or stealing) in a cluster. He then looked at three "outcome" variables: R&D investment ratio for the firm (in 1976), patents received (average number applied for during 1975-1977), and output growth between 1972 and 1977. In each of these cases, his measure of the R&D pool contributed significantly and positively to the explanation of the firm level "outcome" variables even in the presence of industry dummies (based on the sales clustering). Not surprisingly, perhaps, firms in technological clusters with large overall R&D "pools" invested more intensively in R&D than would be predicted just from their industrial (SIC) location. More interesting is the finding that firms received more patents per R&D dollar in clusters where more R&D was performed by others, again above and beyond any pure industry differences (based on a classification of their sales). (See Table 9.) Similarly, his analysis of firm productivity growth during the 1972-1977 period showed that it was related positively to both the average R&D

TABLE 9

PATENT EQUATION ESTIMATION RESULTS

NON-LINEAR TWO-STAGE LEAST SQUARES (1976 CROSS-SECTION)

Dependent Variable: Log of Average Patents Applied for, 1975-1977

	1	2	3	4
Log(R&D) (β_1)	.940 (.034)	.961 (.047)	.937 (.070)	-2.09 (.214)
R&D Elasticity ($\beta_1 + \beta_3 \log(s^T + \delta s^C)$)				.871 (.115)
Log(Pool) (β_2)			.746 (.164)	.551 (.179)
R&D-Pool Interaction (β_3)				.361 (.072)
Within-Cluster Premium (δ)			.763 (.364)	.670 (.371)
χ^2-statistic for the significance of technological cluster effects	n.i.	53.6	42.1	39.2
Root mean square error	.943	.913	.862	.923

Notes: 537 observations. Numbers in parentheses under coefficients are heteroskedasticity consistent standard errors; χ^2 statistics are not corrected for heteroskedasticity. R&D elasticity is calculated for comparison to other equations. For this purpose, the pool variables are evaluated at the mean of the data.

"Pool" = $s^T + \delta s^C$. s^T - weighted R&D of "others". s^C - weighted R&D of others within the same technological cluster. n.i. - not included.

The 99.5% critical value for χ^2_{20} is 39.9.

From: Jaffe (1985)

intensity of the individual firms and the change in the size of the R&D pool available to these firms (Table 10). The magnitude and significance of these effects is robust, allowing also for industry based differences in average rates of productivity growth. In terms of profits, or market value, however, there are both positive and negative effects of neighboring firms' R&D. The net effect is positive for high R&D firms, but firms with R&D about one standard deviation below the mean are made worse off overall by the R&D of others. More generally, the idea of R&D spillovers is made operational by using the information in the patenting patterns of firms to construct a measure of their position in "technological space" and of the closeness between them and it is shown that this position has an observable impact on the firm's success.

7. Summary

In this paper we describe a number of studies whose common denominator is the use of patent statistics to illuminate the process of innovation and technical change. One of the main findings of this project was the discovery of a strong relationship in the cross-sectional dimension. Patents are a good indicator of differences in inventive activity across different firms. While the propensity to patent differs significantly across industries, the relationship between R&D and patents is close to proportional, especially for firms above a minimal size. Small firms do receive a significantly higher number of patents per R&D dollar but this can be explained largely by their being a much more highly selected group. (To be in our sample a small firm must be successful enough to have publicly traded securities.) There is also a statistically significant relationship between R&D and patents in the within-firm time-series

TABLE 10

RESULTS OF SALES EQUATION ESTIMATION-R&D FORM
(Differences, 1977 - 1972)

Dependent Variable: Log(Deflated 1977 Sales) - Log(Deflated 1972 Sales)

	1	2	3	4
ΔLog(Employment)	.721 (.047)	.692 (.038)	.690 (.033)	.681 (.033)
ΔLog(Net Plant)	.037 (.045)	.127 (.047)	.138 (.031)	.155 (.032)
R&D/Sales	1.98 (.41)	1.45 (.46)	1.08 (.28)	1.26 (.52)
ΔLog(Cluster Pool Stock)	.041 (.049)	.098 (.051)	.158 (.038)	.176 (.045)
$\Delta\left(\frac{\text{Out of Cluster Pool Stock}}{\text{Cluster Pool Stock}}\right)$	.00034 (.00029)	.00035 (.00028)	.00011 (.00054)	.00015 (.00052)
F-statistic on Industry Effects	n.i.	6.3 (18,403)	n.i.	2.1 (18,383)
F-statistic on Technological Area Effects	n.i.	n.i.	5.8 (20,401)	1.9 (20,383)
R^2	.618	.702	.703	.732
Root mean square error	.191	.172	.172	.167

Notes: 434 observations. Numbers in parentheses under coefficients are heteroskedasticity consistent standard errors F-statistics are not corrected for heteroskedasticity. n.i.-- not included.

F critical values:	.95	.99
(20,400)	1.6	1.9
(50,400)	1.4	1.6

From: Jaffe, A., 1985

dimension, but it is weaker there. The bulk of the observable effect is contemporeneous. There is some evidence that history also matters, that there are some lagged effects, but they seem to be small and difficult to estimate precisely. These findings can also be interpreted as implying some reverse causality: successful research leads both to patents and to a commitment of additional funds for the development of resulting ideas.

Using data on patent renewal rates and patent renewal fees in selected European countries we have estimated the private value of patent rights, their dispersion, and their decay over time. The average value of patent rights is quite small, about $7,000 and $17,000 per patent in France and Germany respectively. It is also very variable and its distribution is quite skewed. While most patent rights were close to worthless, one percent of them had values in excess of $70,000 and $120,000 per patent in France and Germany respectively. These returns were estimated, however, to decline rather rapidly over time, with rates of obsolesence between 10 and 20 percent per year. While the aggregate value of patent rights appears to be quite high, it is estimated to be only on the order of 10 to 15 percent of total national expenditures on R&D. Hence it is unlikely to be the major factor in determining the overall level of such expenditures. Using these newly developed methods of analysis we show that even though the total number of patent applications fell during the 1970s, their estimated "quality" rose, implying that one cannot take the observed decline in numbers as indicating, necessarily, the exhaustion of technological opportunities. The finding of extreme skewness in the distribution of the value of patent rights has, however, pessimistic implications for the use of patent counts as indicators of short run changes in the output of R&D.

Nevertheless, patent data represent a valuable resource for the analysis of the process of technical change. There are other ways of using them besides simply counting them. It is possible to use a firm's distribution of patenting by field to infer the position of its R&D program in "technological space" and to use this information, in turn, to study how the results of R&D spillover from one firm to another and to illuminate the process of strategic rivalry that the firm finds itself in. If, as is now happening also in the U.S., patent renewal information were to become available at the individual patent and firm level, one could use these data together with information on patent citations to construct more relevant "quality weighted" inventive "output" measures. Even without going that far, the currently available patent data can be used to study longer-run interfirm differences in levels of inventive activity and as a substitute for R&D data where they are not available in the desired detail.

Footnotes

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Appendix

The Compustat-OTAF Patents Match

In accomplishing this match the major problem we faced was that the OTAF tapes do not have CUSIP numbers (the identifying corporation code on the Compustat Tapes). They list only the names of individuals and organizations, of which there were 66,000 or more distinct ones and among which we needed to find our 2700 firm names. The work that had to be done is described in more detail in Cummins et al (1985). Basically, we had first to find all (or most) of the subsidiaries of our 2,700 companies and enter all of their distinct names, 16,000 of them, into the computer; write and run a lexicographical search and match computer program that would assign OTAF names to the Compustat firms; check the results manually; investigate the many discrepancies and resolve various conflicts. The first round of the match yielded about 4,500 OTAF organizations to associate with 1,500 of our firms. After checking the list of patenting organizations with at least five patents in the 11 year period from 1969 through 1979 we found that approximately 8,000 organizations remained which were not matched to the firms in our sample. Based on a sample, about a third of those appeared to be foreign firms and another third remained unidentified after looking them up in the 1981 Directory of Corporate Affiliations. To reduce the number of firms which had to be investigated by hand, we restricted the sample of unmatched organizations to those with more than 50 patents in the 11 year period or at least five patents in the period 1975 to 1977. Of these 900 organizations, a third were matched to our sample or otherwise disposed of. The remaining largest unmatched organizations turned out to be agencies of the U.S. Government, several privately-held companies, and a few service companies which obtained patents for inventors.