Understanding Patents: The Role of R&D Funding Sources and the Patent Office[*]

Paroma Sanyal[**]
Brandeis University
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Abstract:
This paper analyzes the effects of different sources of R&D funding and patent office attributes on the patenting process. Another important contribution is modeling the effect of a random delay in the 'pendency' time as a stochastic process and quantifying its effect on patenting. The empirical estimation is based on four major industries – electronics, chemical and biology, transportation and aeronautics – for the time period 1976-1998. The primary results are: First, the source of R&D funding as well as performer (academic, federal and industry) has a differential effect on patenting. Second, the effects of some types of R&D and spillovers are different post-1990. Third, in the short run patenting is heavily influenced by patent office attributes. The state level analysis sheds light on the differing role of the federal government as an R&D performed and as a source of R&D funds for industry. The results contribute to a better understanding of the shortcomings in the formulation of science indicators.

Keywords: Patents, Innovations, Federal v/s Private R&D
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[**] Economics department, MS 021, Sachar International Center, Brandeis University, 415 South Street, Waltham, MA 02454

INTRODUCTION

Patents have often been used as a proxy for innovations. As a metric for inventive activity, although far from perfect (Griliches, 1990, Cockburn & Griliches, 1988), they are often the best indicator available to a researcher. The complex nature of the patent data, make clear-cut conclusions about the relationship between patents and innovations, difficult. To get a sense of what the number of patents mean, one needs to understand what determines them. It is helpful to disaggregate the patenting process and look at two distinct phases. First, the incentive of the inventers to patent a given innovation needs to be analyzed. Second, the resource-constrained behavior of the US Patent and Trademark Office (USPTO) has to be factored in to gain a better understanding of patent grants. This paper focuses on the determinants of patenting in the United States.

One of the important questions in this area of research is how the patent grant numbers relate to the nature and amount of research and development (R&D) expenditures and other industry fundamentals. Problems in interpreting the patent data stem from a number of factors. First, patent application and patent grants do not always follow the same trend. Grants are heavily influenced by the inefficiencies and constraints of the USPTO (Griliches, 1989). Second, fluctuations in R&D affect patents, but less than proportionately (Griliches, 1989). Third, current patent applications are strongly correlated with current R&D (Pakes, 1985). All these factors make it really difficult to interpret the actual linkage between patents and R&D. This paper attempts to model the determinants of patenting and quantify the effects of those determinants.

Keeping the above facts in mind, any model of patent production needs to recognize several salient factors. It is important to realize that there is no one to one relationship between patenting, innovations and R&D. Both past and present company R&D has a strong positive influence on patenting activity. The source through which R&D activities are funded have different impacts on the productivity of innovations and hence the number of patents. Generally, econometric studies have failed to find significant direct productivity effects of federal R&D, whereas company R&D, both past and current, is highly significant. This has led some researchers to hypothesize that the effect of federal R&D on productivity works through indirect channels (Mansfield and Switzer, 1984; Lichtenberg,1984, 1987, 1988). University R&D has strong positive spillovers regarding corporate patenting. There is evidence of geographic spillovers when industry and university are co-located (Cohen et al., 1997; Feller et al., 1998; Griliches, 1989; Jaffe, 1989; Klevorick 1994; Mansfield (1991); Mowery, 1997; Nelson, 1986).

Patenting is also influenced by a host of market structure variables[1]. Researchers have found a positive link between firm size, R&D and innovation (Cohen & Levin, 1989; Schmookler, 1972), whereas the relationship between market concentration and innovation have been found to be ambiguous ((Mansfield, 1963, 1968[2]; Scherer, 1965; Williamson, 1965). Last, resources at the patent office, patent fees and law changes that alter the length or breadth of patent protection have profound effects on the number of patents granted in the short-run. Inventors may look at the average time it takes to grant a patent and then decide whether to apply for a patent or protect their innovation as a trade secret. In areas, where the half-life of an invention is short, delay in patent processing may imply reduced applications and hence decreased grants.

With these facts in mind, I provide a short theoretical sketch that helps in motivating the subsequent empirical model. This background model incorporates industry characteristics,

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[1] For a detailed analysis please refer to Kamien & Schwartz: “Market Structure and Innovation: A Survey”, in the Journal of Economic Literature, 1975, vol. 13, no. 1, pp. 1 – 37.

different types of R&D and US Patent Office variables and seeks to explain the determinants of patenting under different production function assumptions and cost conditions. Some important contributions of this paper are to look at the direct and spillover effects of federal R&D and university on patenting, the importance of past versus present company R&D, the effect of academic R&D, the influence of market structures, US Patent Office resources as determinants of the number of patents granted and the effect of delays in pendency time. Four major R&D industries, electronics, chemicals/biology[3], transportation and aeronautics are studied.

SECTION 2: MOTIVATING THE EMPIRICAL MODEL

This section provides a brief theoretical justification for the subsequent empirical model. The purpose of this exercise is to analyze the formulation of the patent production and cost functions at the industry level. Inter-firm rivalry and patent races between firms within the industry is ignored and the number of firms in the industry is normalized to one, i.e. consider the whole industry as one giant firm for decision making purposes. The process of obtaining a patent is broken down into two parts. The first stage deals with actual inventions and innovations. At the end of this stage we observe a number of inventions, each with a different value. The second stage deals with patenting that invention. This involves the application for a patent, the waiting period at the patent office (USPTO) and finally the approval or rejection of the patent application. This model tries to combine the flavors of several earlier works in the literature (Griliches, 1986, 1988, 1989, 1990 & Jaffe, 1986, 1989) and presents a unified approach.

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[2] (1963) The author found that during 1919-58 in petroleum refining and bituminous coal the largest four firms did most of the innovating, but this was not true for the steel industry. Thus it is not always the case that the largest firms are the greatest innovators.

[3] Ideally one would have liked to separate chemicals and biology. But data constraints imply that only 3 years of data are available for biology. Also, since we cannot separate chemicals from biology R&D for the other years, the chemicals numbers include both. Thus separating them will produce incorrect R&D numbers.

In the first stage, the industry invests in R&D with the aim of producing inventions and innovations. The innovations may be cost reducing or quality enhancing, or the industry may discover a new product or process altogether. The objective function of the industry is to maximize the value of the innovations it produces. We assume that each industry engages in ‘N’ projects, each of which will yield an invention. Thus, inventions can be modeled as a function of the following variables:

$$N_{kt} = f(CRD_{kt}, FRD_{kt}, URD_{kt}, SP_{kt}) \qquad (1)$$

where: N =1,…n, and denotes the number of inventions, ‘k’ denotes the industry and t denotes the time period. CRD_{kt} is the stock of company performed R&D in the particular industrial category. FRD_{kt} is the stock of federally funded industrial R&D. URD_{kt} is the university performed R&D (contains R&D dollars from all funding sources) in that industrial category. SP_{kt} is the spillover that the industry receives from federal R&D or academic R&D.

Each project N=1,…n, results in an invention. Each invention has a commercial value (V_N) between 0 and ∞, i.e. $V_N \sim [0, \infty)$. In principle, V_N reflects the fact that there is heterogeneity in the value of inventions. The uncertainty in the invention process is reflected by the fact that exante, the industry does not know the exact value of the invention that results from the R&D investment. It only knows the distribution of values – an exponential in this case.

The size of the industry and an R&D composition variable are incorporated as shift parameters in this value function. Usually, the bigger the firm/industry, the more inventions it is going to make. The R&D composition variable, measures what portion of the R&D is financed by the industry’s own resources. In a sense, we expect, that the more of its own resources a firm uses, the greater will be number of inventions, due to shareholder pressure. I assume that the average value of inventions is greater in an industry that finances a majority of R&D from its own resources. Thus SIZE denotes the scale of operation and COMP reflects the composition of R&D, i.e., what portion of total industry performed R&D is funded by the industry itself. Thus the density function of V_N is given by:

$$f(V_N) = (COMP_{kt}^{\lambda} * SIZE_{kt}^{\rho}).\frac{1}{b}e^{-V_N/b} \tag{2}$$

where: 'b' is the mean and variance of the exponential distribution.

The industry applies for a patent if $E(V_N) > E(C_{kt})$, i.e. the expected cost of patenting (C_{kt}) is less than the expected value of the invention (V_N). We assume that if the industry applies for the patent, it gets the patent with probability one[4]. Therefore the industry obtains the patent if:

$$prob\,[V_N \geq C_{kt}] = (COMP_{k,t-r}^{\lambda} * SIZE_{kt}^{\rho}).\frac{1}{b}\int_{C_{kt}}^{\infty} e^{-V_N/b}\,dx \tag{3}$$

Therefore, from equation (1) and (3), the expected number of patents in year t is:

$$P_{kt} = \frac{1}{b}N_{kt}.(COMP_{k,t-r}^{\lambda} * SIZE_{kt}^{\rho}).e^{-C_{kt}/b} \tag{4}$$

Section 2.1: Patent Production and Cost Functions

There are two alternative invention production functions that can be studied. One is the more traditional Cobb-Douglas production function that has been studied thoroughly in the literature. The other formulation tries to model the spillovers more directly. I shall outline both models below.

$$N_{kt} = \alpha.CRD_{kt}^{[\beta_k + \gamma_k\ FRD_{k,t-s}]}URD_{kt} \tag{5}$$

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[4] To simply one layer of the problem, we assume that all patents that are applied for are granted. Alternatively, we could have assumed that there is a fixed grant rate for each industry in each year and thus the number of applications multiplied by this grant rate would give us the number of patents granted. This would not make any difference for our empirical model, and is thus not incorporated here.

$$N_{kt} = A\,(CRD_{kt}^{\delta 1} FRD_{kt}^{\delta 2} URD_{kt}^{\delta 3}) \tag{6}$$

where: N is the number of inventions in industry k in year t and A is the technological constant.

In theory, the patent cost function should include both monetary and non-monetary costs. The major monetary costs would be the lawyers' fees[5] and the USPTO fees. The main non-monetary cost would be time it takes for the patent to be granted, any law changes that affect the cost of patenting. Since the main purpose of the exercise is to motivate the empirical model, data constraints dictate that we consider only those variables that we can quantify. So attention is limited to the quantifiable variables – law change and pendency time.

Let the cost of getting a patent be denoted by:

$$C_{kt} = \phi L_t + \theta D_t \tag{7}$$

where: L_t is the law change variable. D_t reflects the time that the industry expects the USPTO to take to process an application. It is the time between application of a patent and its issue or abandonment. This delay at the USPTO has two parts – a deterministic part already known to the industry before patent application, and a random component. The deterministic part (D^d_t) is termed as the 'pendency time'. It depends on patent office resources, which may include variables like funds at USPTO, number of patent professionals, the degree of automation, the patent processing cost to USPTO income ratio to name a few. D^r_t denotes the random non-recurrent delay. These are random shocks in the patent office budgeting that result in sudden increases of the pendency time. We can assume two alternative distributions for this random

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[5] The cost function can also include variables like the commercialization cost of the invention that the industry has to incur. This constitutes the time between the invention happening and the firm actually applying for a patent. This involves the time that goes into researching the 'newness' of the invention before applying for the patent and also other monetary costs.

delay - the uniform distribution and the exponential distribution. However the exponential distribution is intuitively more appealing as it implies that the probability of a longer delay is smaller than the probability of a shorter delay[6].

Suppose D^r_t follows an exponential distribution[7]. This implies that the probability of occurrence of a shorter delay is greater than that of a longer delay. The probability density function is given as[8]:

$$f(D_t^r) = \frac{1}{a} e^{(-D_t^r/a)} \qquad (8)$$

Assuming $D^r_t > 0$ to guarantee an interior solution, the expected cost of patenting is given by:

$$EC_{kt} = \phi L_t + \theta\, D_t^d - \theta a \qquad (9)$$

Now we have two[9] alternative specifications of the model: Cobb-Douglas production function and the spillover production with D_t^r having an exponential distribution for both the models. Equation (10), later in the paper, gives the reduced form estimation equation.

SECTION 3: DATA DESCRIPTION

This section briefly outlines the data that has been used to formulate the empirical model. The US data is obtained mainly from two sources. The R&D data for the various industries is obtained from the Science and Engineering Indicators (1990 –1998)[10] survey that is published by

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[6] Assuming a uniform distribution means that a long and short random delay are equi-probable.

[7] The uniform distribution is is defined for the domain [0, D_m]. The probability density function is given by: $f(D^r_t)=1/D_m$ for $0<D_m\leq\infty$ and $f(D^r_t)= 0$ otherwise. The mean is $½.D_m$ and the standard deviation is $D_m/\sqrt{12}$.
Therefore the expected cost of patenting (EC_{kt}) is: $EC_{kt}=\phi L_t+\theta D_t^d+\frac{\theta D_m}{2}$

[8] The parameter ‘a’ is the mean and standard deviation of the distribution.

[9] There are four alternative specifications if we include the uniform random delay.

[10] The data could not be extended to 2000 due to an industry classification change (from SICs to NAICs) that makes comparison across the groups difficult.

the National Science Foundation (NSF). The patent data is obtained from NBER's Patent dataset. The figures about the PTO costs, fees, number of examiners, etc. were obtained from the Annual Report of the Commissioner of Patents and Trademark Office (1976-1996).

The state-level data is collected from National Science Foundation's "National Patterns of Research and Development Resources" (1983 – 2000). The total state-wise industrial R&D, federal R&D funding to industry and university funding data is for alternate years from 1981 to 1998 for the top ten R&D performing states (California, Illinois, Massachusetts, Michigan, New York, New Jersey, Ohio, Pennsylvania, Texas, Washington). This data is not disaggregated by industry.

The analysis is conducted at two levels. The first set of regressions is at the industry level. The second part of the analysis is done on state-level shares of patents and R&D and is not disaggregated by industry. The following section gives an explanation of the variables used in both the models. The variables are divided to two sections - the US Patent Office variables and the industry specific variables.

Section 3.1: Patent Office Variables

The dependent variable in the industry-level model is log of patents. For the state-level model, it is the logit-transformed share of the patents granted to that state. Patents refer to the number of patents issued by the USPTO to domestic (US) inventors in various categories[11]. Figure 1(a) shows the overall US patent application and issue. It illustrates that while patent

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[11] Usually there are two parameters by which patents can be assigned – 'inventor state' or 'assignee state'. Suppose the inventor of a patent lives in the US but the company who owns the patent has its headquarters in Japan, then the 'inventor state' search will assign this patent to the US while the 'assignee state' search will assign this patent to Japan. If there are multiple inventors, the 'inventor state' search gives the state of the first inventor. The common convention is to use the state of the first inventor while counting patents – the methodology followed by the NBER

applications have risen dramatically over the years, the increase in patent issue has been more gradual. The next figure shows the total number of assigned to each state. It shows that other than California, the patent issues have not risen dramatically over the years. Most states show a moderate increase in the number of patents. New Jersey and Ohio show a slight fall in the patent numbers.

For the industry-level analysis, I study four industrial categories – electronics, chemicals/ biology, transportation and aeronautics[12]. Figure 2 shows the industry specific patent issue. Electronics and chemicals are the high patenting industries. The average patent numbers are much lower for the biology, transportation and aeronautics industry. All five industries show a dip in patents around 1979. Patents issue again rises from 1983.

The pendency time is the time that elapses between the application for a patent and its issuance and abandonment. This is a variable that is intricately linked with the resources at the USPTO. Figure 3 illustrates that more resources and more patent examiners mean a shorter pendency time. Thus ideally captures the patent office budget constraint and is important in explaining variations in patenting in the short-run (Griliches, 1989). The pendency time peaked at 1983 and has been falling steadily after that, albeit with a slight increase around 1991[13].

In the time frame under consideration, there have been two major law changes (1981 & 1991) that have affected the fees collected by the PTO. The first dealt with fee increases[14] and

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patent data set. For robustness check I also used the 'assignee-state' search criteria to retrieve patent from the USPTO database. Using this as the independent variable did not significantly change the results.

[12] Please ask the author if you need information about the detailed sub-classes and exact class codes used by the PTO.

[13] Although, the pendency time varies by the type of patents, due to unavailability of that data, I use the average pendency time of utility patents.

[14] Before, 1981, the fees charged by the office had been inflexibly set by statute. Patent fees had no changed since 1965 and had declined continuously compared to operating costs. The 1981 law required that the PTO set fees at a rate that would cover 50 percent of the patent process cost, 50 percent of the trademark processing cost and 100 percent of the cost of all other PTO services. (Public Law 96-517). This provision applied : "Except in the case of design patents, the 50 percent of the patent processing cost will be made up from fees recovering 25 percent of

the other altered PTO funding sources[15]. The latter (1991) hiked PTO fees by 69 percent and converted the USPTO from a partially user-fee funded agency to an almost fully user-fee funded agency[16]. In the estimation, the 1981 law change did not have any significant effect on the patent numbers.

Section 3.2: Industry Specific Variables

Total, Federal & Company R&D figures are obtained from the Science and Engineering Indicators[17]. The industries were selected based on their SIC codes as seen from the table 2(A). There can be several types of R&D depending on which entity performs and who funds the R&D. For the industry level model we consider three different types of R&D – federal funding for R&D in that industry, the industry's own funding of R&D and the University performed R&D in that industrial field. From figure 4, we can observe that aeronautics R&D peaked in the mid-eighties mainly due to an enormous increase in federal funding. For the other industries, R&D shows an increasing trend mainly due to an increase in company R&D funding. In these sectors federal R&D funding fell after the mid-eighties. A detailed industry specific R&D graph with the funding sources is illustrated in figures 5(a) – (d). Biology is not included in the tables as data for federal R&D funding is unavailable except for 3 years.

For the US data, there are three variants of the spillover term. First it is constructed as an interaction between current company R&D flow and current federal R&D stock. This term is

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application processing cost and 25 percent of maintenance costs." (Report of the Commissioner of Patents and Trademarks, 1981). This led to substantial fee increases in 1981.

[13] This eliminated public funding for the PTO. This was done in order to produce savings in the federal budget deficit. This change started with the "The Omnibus Reconciliation Act of 1990" (Budget Act – Public Law 101-508) and was formalized by the "Patent and Trademark Office Authorization Act of 1991".

[16] The dummy variable used to account for this change, set year 1990=1.

[17] 1989(table 6-3, 6-4 & 6-5), 1993 (4-31. 4-32 & 4-33), 1998(table at-04-20...21) (1971.'73 are interpolated). The figures were originally in millions of current dollars. They have been converted to thousands of 1992 dollars using the GDP implicit price deflator (base year 1992 = 100).

included in the Cobb Douglas model & the spillover model. In the spillover model, it can also be defined as an interaction between current federal R&D stock and current company R&D stock. Third, spillover between academic and company R&D is characterized as an interaction between current university R&D flow and current company R&D flow. For the state model, the two spillover terms are (i) an interaction between federal intramural R&D stock[18] and total industrial R&D stock and (ii) an interaction term between the stock of federally funded industrial R&D and stock of company funded industrial R&D.

The academic R&D funds (university performed R&D) show the total amount of money that the universities and colleges spend in various academic fields[19]. The source of these funds may be federal, company or the university's own resources. Table 2(B) shows the classification of various academic disciplines under the four broad industrial categories. The classification loosely follows the classification by Jaffe (1989). Figure 6(a) and (b) show the amount of R&D dollars that the universities spend in each industrial sector. It shows that expenditure in the biology and the transportation fields have doubled between 1984 and 1994. Electronics, chemicals and aeronautics R&D spending have increased gradually.

The size of an industry size can measured in several ways. The number of firms in the industry, the amount of output or value added and the total employment in the sector can all be

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[18] The stock of R&D is constructed by the following formula:

$RDSTK_{kt} = RD_{kt} + RD_{k,\, t-1}/(1+r) + RD_{k,\, t-2}/(1+r)^2 + \ldots\ldots\ldots\ldots + RD_{k,\, t-m}/(1+r)^m$

Here k denotes the industry and t denotes the time period. M is set to 4, for the US data. It was the largest possible value that allowed me to estimate the federal stock over the entire period 1976-1995. Here r is the depreciation rate of R&D and its value is 0.12 following Nadiri and Purcha's report of the social rate of depreciation of R&D capital (1996).

[19] There was a missing data problem in the academia performed R&D. Some years were not reported by the NSF because of confidentiality reasons. Below I outline the procedure undertaken to solve this problem. Materials Engineering : Roughly the share of this class in total engineering R&D is between 10.5 - 9.3% between the period 1990-1998. Therefore we take the average of this number (9.9%) and extrapolate the R&D figures between 1980-1990. Thus the 'other eng' figures also change. They are constructed as (1980-1990) [Total R&D in that class - sum(all 5 subclasses)]. I use this to back-cast the years 1976-1979. The 'other eng' figures are the difference between total and the sum of the 5 subclasses.

used to proxy size. In this paper, I use three measures alternative measures for size – gross output[20], share of GDP that is attributed to each industry[21] and employment figures. For the state data I use the state share of gross state product coming from private industries.

The R&D composition term, a proxy for how private the industry is in terms of its R&D funding, is defined as follows:

$$COMP_{k,t} = 1 - (FEDSH_{k,t} + \mathrm{URDSH}_{\mathrm{k,\,t}}) \qquad 0 \le COMP_{k,t} \le 1$$

where: FEDSH denotes the share of federal R&D funds in that industry and URDSH denotes the university expenditure in that particular field in any given year. The transportation and chemical industries are the most private in terms of R&D, biology and aeronautics are the least private and electronics falls in between. However, when we consider chemical and biology together, the combined industry, the combined industry shows the same trend as the chemical industry.

The next section outlines the empirical model and results. It has two main parts. The first discusses the result for the US. This part is based on four industries spanning twenty-three years. For the econometric model we collapse chemicals and biology into one industry due to unavailability of data for federal spending on Biology for a large number of years. The second part analyzes the state results. Here the panel comprises the top ten R&D states for 10 years. This estimation does not distinguish between industry groups.

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[20] Annual estimates of gross output by detailed industry for 1976-95 represents the market value of an industry's production, including commodity taxes, and it differs from GPO, which represents an industry's contribution to GDP. The 1977-98 figures are obtained from the Bureau of Economic Analysis data on Industry (The 1976 figures are extrapolated). The aeronautics class contained some extra SIC codes other than 372 and 376. Since there was no precise aeronautics class in the table, I have proxied it by the 'other transportation equipment' class. This increases the size of gross output, but the effect on industry size is minor

[21] This is the traditional ‘value added’ measure.

SECTION 4: ESTIMATION RESULTS

Section 4.1: US Results

This section presents the estimation results obtained from the two models outlined earlier in the paper. The analysis is done at the industry level. The panel consists of 4 industries (Electronics, Chemical/Biology, Transportation, Aeronautics) and 23 years (1976-1998) of data. The general reduced form equation is given below. It relates current patents (P_{kt}) to company R&D stock ($CRDSTK_{kt}$), federal R&D stock or spillover from federal R&D ($FRDSTK_{kt}$), spillover (SPL_{kt}), academic R&D (URD_{kt}), composition ($COMP_{kt-r}$), size ($SIZE_{kt}$), law change (L_t) and deterministic and random pedency times (D^d_t,).

$$\begin{aligned}\ln P_{kt} &= \ln\alpha + \beta_1 \ln CRDSTK_{kt} + \beta_2 \ln FRDSTK_{kt} + \beta_3 \ln SPL_{kt} + \beta_4 \ln URD_{kt} \\ &\quad + \gamma_1 \ln COMP_{kt} + \gamma_2 \ln SIZE_{kt} + \varphi_1 D^{\mathrm{d}}_{\mathrm{t}} + \varphi_2 D^r_t + \delta_k + \varepsilon_{\mathrm{kt}} \qquad (10)\end{aligned}$$

The error component is ε_{kt} (idiosyncratic error) and δ_k is the industry specific fixed effect. I use a fixed effects panel data model to estimate these equations[22]. For the purposes of econometric estimation certain modifications had to be made to the theoretical model. First, year dummies and a trend term were included in the equation to account for macroeconomic changes. Second, there seemed to be a significant change in regime after 1990. To account for this, all the independent variables were interacted with the 1990 law dummy and included in the regression.

The regression contains a logged dependent variable and the independent variables are a mix of logs and levels. The coefficients of the log variables denote the elasticity[23]. The

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[22] The panel was tested for heteroscedasticity and autocorrelation and robustness checks were performed.

[23] For these variables, the marginal effect is given by: δ(patent grant)/δ(independent variable) = (coefficient * patent grant)/independent variable. The marginal effect of the variables that are not in logs (like pendency time) is given by: δ(patent grant)/δ(independent variable) = coefficient * patent grant

interaction terms with the 1990 dummy denote how important each effect is post 1990.The interpretation of the coefficients is as follows: For pre-1990 - the elasticities are denoted by the coefficients of the explanatory variables. For post-1990: the elasticities are denoted by coefficient of variable plus coefficient of interaction term if the interaction term is significant. Otherwise the explanatory variable has the same elasticity pre and post 1990.

The coefficients from the models that contain both level effects and spillover terms need a more detailed analysis. The total effect that any variable has on patenting will then be determined by the combination of effects from the level and interaction term. To get a sense of what this means, we re-write equation (10) as:

$$\ln P_{kt} = \ln \alpha + \beta_1 \ln CRDSTK_{kt} + \beta_2 \ln FRDSTK_{kt} + \beta_3 \ln(FRDSTK_{kt} * CRDFLW_{kt}) \\ + \beta_4 \ln URD_{kt} + \gamma_1 \ln COMP_{kt} + \gamma_2 \ln SIZE_{kt} + \varphi_1 D_{\mathrm{t}}^{\mathrm{d}} + \varphi_2 D_t^r + \delta_k + \varepsilon_{\mathrm{kt}} \qquad (11)$$

where: (FRDSTK* CRDFLW[24]) is the spillover term (SPL_{kt}) from equation (10). For example, to look at the total effect of federal R&D stock on patents[25], we differentiate the above expression with respect to FRDSTK to get:

$$\partial \ln P_{kt} \Big/ \partial \ln FRDSTK_{kt} = \beta_2 + \beta_3 \qquad (12a)$$

or $$\partial P_{kt} \Big/ \partial FRDSTK_{kt} = (\beta_2 + \beta_3) * \left(\frac{P_{kt}}{FRDSTK_{kt}} \right) \qquad (12b)$$

Equation (12b) denotes the total effect that a variable has on patents if both level and spillover terms are included in the regression. The variables P_{kt} and $FRDSTK_{kt}$ are evaluated at their means[26].

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[24] CRDFLW denotes the current company R&D Flow.

Section 4.1.1: CobbDouglas Model

Appendix Table 3(A) outlines the Cobb-Douglas type production function approach to patents. It explains how inputs such as different types of R&D are turned into output, i.e. patents[27]. The model regresses the log of patents on the logs of company R&D stock, federal R&D stock, spillover, academia performed R&D, size, R&D composition and also includes the pendency time and random delays in patent processing. The panel is balanced with 23 years of data for each of the four industrial categories.

We find that company R&D is positive and strongly significant pre-1990. In this period, the elasticity of patents with respect to R&D is 0.807, i.e. for one percent increase in company R&D stock, patents increase by 0.807 percent. Converted to dollar term, this implies that for every dollar increase in company R&D stock, patents are going to increase by 0.2. Post-1990, this elasticity is also positive (0.055), but much smaller. In this period, one million dollar increase in company R&D stock will lead to patents increasing by 0.01. For federal R&D, the pre-1990 the elasticity is positive and significant (0.993) but post-1990, although numerically smaller, it is negative and significant (-0.294). This implies that post-1990, the more federal 'soft funds' an industry can fall back on, the less patents it's going to receive.

The spillover term shows the opposite trend. Pre-1990, federal R&D had a negative spillover on current company R&D flow (-0.972) – there seems to be some evidence of crowding

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[25] Analyzing the total effect of company R&D stock is problematic because the spillover term does not contain the company R&D stock.

[26] Fore pre-1990, the means are taken till 1989 (14 years). For post-1990, the means are from 1990-1998 (9 years).

[27] In recent patent literature, there has been discussion about including lagged versus current R&D in the equation. A common finding is that current R&D is significantly correlated with current patent applications (Jaffe, 1986). A tentative explanation for this high correlation is given by the fact that a huge amount of money is spent on developing a product once the patent application is done. For my production function type approach, linking patent grants to current R&D flow is problematic, as it is not an input for the patents that are being currently issued. Thus, I use stocks of R&D to avoid the problem of playing with lags.

out. However, post-1990, the spillovers are positive (0.478) and significant. The table below provides the total effect that federal R&D stock has on patents for both the time periods. Here β and χ are not the elasticities reported in Appendix Table 3(A), model (i). They are the marginal effects. All R&D variables are in thousands of dollars.

Table 1: Total Effect of Federal R&D Stock on Patenting

	Pre-1990	Post-1990
Marginal Effect of FRDSTK	0.0028	-0.002
Marginal Effect of SPL	-0.0000000003	0.00000000023
Total Effect of FRDSTK on Patents	0.00006	0.0014

Note: These marginal effects are denoted by: δ(patent grant)/δ(independent variable) = (coefficient * patent grant)/independent variable. The total effect is calculated from equation (12b).

From the table above we see that pre-1990, a one million dollar increase in federal R&D stock increases patents by 0.06 and post-1990 it increases patents by 1.4. Thus even though spillover or level effect by itself may be negative, I find that the total effect of federal R&D stock is positive in both periods. Also, post-1990, federal R&D is much more effective than pre-1990.

Current university R&D is not significant pre-1990. In the latter period it has a positive and significant effect on patenting. Universities spend more money in those fields where technological opportunities are the greatest. Thus, this could be interpreted as a variable that reflects the increase in technological opportunity in the industry after 1990. The composition variables are not significant in either period. The size variable is positive and weakly significant (at 17 percent).

The 'pendency time' variable is significant and negative in both periods. The greater the delay in processing a patent, the lesser the number of patents issued. This supports Griliches's claim (Griliches, 1989) that in the short-run patents are very heavily affected by patent office variables. The effect is greater in the post-1990 period. In the earlier period a 1 percent increase in pendency time decreased patents by 0.05 percent, whereas post-1990 the percentage decrease is 0.5, ten times greater than before. The table below translates the coefficients into actual numbers, for e.g., pre-1990, a one-month increase in pendency time decreases patents granted by 348.

Table 2: Marginal Effect of Pendency Time & Random Delay on Patenting

Marginal Effects	Pre-1990	Post-1990
Patent Pendency Time	-346.6	-5448.2
Random Exponential Delay	-76.3	-1870.8

Note: These marginal effects are denoted by: δ(patent grant)/δ(independent variable) = (coefficient* patent grant)/independent variable.

Another interesting observation that emerges from this model is, that not only does the actual pendency time matter, but the random variance in pendency time also has a significant negative effect on patents granted. In fact post-1990, this random delay seems to affect patenting more severely that the earlier period with a one-month random delay decreasing patents by 1871.

Section 4.1.2: Spillover Model

The specifications in Appendix Table 3(B) attempts to directly capture the spillover from federal and academic R&D. This model explores the relationship between company R&D, federal R&D, academic R&D, spillovers and patents. The spillover terms in this model capture the effect of federal R&D stock on both current company R&D stock and flow[28]. By not including the federal R&D term directly, this model attempts to explore such spillovers more

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[28] Spillover 1 = Current Federal RD Stock * Current Company RD Flow, Spillover Term 2 = Current Federal RD Stock * Current Company RD Stock

thoroughly. The academic spillover term captures the spillover from current academic R&D to current company R&D.

From Appendix Table 3(B), I find that current company R&D stock is positive and significant pre-1990 for both specifications. Post-1990, the first model shows a positive effect (0.055) whereas the second specification shows a negative effect (-0.129). However when we consider the total effect that company R&D has on patenting[29], it is positive for both specifications. The federal R&D spillover terms have no effect on patenting in the pre-1990 period in either model. Post-1990, the federal spillover is positive and significant and the coefficients have the same magnitude in the two models. This implies that in both models, a one percent increase in federal R&D spillovers will lead to a 0.16 percent increase in patents. The pendency time and random delay behave exactly like the earlier Cobb-Douglas model and is negative and significant in both periods.

Pre-1990, academic research is positive and significant although the spillover from academic to current company R&D flow is negative suggesting evidence of crowding out. Post-1990, the coefficient of university R&D is negative and significant, ranging from –0.52 to 0.7. This implies that, ceteris paribus academic spending on research dampens patenting activity after 1990. But at the same time, the spillover from academic to company R&D is positive and significant, implying that academic R&D has the power to make company R&D more effective. The total effect is slightly negative in both periods.

From the preceding discussion, the main facts that emerge are (a) company R&D stock has a positive and significant affect on patenting in both the periods under consideration, although the effect is smaller post-1990, (b) the total effect of federal R&D stock on patenting is

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[29] Calculated by equation (12b)

also positive and significant, (c) academic R&D presents a mixed picture with the overall effect being small but negative. A tentative explanation for this may be that most academic R&D goes to basic research that does not yield many patents, (d) the pendency time has a negative and significant effect on patenting as does the random delay. The following section presents the results of the state-share models.

Section 4.2: State Results

The state analysis is done for the top ten R&D states in the US. The panel consists of 10 states and 10 years of data for each of them. Between them, these states accounted for 64 percent of the total US R&D and 62 percent of the issued patents in 1995. In the US data, the main purpose of the models was to explain what drives patenting in the United States. For the state data I ask a slightly different question. Here we are interested in what determines the state share of patents. This model does not distinguish between the various industries[30]. It is interesting to study the state shares because it gives us an idea about the how and why the relative position of the states change. Figure 7 illustrates how industrial R&D shares and patents shares are related. We observe, that compared to the other states, California’s share of patents is much less compared to its share of industrial R&D. It gets about 22% of the US industrial R&D but accounts for only 16% of the patents. The bias is even more pronounced for federal R&D. Compared to this, a state like New York, accounts for roughly 8 percent of the US industrial R&D and patents.

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[30] This is due to severe data constraint. The state-wise breakdown of R&D funding by industry is extremely hard to come by.

The dependent variable in all the state models is the share of patents in each state[31]. All the independent variables are also in shares. In this context one cannot estimate a straight panel data model regressing the patent shares on other independent variables. One needs to incorporate the constraint, that the linear predictions will be bounded between zero and one. A common way to solve this is to apply a logit transformation[32] to the dependent variable. Thus for all the specifications in Appendix Tables 4(A) and (B), the dependent variables are logit transformations of the state share of patents. State fixed effects are incorporated in all models to control state level effects.

Appendix Table 4(A) gives the results of the basic and spillover state-share model. Models (i) – (ii) estimate the basic model. The main difference between the models is the level of disaggregation of the various R&D terms. Model (i) breaks up R&D expenditure by the performing entity, viz. state share of total federally performed intramural[33] R&D, state share of total industry performed R&D and state share of total academia performed R&D. Model (ii) disaggregates R&D by the source of funds. Model (iii) disaggregates both industry performed and academia performed R&D by the source of funds. All the independent variables have been constructed from stocks of R&D.

In all the models, the effect of the state share of federal intramural R&D stock is positive and significant. This implies that the higher the share of federal intramural R&D in a state, the higher its share of patents. Share of total industry performed R&D also has a positive and significant effect. When this is disaggregated (models ii & iii), the estimates show disparate

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[31] State Share of Patent = Total number of utility patents granted to that state/Total number of US utility patents. The state of the first inventor is allotted the patents in case of multiple inventors.

[32] Let ‘s’ be the state share of patents in a year (dependent variable). The logit transformed dependent variable will then be: log (s/(1-s)). The marginal effects are given by: $\delta s/\delta x = \beta e^{\beta x}(1-s)/(1+e^{\beta x})$ where ‘x’ is an independent variable in levels and $\delta s/\delta x = \beta x^{(\beta-1)}(1-s)/(1+x^{\beta})$, when x’ is an independent variable in logs.

[33] Federal intramural R&D implies federally performed and federally funded R&D expenditures.

effect of funding source on patents. The share of company funded industrial R&D in the state has a strong positive on state patent shares, whereas the federally funded industrial R&D has no effect on the state share of patents. This seems to hint at the fact that federally funds may be directed at basic research activities that do not yield many patents. The company funds on the other hand, may be directed more towards the development phase of a product or applied research that yields more patents. Company funded academic R&D has no effect of patent shares where as federally funded academic R&D seems to depress patent shares (model iii). This indicates that federal grants to academic institutions alleviate the need for universities to patent aggressively. With federal funding universities can focus more on basic research that do not yield many patents and thus the negative effect of federal funds on patenting. The state share of industrial GSP is insignificant in all the models.

The next set of results (Models (vi) and (v)) investigates the role of spillovers. Three alternative specifications of spillovers are outlined. Spillover term 1 is designed to capture the spillover effects from federal intramural research to industry-performed research – for e.g. the spillover from NASA research funds to the global positioning system research by the electronics/computer industry. It is the interaction between the stock[34] of federal intramural funds and the stock of total industry performed R&D. Spillover term 2 denotes the spillovers between federally funded and company funded industrial research. It is the interaction between the stock of federal funds for industry R&D and the stock of company funds for industry R&D. Spillover term 3 captures a specific aspect of the spillovers from the academia to the industry, viz. the spillovers that occur between industry sponsored academic research and industry research. It is the interaction between the stocks of industry funds for academia performed R&D

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[34] Stocks are constructed as in the previous US model with a 12 percent discount rate.

and the stock of total industry performed R&D. In the estimation equation, these spillover terms have been turned to shares, because we are interested in knowing what happens to patent share when the share of spillovers in the state increase[35].

The level results are the same as in the basic model. All the alternative specifications show that the state share of federal funds for intramural R&D performers and industry performed R&D have a strong positive effect on patent shares. When industry R&D is disaggregated by funding source, we find that company funds, rather than federal funds are a source of patents. In model (i) we find that federal intramural R&D that has a negative spillover (spillover term 1), whereas federal funds for industrial R&D have a positive spillover (spillover term 2). In the basic model earlier, academia performed research seemed to have no effect on patent shares. In the spillover model we find that even though the level effects are negligible, academic R&D that is funded by the industry has a strong positive spillover of industrial R&D.

This insignificant level coefficient of the share of federal funds for industrial R&D coupled with the positive spillover term implies that, although not effective by itself, federal funds to industry work by enhancing the productivity of company funded R&D. A good example of this would be in the electricity industry. After deregulation, EPRI (the collaborative R&D organization) is using the ‘public’ part of the research money to conduct the earlier part of the research when results are still uncertain. Once the project seems commercially viable, the utility companies step in with their funding. Thus spillovers from federal R&D share increase patent share through subsidizing commercial research. A similar explanation can be forwarded for industry funded academic R&D. However, the negative effect of federal intramural R&D on total industry performed R&D attests to the fact that large federal intramural expenditures have a

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[35] Therefore I use: State share of spillover = Total state spillover/Total US spillover.

tendency to crowd out industrial R&D, the main source of patents, and thus depress the patent numbers.

An important thing that should be kept in mind while drawing conclusions about state level results is the dominance of California. It accounts for 16 percent o the US patents and 20 percent of total US R&D funds. Of the top 10 R&D states, it accounts for 27 percent of the patents, 32 percent of the total R&D and 41 percent of the total federal R&D. For this table we estimate an error components model to separate out the California effect and to allow us to introduce a California dummy. The Hausman test fails to reject the random effects specification. We can conclude that there is a significant California effect. In the basic R&D model if we introduce a California specific dummy (Appendix Table 4(B)) it turns out to be significant and negative. Deleting California from the sample or introducing the dummy makes all the positive coefficients larger in magnitude, although there is no fundamental change in the results.

SECTION 5: POLICY IMPLICATIONS & CONCLUSIONS

Based on the empirical findings of the model some preliminary policy recommendations can be advanced. First, any government policy that seeks to increase patents through direct federal funding of industrial research or by the way of spillovers will be more effective post-1990 than the period before it. Second, company R&D is a significant determinant of patents, although post-1990, its effect is becoming less elastic – maybe hinting at the exhaustion of inventive opportunity. Third, university performed R&D seems to dampen patenting and a more through investigation is needed before any conclusions can be drawn. Fourth, random and non-random patent office delay severely hampers patenting. Thus, the government should not appropriate any resources for the USPTO and divert it elsewhere. Decreasing resources at the patent office will adversely affect the number of patent issued. The patent office should aim at reducing its ‘pendency time’. Fifth, random fluctuations in the ‘pendency time’ should be avoided as this has a negative effect on patents. The USPTO should announce the expected ‘pendency time’ at the beginning of the year and maintain that through the year. This would reduce the uncertainly of the timing of patent issue and would help the companies plan better. Sixth, from the state models we see that not only is the performed of R&D important, but the funding source also determines what effect the R&D expenditure will have on patenting. Thus the empirical results point to an important role for the government.

As economists delve more into the areas of technology, invention and productivity, patents will remain one of the main yardsticks by which they measure the innovative capacity of a society of industry. In this context one needs to understand how various forces interact to generate a patent. This paper’s contribution is to show how various factors, some of which have little to do with an entity’s inventive capacity, influence patents. It illustrates how types of R&D expenditure, structure of the market and patent office resources determine the domestic patent numbers. Another contribution of the paper is to break down R&D by performing and funding agency and study their differing effects on patenting. It illustrates that in the short run, a decline or increase in the number of patents has more to do with fluctuations in the above variables than with any fundamental change in inventive opportunity. Further work needs to be done in this area to understand the patenting process in depth and make patents better yardsticks of the innovation capacity of a society.

Appendix Table 1(A)

Summary Of Main Variables For Industry Level Analysis

Variable	Mean	S.D.	Min	Max		Variable	Mean	S.D.	Min	Max
Log (Patents Granted to US Residents)	7.92	1.82	4.51	10.36		Log(Spill - Past Fed RD Flow on Curr Com RD Flow)	30.37	1.65	25.16	32.62
Log (Total R&D Performed in Industrial Field)	16.36	0.47	15.35	17.20		Log(Spill - Past Fed RD Stk on Curr Com RD Flow)	31.50	1.74	26.04	33.83
Log (Com Funding for Industrial R&D)	15.82	0.40	14.97	16.89		Log(Spill - Curr Fed RD Stk on Curr Com RD Stk)	32.68	1.75	27.16	35.08
Log (Stk Com Funding for Industrial R&D)	17.00	0.39	16.20	18.00		Log(Composition)	-0.54	0.45	-1.52	-0.11
Log (Fed Funding for Industrial R&D)	14.39	1.82	7.90	16.92		Log(Size)	6.96	0.37	6.31	7.58
Log (Stock Fed Funding for Industrial R&D)	15.68	1.74	9.81	18.08		Pendency Time	20.99	2.22	18.20	25.50
Log(University Performed R&D in Industry Field)	13.26	1.24	10.99	16.38		Random Delay (Exponenrial, s.d.=4mths)	3.39	3.57	0.03	13.95

Appendix Table 1(B)

Summary Of Main Variables For State Level Analysis

Variable	Mean	Std. Dev.	Min	Max
State Share of Patents	0.064	0.036	0.013	0.197
State Share of Federal Intramural R&D Stock	0.030	0.033	0.005	0.143
State Share of Total Federal R&D Stock	0.051	0.060	0.010	0.247
State Share of Total Industry Performed R&D	0.070	0.052	0.023	0.225
State Share of Industry Performed Federally Funded R&D	0.070	0.102	0.003	0.435
State Share of Industry Performed Federally Funded R&D	0.070	0.039	0.009	0.212
State Share of Total Academia Performed R&D	0.016	0.011	0.004	0.066
State Share of Academia Performed Federally Funded R&D	0.054	0.037	0.012	0.144
State Share of Academia Performed Industry Funded R&D	0.045	0.024	0.007	0.095
State Share of Private Industrial GSP	0.055	0.032	0.017	0.140
State Share of Spillover 1(Stock of Fed Intramural RD to Stock of Total Industry Performed R&D)	0.003	0.007	0.0002	0.032
State Share of Spillover 2(Stock of Fed RD Funds to Industry to Stock of Company Funds for Industry)	0.008	0.016	0.0002	0.067
State Share of Spillover 3 (Stock of Industry Funds for Univ. to Total Stock of Industry Performed R&D)	0.004	0.004	0.0002	0.021

APPENDIX TABLE 2(A)

MATCHING UP INDUSTRIAL CLASSIFICATIONS AND SIC CODES

Industry	SIC Code	Sub-Classes
Electronics	36, 357, 393	Radio and TV receiving equipment, Communication equipment, Electronics components, Other electrical equipment, Computers Musical Instruments
Chemical	28 (except 283), 348	Industrial chemicals, Other chemicals, Explosives
Biology	283, 384, 385	Drugs and medicine, Surgical Instruments, Opthalmic goods
Transportation	37(except 372 & 376)	Motor vehicles and equipment, Other transportation equipment.
Aeronautics	372, 376	Aircrafts and missiles.

APPENDIX TABLE 2(B)

MATCHING UP INDUSTRIAL CLASSIFICATION AND ACADEMIC DISCIPLINES

Industry	Academic Discipline
Electronics	Electrical Engineering, Astronomy, Physics, Other Physical sciences, Math and Computers.
Chemical	Chemical Engineering, Materials Engineering, Chemistry.
Biology	Life Sciences
Transportation	There was no transportation category. So it was proxied by the Mechanical Engineering sub-class.
Aeronautics	Aerospace Engineering

APPENDIX TABLE 3(A)

COBB DOUGLAS MODEL WITH RANDOM DELAY

Fixed Effects Model

(standard errors in parentheses)

Dependent Variable	**Log(Patents Issued)**
Independent Variable	**(i)**
Log (Company R&D Stock for Industrial R&D)	0.807 (0.360) **
Log (Federal R&D Stock for Industrial R&D)	0.993 (0.264) **
Log (Spillover Term)	-0.972 (0.258) **
Log(University Performed R&D in Industry Field)	-0.311 (0.292)
Log(Composition Term)	0.291 (0.249)
Log(Size)	0.304 (0.220)
Pendency Time	-0.050 (0.012) **
Random Delay in Pat Process:Exp Distr. (s.d.=4 mths.)	-0.011 (0.006) **
Log (Com. R&D Stock for Industrial R&D) * Dum90	-0.752 (0.483) **
Log (Fed. R&D Stock for Industrial R&D) * Dum90	-1.287 (0.378) **
Log (Spillover Term)* Dum90	1.500 (0.389) **
Log(Univ. Performed R&D in Industry Field) * Dum90	0.092 (0.060) *
Log(Composition Term) * Dum90	-0.087 (0.175)
Log(Size)* Dum90	-0.389 (0.330)
Pendency Time * Dum90	-0.448 (0.200) **
Random Delay in Pat Process:Exp. Distri. (s.d.=4 mths.) * Dum90	-0.160 (0.049) **
Constant	-35.79 (43.20)
R-Squared	0.345

Note: The estimation technique is a fixed effects panel data model. The panel is balanced with 23 observations per group. The sample size is 92.The period under consideration is 1976-1998. Both models contain year dummies. The interaction terms denote how important each effect is post 1990. The interpretation of the coefficients is as follows: For pre-1990 - the marginal effects are denoted by the coefficients of the explanatory variables. For post-1990: the marginal effects are denoted by coefficient of variable + coefficient of interaction term if the interaction term is significant. Otherwise the explanatory variable has the same marginal effect pre and post 1990. The models also include a time trend that is insignificant. The exponential distribution is given by $f(D_r)= (1/b)e^{(-Tr/b)}$ and s.d. = b.. All dollar terms are in thousands of 1992 dollars. The spillover term is constructed by interacting the federal R&D stock with current company R&D flow. The composition term shows how private the industry is. ‘**’ denotes significance at 5 percent and ‘*’ denotes significance at 10 percent.

APPENDIX TABLE 3(B)

SPILLOVER MODEL WITH RANDOM DELAY

Fixed Effects Model
(standard errors in parentheses)

Dependent Variable	**Log(Patents Issued)**	
Independent Variable	**(i)**	**(ii)**
Log (Company R&D Stock for Industrial R&D)	0.807 (0.360) **	0.786 (0.361) **
Log (Spillover Term 1)	0.021 (0.057)	-
Log (Spillover Term 2)	-	0.021 (0.062)
Log(University Performed R&D in Industry Field)	0.682 (0.343) **	0.661 (0.360) *
Spillover From Academic to Industry R&D	-0.993 (0.264) **	-1.005 (0.284) **
Log(Composition Term)	0.291 (0.249)	0.291 (0.248)
Log(Size)	0.304 (0.229)	0.303 (0.230)
Pendency Time	-0.050 (0.012) **	-0.050 (0.012) **
Random Delay in Pat Process:Exp Distr. (s.d.=4 mths.)	-0.011 (0.006) **	-0.011 (0.006) **
Log (Com. R&D Stock for Industrial R&D) * Dum90	-0.752 (0.483) **	-0.915 (0.485) **
Log (Spillover Term1)* Dum90	0.163 (0.062) **	-
Log (Spillover Term2)* Dum90	-	0.163 (0.062) **
Log(Univ. Performed R&D in Industry Field) * Dum90	-1.196 (0.384) **	-1.358 (0.387) **
Spillover From Academic to Industry R&D* Dum90	1.288 (0.378) **	1.450 (0.389) **
Log(Composition Term) * Dum90	-0.087 (0.174)	-0.087 (0.175)
Log(Size)* Dum90	-0.389 (0.330)	-0.389 (0.330)
Pendency Time * Dum90	-0.448 (0.200) **	-0.448 (0.200) **
Random Delay in Pat Process:Exp. Distri. (s.d.=4 mths.) * Dum90	-0.160 (0.049) **	-0.160 (0.049) **
Constant	-35.79 (43.20)	-35.79 (43.20)
R-Squared	0.345	0.345

Note: The estimation technique is a fixed effects panel data model. The panel is balanced with 23 observations per group. The sample size is 92.The period under consideration is 1976-1998. Both models contain year dummies. The interaction terms denote how important each effect is post 1990. The interpretation is similar to the earlier table. The models also include a time trend that is insignificant. The exponential distribution is given by $f(D_r)= (1/b)e^{(-Tr/b)}$ and s.d. = b.. All dollar terms are in thousands of 1992 dollars. The spillover term is constructed as follows: Spillover 1 = federal R&D stock * current company R&D flow, Spillover 2 = federal R&D stock * company R&D stock. The composition term shows how private the industry is. ‘**’ denotes significance at 5 percent and ‘*’ denotes significance at 10 percent.

APPENDIX TABLE 4(A)

STATE SHARE MODEL

Dependent Variable is the Logit Transformed Share of Patents
Fixed Effects Estimation
(standard errors in parenthesis)

	Basic Model			**Spillover Model**	
	(i)	**(ii)**	**(iii)**	**(iv)**	**(v)**
State Share of Total Federal Intramural R&D Stock	3.976 ** (1.945)	7.139 ** (1.1915)	6.259 ** (1.840)	17.227 ** (2.960)	4.530 ** (1.978)
State Share of Total Industry Performed R&D Stock	10.054 ** (3.006)	-	-	7.096 ** (2.675)	6.642 ** (3.109)
State Share of Industry Performed Federally Funded R&D Stock	-	-0.559 (0.854)	-0.234 (0.812)		
State Share of Industry Performed Industry Funded R&D Stock	-	5.457 ** (1.141)	6.547 ** (1.191)		
State Share of Total Academia Performed R&D Stock	-0.392 (2.458)	-0.240 (2.251)	-	-0.042 (2.420)	3.703 (2.300)
State Share of Academia Performed Industry Funded R&D Stock	-	-	-0.007 (2.079)		
State Share of Academia Performed Industry Funded R&D Stock	-	-	-2.435 ** (1.192)		
State Share of Spillover Term 1				-109.65 ** (19.567)	-
State Share of Spillover Term 2				12.070 ** (4.635)	-0.026 (6.405)
State Share of Spillover Term 3				-	28.385 ** (13.776)
State Share of Private Industrial GSP	3.099 (4.400)	-1.502 (3.747)	-0.602 (3.816)	6.575 * (3.897)	-2.045 (4.566)
Constant	-3.816 ** (0.299)	-3.278 ** (0.208)	-3.291 ** (0.209)	-3.900 ** (0.269)	-3.462 ** (0.309)
Overall R-Square	0.616	0.561	0.557	0.771	0.552

Note: The panel consists of 10 states and 10 years for each state. The range is from 1981-1998 with data for alternate years starting from 1981. The last 2 years of data are from consecutive years – 1997 and 1998. The sample size to Model (i) is 100 and for (ii)-(v) it is 97.All variables are in terms of shares, i.e. the state magnitude as a share of the US magnitude. The coefficients are not the marginal effects as the dependent variable is a logit transformation. Spillover Term 1 = Stock of federal intramural funds interacted with Stock of Total Industry Performed R&D. Spillover Term 2 = Stock of federal funds for industry R&D interacted with Stock of company funds for industry R&D. Spillover Term 3 = Stock of industry funds for academia performed R&D interacted with total industry performed R&D Stock. '**' denotes significance at 5% and '*' denotes significance at 10%.

APPENDIX TABLE 4(B)

STATE SHARE MODEL: CALIFORNIA EFFECT

Dependent Variable is the Share of Patents in each State
Random Effects Estimation
(standard errors in parenthesis)

	With CA	**Without CA**	**CA Dummy**
State Share of Total Federal Intramural R&D Stock	3.296 ** (1.836)	11.488 ** (2.066)	4.40 ** (1.761)
State Share of Total Industry Performed R&D Stock	6.706 ** (2.195)	9.259 ** (2.337)	10.674 ** (2.517)
State Share of Total Academia Performed R&D Stock	-0.909 (2.352)	0.005 (2.660)	0.595 (2.402)
State Share of Private Industrial GSP	4.469 (3.427)	12.645 ** (2.839)	9.809 ** (2.727)
California Dummy	-	-	-1.706 ** (0.499)
Constant	-3.628 ** (0.206)	-4.272 ** (0.176)	-4.075 ** (0.183)
$\sigma^2_u / (\sigma^2_\varepsilon+\sigma^2_u)$	0.896	0.759	0.700
Overall R-Square	0.649	0.850	0.838
Sample Size	100	90	100

Note:. The panel consists of 10 states and 10 years for each state. The range is from 1981-1998 with data for alternate years starting from 1981. The last 2 years of data are from consecutive years – 1997 and 1998. Everything is in terms of shares, i.e. the state magnitude as a percentage of the US magnitude. The coefficients are not the marginal effects as the dependent variable is a logit transformation. $\sigma^2_u / (\sigma^2_\varepsilon+\sigma^2_u)$ shows the share of variance due to random effects. The Hausman test could not reject the hypothesis of ‘no systematic difference between coefficients for the fixed versus random effects model’. ‘**’ denotes significance at 5% and ‘*’ denotes significance at 10% level.

APPENDIX FIGURES

FIGURE 1(A): TOTAL PATENT APPLICATION AND PATENT ISSUE TO US RESIDENTS (US TOTALS)

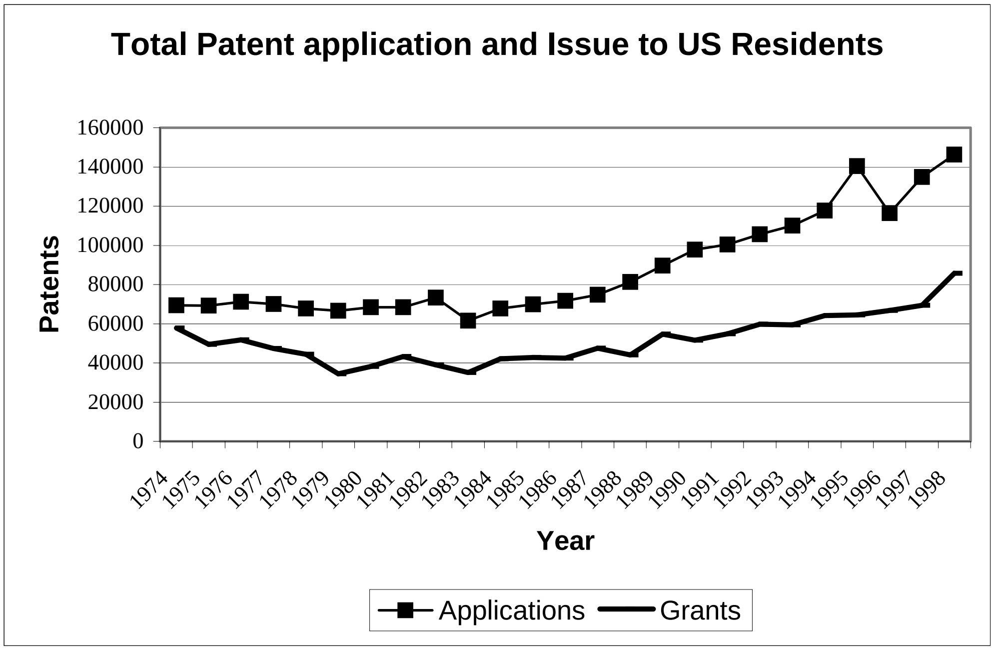


FIGURE 1(B): TOTAL NUMBER OF PATENTS IN EACH STATE

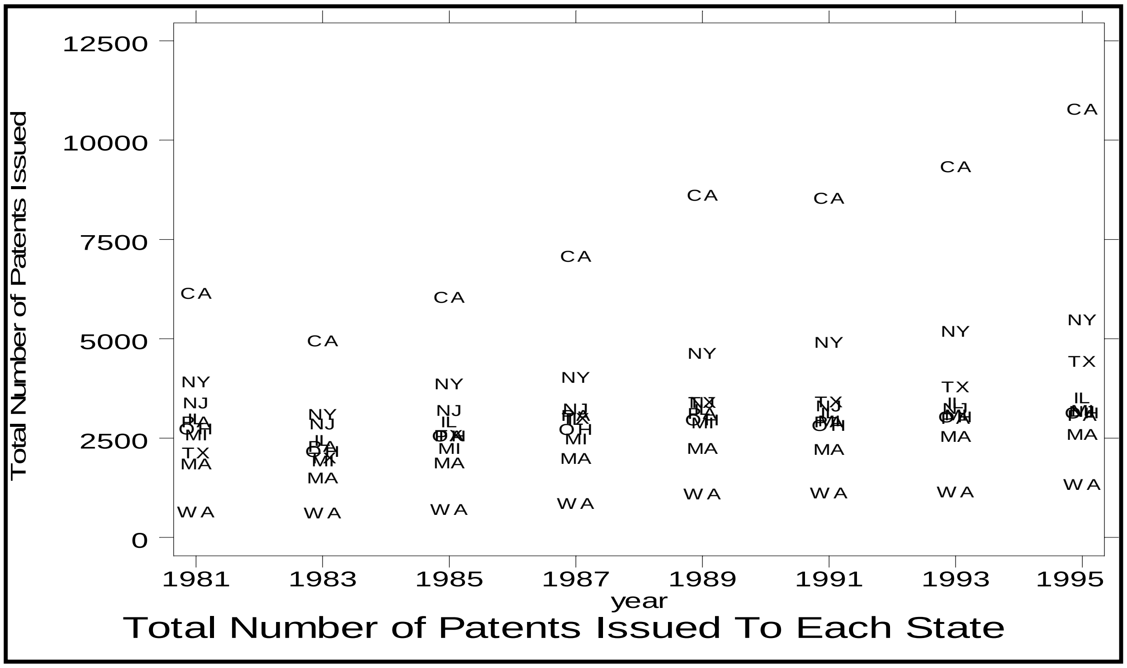


FIGURE 2: PATENTS ISSUED IN FIVE INDUSTRIES: US DATA

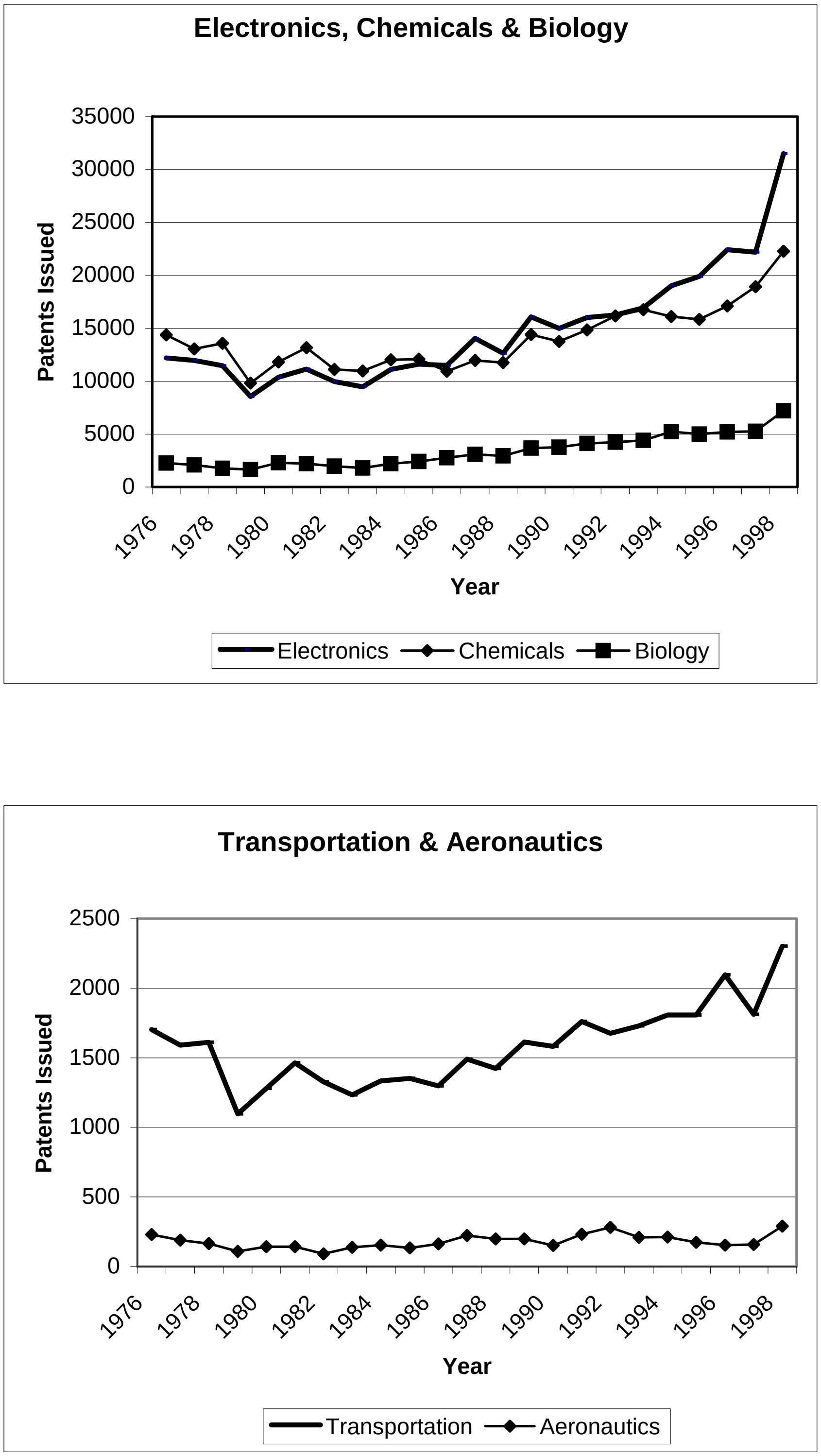


FIGURE 3: PATENT OFFICE EMPLOYMENT & PENDENCY TIME

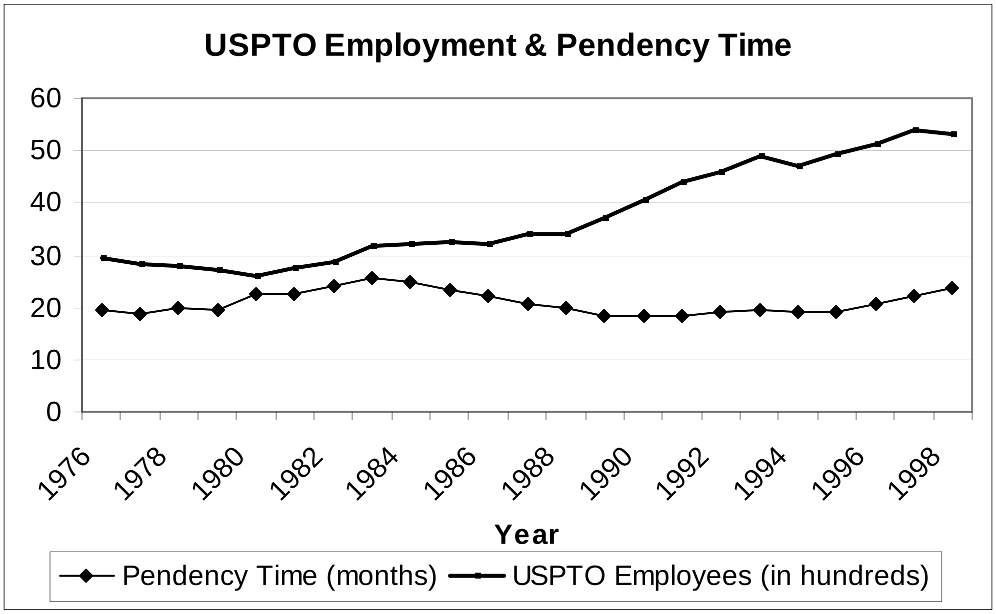


FIGURE 4: TOTAL INDUSTRY PERFORMED R&D EXPENDITURES, US DATA

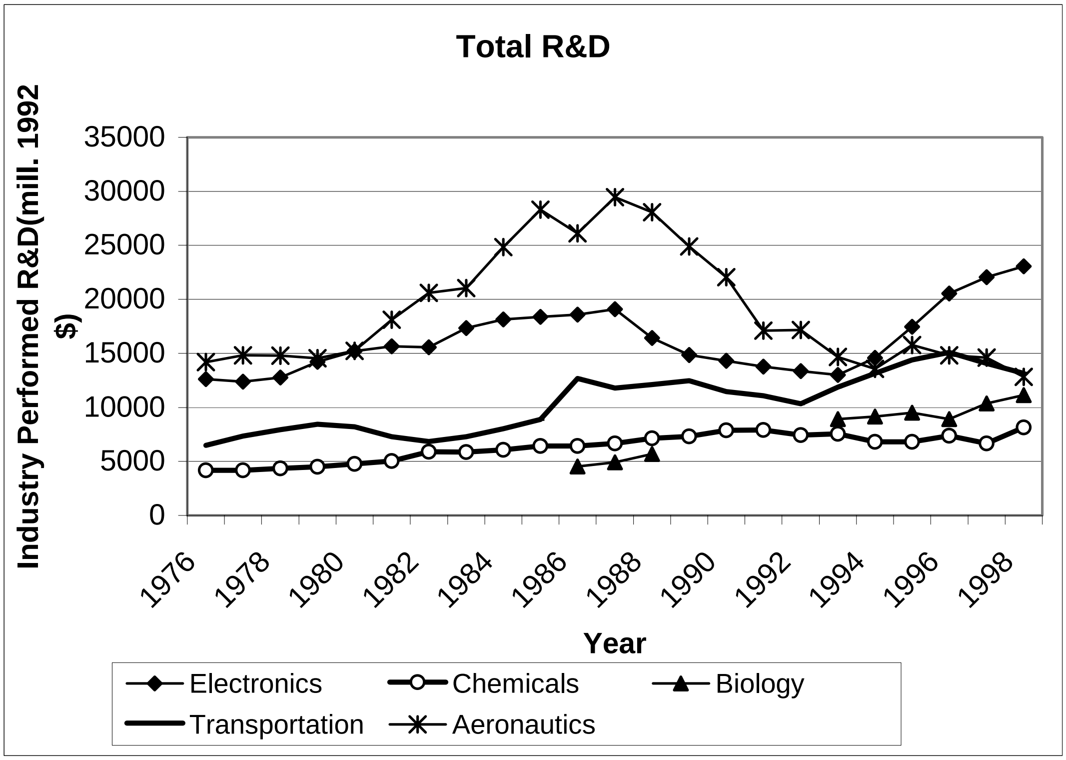
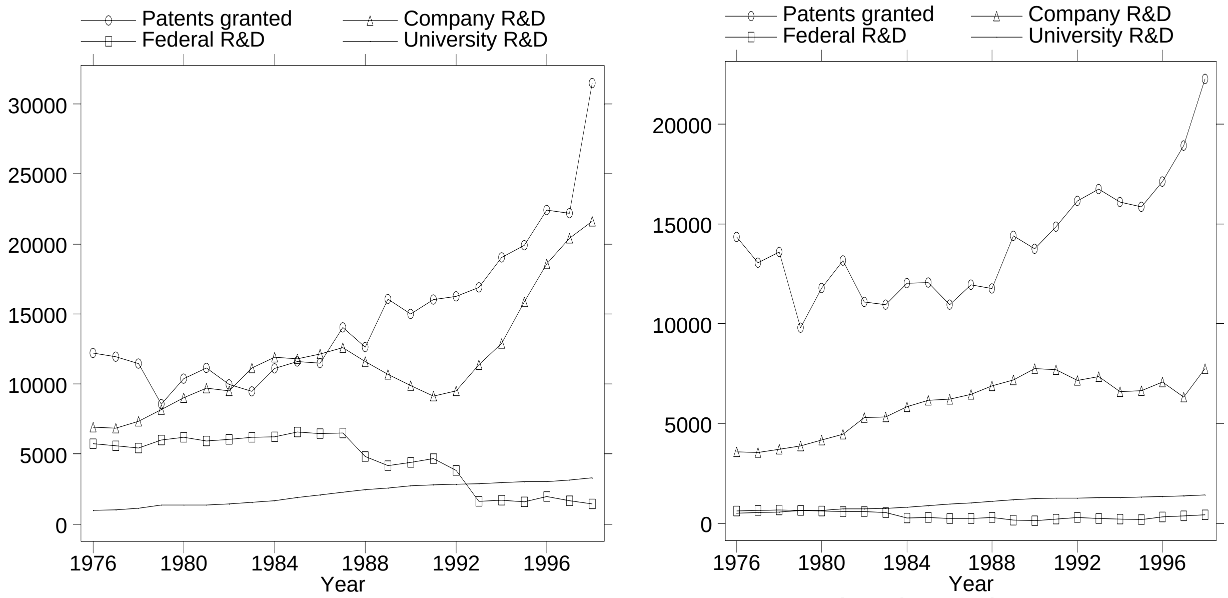
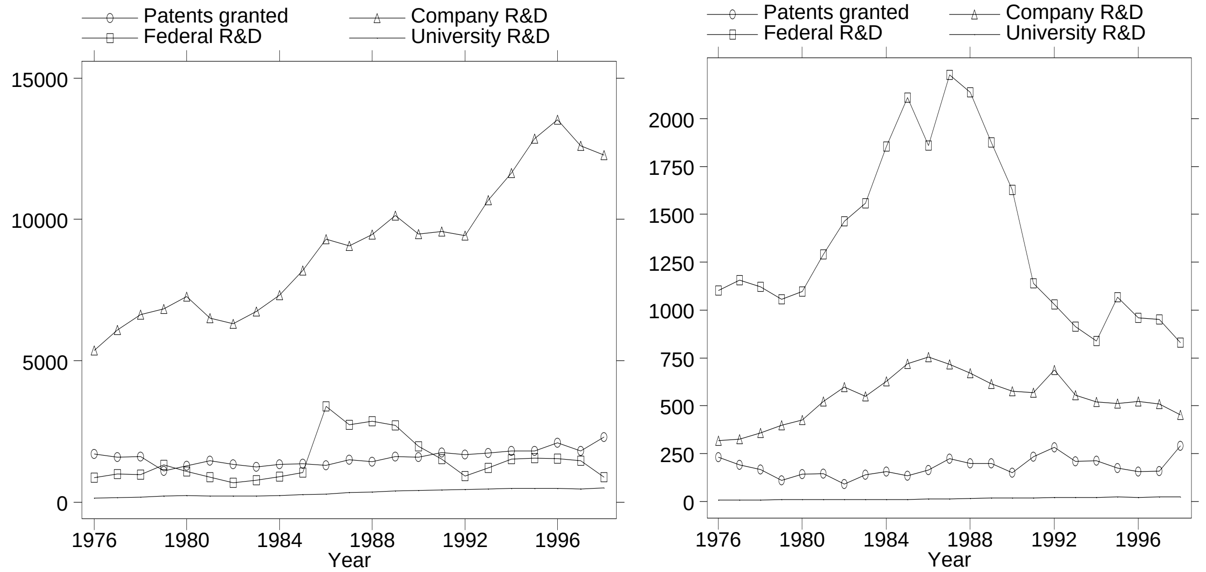


FIGURE 5: US R&D EXPENDITURE AND PATENTS IN THE FOUR SELECTED INDUSTRIES



Electronics Industry

Chemical Industry



Transportation Industry

Aeronautics Industry

Note: In all the industries except Aeronautics, the R&D variable is in millions of 1992 dollars. For the aeronautics industry, the R&D variable is in tens of millions of 1992 dollars.

FIGURE 6: UNIVERSITY AND COLLEGE R&D EXPENDITURES, US DATA

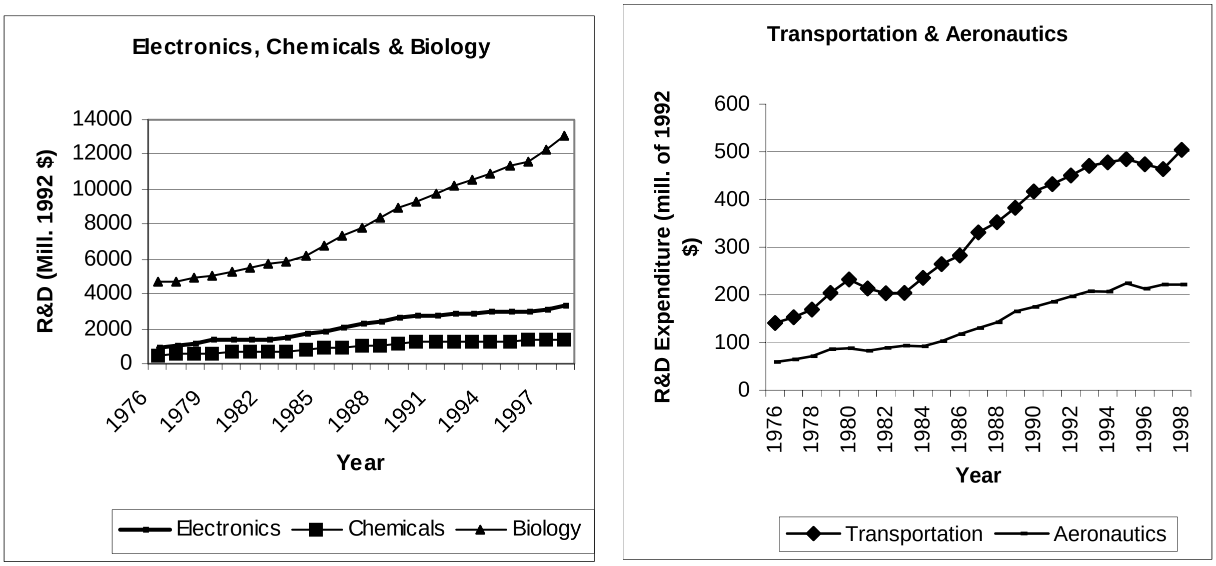
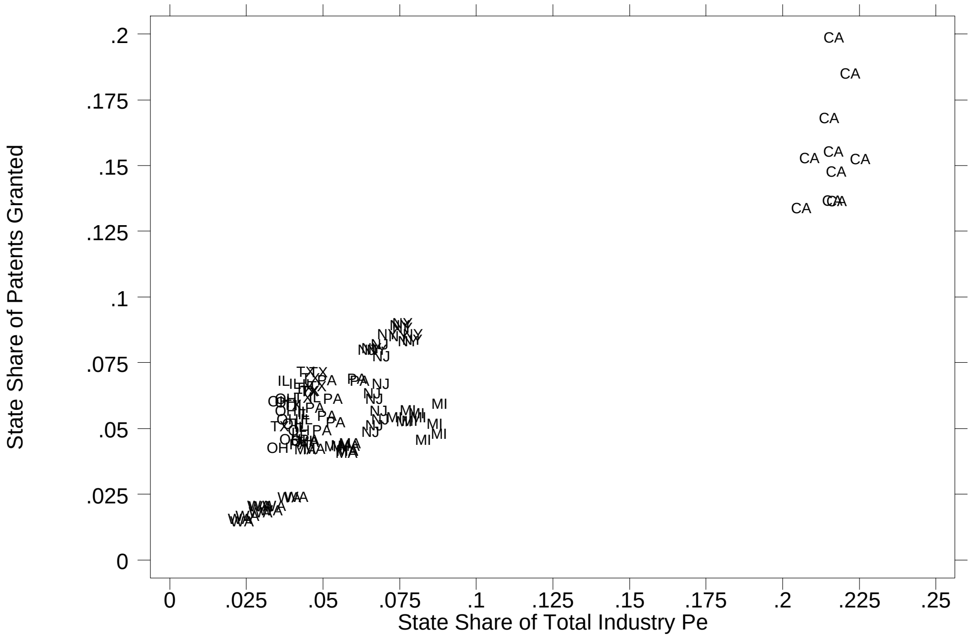


FIGURE 7

STATE SHARE OF PATENTS V/S STATE SHARE OF INDUSTRIAL R&D



State Share of Total Industry Performed R&D

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