STRONGER PROTECTION OR TECHNOLOGICAL REVOLUTION: WHAT IS BEHIND THE RECENT SURGE IN PATENTING?

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Stronger Protection or Technological Revolution:
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ABSTRACT

We investigate the cause of an unprecedented surge of U.S. patenting over the past decade. Conventional wisdom points to the establishment of the Court of Appeals of the Federal Circuit by Congress in 1982. We examine whether this institutional change, which has benefitted patent holders, explains the burst in U.S. patenting. Using both international and domestic data on patent applications and awards, we conclude that the evidence is not favorable to the conventional view. Instead, it appears that the jump in patenting reflects an increase in U.S. innovation spurred by changes in the management of research.

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1 Introduction

This paper is motivated by the unprecedented recent jump in patenting in the United States. Applications for U.S. patents by U.S. inventors have risen more since 1985 (in either absolute or percentage terms) than in any other decade this century (Figure 1).[1] From the turn of the century until the mid 1980s, applications fluctuated within a band of between 40 and 80 thousand per year, but in 1995 U.S. inventors applied for over 120 thousand patents on their inventions. The number of patents actually *issued* by the U.S. patent office to U.S. inventors has risen a bit less dramatically (Figure 1), but this is to be expected given the time required to examine applications. The patents issued series reached an all-time high in 1996.

The central hypothesis we test is that the jump in patenting reflects an increase in the propensity to patent inventions, driven by changes in the legal environment for patent holders. The upturn in patenting in the United States followed the most dramatic shift in domestic patent policy over the past 150 years. In 1982, a specialized appellate court to hear patent cases, the Court of Appeals of the Federal Circuit, was established by Congress. (Previously, the cases had been heard by quite inconsistent appeals courts in each district.) The new court's decisions have been widely regarded as being "pro patent" (Merges, 1992): i.e., they have broadened the rights of patentees. We label this view the *friendly court hypothesis* of why patenting has surged.

We contrast this hypothesis with two alternative explanations. The first of these is that the jump in patenting reflects a widening set of technological opportunities. In particular, the past two decades have seen an explosion of new firm formation and innovation in the high technology sector, particularly in the biotechnology, information technology, and software industries. The specialized financial intermediaries that are critical in funding such firms, venture capital organizations, have grown by more than ten-fold (in inflation-adjusted dollars) during this period. The jump in patenting may indicate a burgeoning technological revolution, as hypothesized by Greenwood and Yorukoglu (1997). Alternatively, applications of information technology to the discovery process itself may have substantially increased the productivity of R&D (Arora and Gambardella, 1994; Brody, 1995). A third possibility is that changes in the management of R&D facilities in the past decade—in particular a shift to more applied activities—has raised the yield of patentable discoveries, as articulated in Rosenbloom and Spencer (1996). We lump together this set of ideas as the *fertile technology hypothesis* of why patenting has surged.[2]

A second alternative view is a variant of the friendly court hypothesis. It is suggested by the voluminous political economy literature on interactions between firms and regulators. This body of work documents how entrenched incumbents can use regulatory or administrative changes to enhance their position relative to entrants. In particular, if the shift to stronger patent protection in the United States was not an exogenous event, but a response to the lobbying of a certain set of parties, we would expect these groups to gain more. One implication is that the entities that benefited the most were domestic firms: numerous accounts, such as Takenaka (1994), suggest that many overseas firms believe the U.S. patent system has become less friendly to foreign patentees. A second implication is that the strengthening of patent protection may have benefited only a *subset* of domestic firms. In particular, the firms most active in pushing for these reforms appear to have been larger firms with established patent departments (Adelman, 1987; Lerner, 1995). Were these firms able to alter the patent system in their favor, they might respond by patenting more aggressively. [Evidence for this hypothesis is presented in Lerner (1995) and Lanjouw and Lerner (1996).] We term this suggestion the *regulatory capture hypothesis.*

Why do we care why U.S. patenting has jumped? First, if the increase in patenting is due to legal changes, then it raises important issues for public policy. A long series.of economic models (reviewed, for instance, in Tirole, 1989) have argued that the design of patents involves careful trade-offs. Economists have urged policy-makers to balance the *ex ante* incentives to pursue research that patent protection offers with the monopolies created by patent protection. If patent protection has been substantially broadened–as suggested by the friendly court hypothesis–a careful analysis of the resulting impact on social welfare is in order. Second, patents have long been used as an indicator of innovative activity and technological change in both micro and macro-economic studies, as reviewed in Griliches (1990). Recently Kortum (1997) has argued that the relatively constancy of U.S. domestic patenting prior to the late 1980s is consistent with the behavior of other indicators of technological change, in particular constant productivity growth and rising research effort. From that perspective, a jump in research productivity–as suggested by the fertile technology hypothesis–signals accelerating technological change and a favorable outlook for U.S. productivity growth as more inventions are adopted.

The goal of the paper is to see if the data are more consistent with the friendly court hypothesis or the two alternative views. We examine evidence from several sources: aggregate statistics on international patent applications, detailed statistics by technology class and assignee of patents granted in the United States, and aggregate measures of research effort. The international patent data allow us to differentiate between the United States as a *destination* for patents and the United States as a *source* of patentable inventions. We can also decompose the rise in patenting by technology and patentee. Is the rise in patenting concentrated in a few dynamic technologies or experienced widely across most technologies? Is the increase confined to the firms which have been most active in patenting in the past, or is it also occurring among less established patentees?

The friendly court hypothesis suggests that the upturn in patenting should be driven by changes in the United States as a destination. Both U.S. and foreign firms should find patenting in the United States increasingly attractive, both absolutely and relative to patenting elsewhere. Furthermore, the increase in patenting by firms should be relatively uniform, both across technologies and patentees.

The alternative views suggest other patterns. The fertile technology hypothesis suggests that the increase in patenting by U.S. inventors is due to a surge in discovery and innovation. In this case, either the United States should increase as a source of patenting (if discoveries are being disproportionately made here) or there should be a general increase in patenting activity world-wide (if the technological revolution is more widespread). If the surge in innovation is driven by breakthroughs in specific technologies then we should see an uneven increase in patenting across technologies. If the increase in technological activity is largely due to an improvement in the technology or the management of the discovery process, however, this pattern may not appear. In neither case would the United States appear to be a more popular destination. The regulatory capture view suggests that we should see the changes in U.S. patent law disproportionately taken advantage of by domestic patentees (i.e., we should see a surge in U.S. patents, but only by domestic patentees) and particularly by firms which were already major patentees.

By a process of elimination, we tentatively conclude that the evidence from patent data is most consistent with a variant of the fertile technology view. Contrary to the suggestion of the friendly court hypothesis, the United States has not increased as a destination for patents. Rather, the increase in patent activity here seems to be a consequence of a world-wide increase, along with a recent improvement in the relative performance of U.S. inventors. While this pattern might also be consistent with the regulatory capture view, the pattern of patenting by firm size is not. In particular, the increase in patenting appears to be uniformly distributed, with the relative share of patents by new and small patentees actually increasing more dramatically than in the past. Less consistent with the first variant of the fertile technology hypothesis. is the evidence by technology class: we see a more general increase in patenting, rather than a surge in particular activities. Eliminating biotechnology and software patents has little impact on the overall increase in patenting. This suggests that much of the increase may be due to improvements in the management or automation of the innovation process itself.

We subject our tentative conclusion–that a broad increase in research productivity underlies the increase in patenting–to a final test based on the recent behavior of U.S. research effort. Using a model of the determinants of research and patenting, we show that a permanent rise in research productivity should lead to a transitory increase in research intensity (e.g. the fraction of income spent on research). The data are not fully consistent with this prediction, as research intensity has leveled in the 1990s while patenting has continued to rise. We therefore temper our conclusion by acknowledging that changes in the management of research–involving a reallocation of efforts to more applied activities and a consequent increase in patentable discoveries–may have had costs as well benefits. The net impact on research productivity was potentially modest.

The plan of the paper is as follows. In the second section, we review the institutional changes that have taken place in the patent system of the United States. We then analyze in the third section the aggregate patterns of international patenting. Section 4 examines differences in patenting across different technologies, while section 5 presents various supplemental analyses using the patent data. Section 6 considers the puzzle raised by the recent behavior of research activity. The final section draws conclusions.

2 Changes in U.S. Patent Policy

In recent years, the United States has been among the most aggressive nations in reforming its patent system.[3] This section will review the U.S. changes; the lesser-reaching changes in Europe and Japan are reviewed in Appendix A.1.

The dramatic changes in U.S. patent policy perhaps should not be surprising, since the United States has had in many respects the most idiosyncratic patent system. Wegner has gone so far as to state that "there are really but two different systems among the major patent systems of the world, an 'international' system that is found in Europe and Japan, and an 'American' system that until 1989 was found also in Canada but today is uniquely American" (1993, p. 1). The United States system itself has been characterized by several swings in the effectiveness of patent protection.

While patent awards date back to those made by the various colonies beginning in 1641, the key features of the system were determined through a series of judicial decisions during the first three decades of the 1800s and the Patent Law of 1836. Among the key features that have largely remained unchanged until recently were:

- the awarding of the patent to the first to discover an innovation, rather the first to file for an invention.
- the principle that patent applications would not be published until they were awarded.
- the broad interpretation of patent scope through the doctrine of equivalents.

During the period from 1836 until World War II, this legal structure underwent few alterations.

The "golden age" of patenting, as it is sometimes referred to, ended in the late 1930s. Federal agencies began taking an increasingly hostile view of patents, deeming them as anti-competitive and inconsistent with a free market, as did many of President Roosevelt's Supreme Court appointees. The Department of Justice created a special section in the Antitrust Division which was concerned exclusively with anti-patent litigation; the Federal Trade Commission similarly scrutinized transactions involving intellectual property.

A number of calls for reform, such as that of a 1966 presidential commission, went largely unheeded. Meanwhile, the resources going into examining patent applications had been (in inflation-adjusted dollars) steadily reduced. By 1980, the U.S. Patent and Trademark Office (USPTO) was an understaffed, overworked agency in a state of disarray. The USPTO's limited resources prevented it from effectively reviewing more than a small subset of previously-issued patents before judging whether or not a new one should be granted. Consequently, patent awards were often made on the basis of insufficient evidence.

The patent enforcement situation was no better. There was a lengthy backlog of patent cases in many courts. Furthermore, the circuit courts responsible for hearing the cases had geographical rather than subject-matter jurisdiction. This led to "forum shopping," defined by the U.S. Commission on the Revision of the Federal Court Appellate System as "mad and undignified races ... between a patentee who wishes to sue for infringement in one circuit believed to be benign toward patents, and a user who wants to obtain a declaration of invalidity or non-infringement in one believed to be hostile to them" (1975, p. 15). The inconsistencies across regions provided incentives to litigate around patents and circumvent procedures of one region in favor of those of another.

Beginning in 1980, the U.S. Congress, with the encouragement of Presidents Carter and Reagan, sought to address the problems of the patent system. More patent legislation was enacted between 1980 and 1982 than had been passed in the previous two decades. This flurry of legislation included (i) a measure designed to cut the time and cost involved in patent suits by allowing the PTO to re-examine patents that were challenged because they were based on findings that had already been patented or published; (ii) a law that extended patent duration on certain types of products (primarily pharmaceuticals and chemicals) by up to seven years to compensate firms for the loss of marketing time resulting from the complex regulatory clearance process; and (iii) a law designed to enable non-profit research groups to patent and commercialize technologies developed with federal funds (the Bayh-Dole Act).

The fourth measure, and perhaps the most important, was the Federal Court Improvements Act, enacted in March 1982. This act created the Court of Appeals of the Federal Circuit (CAFC). Two existing courts—the appellate division of the Court of Claims and the Court of Customs and Patent Appeals (which heard appeals of cases from these agencies)—were merged into a single twelve-judge court. It was assigned jurisdiction over appeals of patent cases in all the federal circuits.

The stated purpose of the CAFC was to consolidate and reconcile patent decisions in an efficient manner. But as Merges points out: "While the CAFC was ostensibly formed strictly to unify patent doctrine, it was no doubt hoped by some (and expected by others) that the new court would make subtle alterations in the doctrinal fabric, with an eye to enhancing the patent system. To judge by results, that is exactly what happened" (1992, p. 9). This claim is borne out by the statistical patterns.[4] Circuit courts upheld 62 percent of district court decisions holding patents to be valid and infringed while it reversed 12 percent of the decisions holding patents to be invalid or not infringed between 1953 and 1978 (Koenig, 1980). From 1982 to 1990, the CAFC affirmed 90 percent of district court decisions holding patents to be valid and infringed, and reversed 28 percent of the judgments of invalidity and non-infringement (Harmon, 1991).

This increase in patent protection was accomplished largely through the doctrine of equivalents. The doctrine of equivalents was the idea that inventors should be prevented not only from similar products or processes but also those outside the literal scope of the claim if they do "substantially the same thing in substantially the same way to achieve substantially the same result" (*Machine Co. v. Murphy,* 97 U.S. 120, 125 (1877)). The CAFC resorted extensively to the doctrine of equivalents, greatly enhancing average patent scope. In addition, analysts have noted that the court displayed a much greater willingness to sustain large damage awards, to grant preliminary injunctive relief to patentees during the resolution of disputes, and to make a variety of other rulings that have been construed as "pro-patent."

3 Evidence from Patenting Across Countries

According to the friendly court hypothesis, the changes in U.S. patent policy in the early 1980s should have increased the desirability of patent protection in the United States. This implication can be tested using international patent data. A single invention must be patented in each country in which patent protection—which limits imitators from producing or selling there—is desired. Consider the United States and France, for example. In addition to U.S. patent applications by U.S. inventors, we observe French applications by French inventors, U.S. applications by French inventors, and French applications by U.S. inventors. We expect U.S. applications by French inventors and U.S. applications by U.S. inventors to both be stimulated by a strengthening of patent protection in the United States. There is little reason, however, to expect such a strengthening to alter either French applications by French inventors or French applications by U.S. inventors.

The fertile technology hypothesis implies quite a different pattern. A burst of technological opportunities in the United States should lead to a surge in U.S. and French applications by U.S. inventors. If the improvement in technological opportunities is a global phenomenon then we also expect an increase in U.S. and French applications by French inventors. We begin our analysis of the international patent data with an informal look at patent applications among the major industrialized countries.

3.1 A Glimpse at the Data

Figure 2 compares patent applications by domestic inventors in the United States, Japan, France, Germany, and the United Kingdom.[5] None of the other countries display a pattern like the one in the United States, with its sharp upswing beginning in the mid 1980s. Domestic applications in the three European countries have been essentially flat with a slight upturn beginning in the late 1970s, just after the European Patent Office was established. By contrast, Japan has witnessed a steep upward trend (reflecting its transition from a technological follower in the 1950s to a technological leader in the 1990s) that is only now beginning to subside.[6] Figure 2 demonstrates that the recent jump in patenting is something peculiar to the United States.

Figure 3 plots patent applications in the United States by inventors from different countries. Patenting by foreigners in the United States has been rising, but it is a sustained rise over the entire forty-year period. There is some evidence of a more rapid increase beginning in the mid-1980s for France and the United Kingdom, but it is not sustained through the 1990s. Overall, the pattern of foreign patenting in the United States shows little similarity to the jump in U.S. domestic applications.

Figure 4 looks at applications for foreign patent protection by U.S. inventors. Applications in the four different foreign countries move together, rising through the 1960s, falling through the 1970s, and rising at increasing rate since then. Although foreign applications represent a fraction—only about 25 percent—of U.S. domestic applications, they display a similar rapid run-up in the late 1980s and early 1990s. A notable difference is that U.S. applications abroad begin to pick up about five years before domestic applications. Nonetheless, comparing Figures 3 and 4, U.S. patenting abroad matches the recent behavior of U.S. domestic applications much more closely than does foreign patenting in the United States.

Our descriptive analysis of the international patent data suggests that the recent jump in patenting is largely a U.S. phenomenon. The analysis points to the United States' increased potency as source of patentable inventions not its increased desirability as a destination for patents. To investigate further, we apply a more systematic decomposition derived from a simple model of the decision to seek patent protection.

3.2 A Model of Patenting

We decompose the number of applications by inventors from country i (the source country) for patent protection in country n (the destination country) at date t, P_{nit}, into three fundamental factors: (i) *invention*, α_{it}, the rate at which country i generates patentable inventions at date t; (ii) *diffusion*, ϵ_{ni}, the fraction of inventions from country i that find a use in country n; and (iii) the *propensity to patent*, f_{nt}, the fraction of inventions that are worth trying to patent in country n at date t out of those that have a use there. The implied patenting equation is,

$$P_{nit} = f_{nt}\epsilon_{ni}\alpha_{it}. \tag{1}$$

Using equation (1) does not require taking a stand on the determinants of inventiveness, although presumably α_{it} depends on resources devoted to research prior to date t in the source country i. A set of factors for each source country and year combination encompasses essentially any model of the invention process. Similarly, the parameters ϵ_{ni} encompass any time-invariant pattern of diffusion among countries. On the other hand, the restriction that the propensity-to-patent terms f_{nt} depend only on the destination country requires explanation. The model sketched out below does yield this restriction.

We assume that the value of an invention in country n depends on two components: (i) the invention's quality, $q > 0$, (which is common across the countries where the invention is used) and (ii) country n's effective market size, v, (which depends on whether or not the invention is patented in country n). Accordingly, at date t, the value of an invention of quality q in country n is qv_{nt}^{k}, where $k = pat$ if the invention is patented in country n and $k = not$ otherwise. For patent protection to have value requires $v^{pat} > v^{not}$.

To capture the heterogeneity of invention value, we assume that quality is random, drawn from a distribution function $F(q)$. To explain why all inventions are not patented, we let c_{nt} be the cost of patenting in country n. Assume that the inventor knows the quality of his invention and whether or not the invention will be useful in country n before deciding whether to apply for patent protection there. Then the propensity to patent in country n (as a fraction of the inventions that are useful there) is simply $f_{nt} = 1 - F(c_{nt}/(v_{nt}^{pat} - v_{nt}^{not}))$. The propensity to patent is increasing in the strength of patent protection in country n, as measured by $(v_{nt}^{pat} - v_{nt}^{not})/c_{nt}$. In this simple model, the propensity to patent does not depend on the source of the invention.[7]

The model laid out above can also be used to assess whether an increase in the strength of patent protection could plausibly explain a substantial jump in U.S. patenting. To do so we parameterize the model following the logic of the quality-ladders model of growth (see Grossman and Helpman (1991) and Eaton and Kortum (1996) for details) and then calibrate it. The effective quality of an invention (in terms profitability) is $q = (s-1)/s$ where $s > 1$ is the inventive step (i.e. the factor of quality improvement made possible by an invention). We assume that the inventive step is drawn from the Pareto distribution, i.e. the probability of the step being less than s is $1 - s^{-1/\lambda}$. Assuming stationary growth, we get $v_{nt}^{k} = M_{nt}/(\rho + \iota_{n}^{k} + I - g)$ where M is the size of the market for the invention (which grows at a constant rate g), ι^{k} is the imitation rate (which depends on whether or not the invention is patented), ρ is the discount rate, and I is the rate of invention (which determines the obsolescence rate).

We calibrate the model to deliver a propensity to patent in the United States of 70 percent in 1982, in the middle of the 60-80 percent range reported in Mansfield (1986). The imitation rate for patented inventions is set to $\iota^{pat} = 0.2$, based on survey evidence from Mansfield, Schwartz, and Wagner (1981). We assume that the cost of a patent application is $c = \$10,000$ (calculations from University of Pennsylvania Center for Technology Transfer (1995) justify an overall patenting cost nearly this high). The parameter of the distribution of inventive steps is set to $\lambda = 0.10$, implying that the average invention represents a 10 percent improvement. We set the discount rate to $\rho = 0.07$, the obsolescence rate to $I = 0.09$, and the growth rate to $g = 0.039$. The market size is set to $M = \$1.86$ million.[8] Based on all the other parameters, an imitation rate for unpatented inventions of $\iota^{not} = .217$ generates a propensity to patent of 70 percent.[9] If the strengthening of patent protection causes ι^{pat} to fall from 0.20 to 0.18 then the propensity to patent rises from 70 to 86 percent, generating a 23 percent increase in patenting, holding fixed research effort. (In section 6 we endogenize research effort.) The results suggest that a strengthening of patent protection could, in principle, explain a large part of the increase in U.S. patenting. We now return to our analysis of the data to see if there is any evidence for such an effect.

3.3 A Statistical Decomposition

The statistical decomposition starts with equation (1). The idea is to estimate that equation in order to see which set of effects accounts for the big jump in U.S. domestic applications. The friendly court hypothesis predicts that destination-country by year effects (f_{nt}) should account for the increase, while the fertile technology hypothesis predicts it should be the source-country by year effects (α_{it}) that matter (or perhaps simply an overall time effect).

We first extend equation (1) to capture the fact that foreign patenting has been rising relative to domestic patenting. For example (from Figures 2 and 4) note that the number of U.S. applications for French patents was only about 10 percent as large as the number of U.S. applications for U.S. patents in 1955, but that ratio had risen to almost

25 percent by 1993. There are two potential explanations for this increased globalization of patenting. One is that international technology diffusion has become more important over time. The other is that reforms of the patenting process have made it less costly to obtain patent protection abroad (see the discussion of these reforms in Appendix A.1.) Without attempting to determine their underlying source, we simply add globalization terms, $g_{h(ni)t}$, to equation (1), where $h(ni)$ is a subscript for the home country: it equals 1 if $n = i$ and equals zero otherwise. Including a multiplicative i.i.d. error u, and taking logs, our patent equation becomes,[10]

$$\ln P_{nit} = \ln f_{nt} + \ln \epsilon_{ni} + \ln \alpha_{it} + \ln g_{h(ni)t} + u_{nit}. \tag{2}$$

We estimate equation (2) using data on patent applications for each year from 1955 to 1993 in Germany, France, the United Kingdom, Japan, and the United States by inventors from each of these five countries or from elsewhere. This gives us 1170 observations (39 years by 5 destinations by 6 sources). The dependent variable is the natural log of patent applications, while the explanatory variables are simply sets of dummy variables: destination-country and year specific for f_{nt}, destination and source-country specific for ϵ_{ni}, source-country and year specific for α_{it}, and home-country and time specific for $g_{h(ni)t}$ (subject to appropriate normalizations).[11]

The basic fit of equation (2) and the explanatory power of each set of dummy variables is presented in Table 1. Notice that one-dimensional effects (e.g. source-country effects) are entered separately so that two-dimensional effects (e.g. year by source-country effects) only capture deviations from the one-dimensional effects. The model picks up almost all of the variation in the dependent variable, $\ln P_{nit}$. It is easy to reject any restriction of the model, corresponding to dropping one of the sets of dummy variables. Nonetheless, it is interesting to identify which sets of factors have substantial explanatory power. Among the two-dimensional sets of dummy variables, the year by source-country dummies account for much of the variation in the data. The year by

Table 1: Model Fit

Set of dummy variables	number of parameters	sum of squares
destination-country	4	16.6
source-country	5	299.2
year	38	258.5
domestic-foreign	1	733.3
domestic-foreign by destination-country	4	122.4
source-country by destination-country	15	23.7
year by destination-country	152	10.0
year by source-country	190	167.0
domestic-foreign by year	38	21.2
Total explained		1651.8
Unexplained		16.2

destination-country dummies do not. In other words, there is little variation over time in the international patent data that is common across inventors (from different countries) seeking patents in a given destination. This finding appears to be evidence against the friendly court hypothesis.

To see clearly the factors underlying the increase in U.S. domestic patent applications, we reparameterize the model along the lines of equation (1).[12] We define nine sets of multiplicative effects: (i) destination-country effects D, (ii) source country effects S, (iii) year effects T, (iv) home effects (domestic-foreign) H, (v) destination-country by source-country effects DS, (vi) destination-country by year effects DT, (vii) source-country by year effects ST, (viii) destination-country by domestic-foreign effects DH, and (ix) year by domestic-foreign effects TH. In terms of these effects, the exponentiated value of the fitted values $\hat{P}$ from estimating equation (2) exactly satisfy,

$$\hat{P}_{nit} = AD_nS_iT_tH_{h(ni)}(DS)_{ni}(DT)_{nt}(ST)_{it}(DH)_{nh(ni)}(TH)_{th(ni)}, \tag{3}$$

for $n = 1, ..., 5$; $i = 1, ..., 6$; $t = 1, ..., 39$; $h(ni) = 1$ if $n = i$ ($h = 2$ otherwise); and where A is an overall constant term. These equations are subject numerous restrictions, for example:

$$\sum_{n=1}^{5} \ln D_n = 0;$$

$$\sum_{n=1}^{5} \ln(DS)_{ni} = 0 \quad i = 1, \ldots, 6, \quad \sum_{i=1}^{6} \ln(DS)_{ni} = 0 \quad n = 1, \ldots, 5; \tag{4}$$

and

$$\ln(DS)_{nn} = 0 \quad n = 1, \ldots, 5.$$

The parameters are now multiplicative effects and should be interpreted relative to a standard of 1. Since the parameter estimates satisfy identifying restrictions such as (4), the geometric means of the effects along any dimension is 1.[13] To get the parameters in equation (3) we apply an iterative proportional fitting algorithm (Bishop, Fienberg, and Holland, 1975) to the exponentiated fitted values, $\hat{P}$, obtained by estimating equation (2).

The fit of the model and the estimated effects describing the behavior of U.S. domestic patent applications since 1975 are illustrated in Figure 5. (The parameters themselves, for recent years, are contained in Table 2). The top two lines of Figure 5 show that the model explains the basic contour of U.S. domestic patent applications and particularly the upturn after 1985. The estimated parameters provide a simple interpretation of what happened. In the early years, the aggregate time effects gave an upward tilt to patenting but were offset by a decline in the bias toward patenting domestically and a smaller decline in the relative importance of the United States as a source of innovations. On net, U.S. domestic applications were roughly constant. Beginning in the late 1970s, the aggregate time effect began to rise more steeply and the bias toward patenting domestically flattened. Furthermore, the United States' relative position as a source stabilized in the 1980s. Together these trends led to a rise in U.S. domestic applications in the mid 1980s. By the end of the 1980s, the U.S. relative position as a source began to move up, leading to a more rapid increase in U.S. domestic applications. The U.S.

Table 2: Estimated Effects Describing U.S. Domestic Applications

Year (t)	Actual Patents (P)	Estimated Patents ($\hat{P}$)	Year Effect (T)	Home Bias (TH)	U.S. Source (ST)	U.S. Destination (DT)
1982	63316	63483	1.20	0.91	0.81	1.05
1983	59391	64500	1.21	0.92	0.86	1.00
1984	61841	67320	1.28	0.90	0.84	1.02
1985	63874	64128	1.29	0.89	0.82	1.00
1986	65487	66907	1.35	0.88	0.82	1.00
1987	68671	71871	1.43	0.87	0.79	1.06
1988	75632	74938	1.53	0.84	0.80	1.06
1989	82956	79912	1.63	0.82	0.84	1.05
1990	91410	85769	1.74	0.79	0.87	1.05
1991	89024	91319	1.72	0.80	0.90	1.08
1992	94017	102861	1.78	0.80	0.96	1.10
1993	102245	108765	1.80	0.81	1.01	1.08

position as a destination for patenting displays little variation over time.

Since our focus is on the rapid upturn in U.S. patenting over the past decade, we enlarge that part of the picture. Figure 6 illustrates the patterns of source-country effects over the past 12 years (each country's source effect is scaled to unity in 1982). Over the past five years the United States has become a more potent source of patentable inventions. The increase is large, about 25 percent relative to the average and about 40 percent relative to Germany. During the 1980s (and in the previous years not shown) the rise in Japan was more dramatic, but recently Japan has slipped. The three European countries, particularly Germany, decline throughout.

Figure 7 takes a closer look at the destination-country effects. To facilitate comparison with Figure 6, the vertical scale remains the same, but the time-period is extended back to 1975 in order to investigate the influence of the establishment of the European Patent Office in 1978. The most striking feature of Figure 7 is the lack of variation in the destination-country effects relative to the source-country effects in Figure 6. A second feature is the rise in the three European countries as destinations, suggesting that the European Patent Office did make patenting easier. The United States does increase as a destination since 1982, but the magnitude of the change is small.

If our model is correct, then the empirical analysis suggests that the friendly court hypothesis is not the explanation for the rise in U.S. patenting. This finding, although surprising, is corroborated by survey evidence that the importance of patents has not increased relative to other means of appropriating the returns to invention (Cohen, Nelson, and Warsh (1997)). In light of this evidence, a more plausible explanation for the rise in patenting is that either technological opportunities or the process of doing research has improved, particularly in the United States as of late. To distinguish between these two variants of the fertile technology hypothesis we turn to an analysis of patenting across different technology classes.

4 Evidence from Patenting Across Technologies

By their very nature, opportunities arise in specific areas of technology. If the arrival of new technological opportunities is driving the surge in U.S. patenting, then we expect the increase in patenting to be highly concentrated in technology space. The majority of technologies should experience little increase in patenting while a few experience a dramatic rise. Other explanations of the increase in patenting do not predict that it should technologically-concentrated. The friendly court hypothesis suggests that the propensity to patent should be as sensitive to institutional changes in the U.S. patent system in one technology as in any other. Alternative variants of the fertile technology hypothesis—such as an improvement in the management of research or the technology of doing research—also predict an impact on patenting across a wide spectrum of technologies.

To check the prediction (of a variant of the fertile technology hypothesis) of a technologically-concentrated increase in patenting, we exploit the technological dimension of the data generated by patent classes. During the patent examination process, patents are assigned to detailed technologies as defined by patent classes. These assignments are performed with care to facilitate future searches of the prior art in a specific area of technology (technology assignments are described in more detail in Appendix A.2.2).

We begin by examining how patenting has grown in different patent classes. This allows us to determine whether the increase in patenting is broadly distributed across technologies or confined to a only a few. Next, we examine two particular technologies. Biotechnology and software have been areas with extensive new firm formation, rapid technological change, and extensive use of patent protection. We attempt to single out technology classes in these areas to see if they are major contributors to the overall rise in patenting.

Since patents are assigned to technologies during the examination process, we must use patents actually issued (rather than patent applications) for this analysis. To make the data more comparable to the applications data, and to avoid anomalies in the mean lag between application and grant, we continue to date the patents according to the application year. Since our goal is to understand the rise in U.S. patenting by U.S. inventors, we limit the analysis to that subset of the data.[14] The classes of technology are defined by the International Patent Classification System (WIPO, 1984). Benefits associated with using this classification system (as opposed to the U.S. patent classification system) are described in Appendix A.2.2. We use the "4-digit" level of the IPC System, containing on the order of a thousand classes.[15]

4.1 All Technologies

We examine the (application) years 1980-1991 and divide that twelve-year period into two six-year periods: 1980-1985 and 1986-1991. During the first six years patenting was slowly declining while over the second six years patenting began to increase rapidly. Over 58 percent of the 537 thousand patents in our sample appear in the second six-year period. To give a sense for the size of the technology classes, Figure 8 plots their distribution in each of the two six-year periods. There is a wide disparity in the size of technology classes.[16] The later period witnessed an increase in the number of very small and of very large patent classes (with a decrease in the number of medium sized classes). The increase in very large patent classes is of particular interest because it may indicate a few vibrant technologies driving the overall increase in patenting.

The size distribution of technology classes, however, hides the churning that may be occurring within the distribution. To get at what was happening within technology classes we calculate, for each one, the fraction of its patents that came in the second six-year period. We then plot the distribution of this ratio. We know that the mean of the ratio (when weighted by the sizes of the patent classes) is 0.58.

There are two reasons for this fraction to vary by technology class: the first is underlying structural differences and the second is randomness in outcomes. The structural factors are that different technology classes may have experienced different increases in technological opportunities. The technologies that experienced a relative improvement in opportunities should, in general, have large fractions of patents appearing in the second period. But, even if there are no structural differences across the technology classes, randomness in the inventive process will generate variation across technology classes in the fraction of patents appearing in the second period. If there are structural differences, randomness will add to the underlying structural variation. In order to highlight the structural variation, we select only the 537 technology classes with at least 50 patents

Table 3: Fast-Growing Patent Classes

IPC	Definition	Patents 2nd Period (1986-1991)	Patents Both Periods (1980-1991)	Fraction in 2nd Period
B05D	Processes for Applying Liquids to Surfaces	2042	2541	0.80
B21F	Working or Processing of Wire	256	341	0.75
B32B	Layered Products	5029	6071	0.83
H04J	Multiplex Communication	997	1296	0.77
H04K	Secret Communication	250	315	0.79

over the entire twelve-year period. Over 99 percent of patents are assigned to these larger patent classes.

In Figure 9 we plot the density of the fraction of patents in the second period across all technology classes with over 50 patents (the unweighted mean of this distribution is 0.54). The striking feature of Figure 9 is that there are few technology classes in the upper tail. In particular there are only 11 technology classes in which over 75 percent of the patents came in the second period. The left tail of the distribution is somewhat fatter. In particular, 158 patent classes experienced a decline in patenting. But, the basic impression is that there is a widespread increase in patenting (experienced by over 70 percent of the technology classes).

There are not very many technology classes that appear to be rapidly improving areas for discovery. We display in Table 3 the five classes containing over 300 patents in which over 75 percent of the patents appear in the second period.

The fastest growing technologies are generally related to biotechnology and software: B05D shows up in the patenting of both biotech and software firms, B32B shows up in the patenting of biotech firms, and both H04J and H04K show up in the patenting of software firms (Appendix A.2.2). Nonetheless, these technologies alone do not explain much of the increase in patenting over the period. We now turn to a more systematic attempt to identify technology classes associated with biotech and software.

4.2 Biotechnology and Software

Since we believe that biotech and software are the most technologically dynamic fields over this period, we perform an analysis focusing on their impact. In particular we look at patent classes in which software and biotech firms do most of their patenting. Our procedure for generating time series of patents for software and for biotech is described in Appendix A.2. While we do not seek to ascertain all the classes in which these firms patent, we do identify the key patent classes in which either biotech or software firms play a major role.

Figure 10 shows that patenting in both biotech and software has risen considerably since the late 1970s, both absolutely and as a share of the total patenting in the United States. But, it also makes clear the overall increase in U.S. patenting is not simply a biotech- and software-driven phenomenon. Total patenting rose by almost 70 percent from 1983 to 1991 (based on the data of patents granted by year of application). With biotech and software patents excluded, the increase in overall patenting is reduced by only five percentage points.

5 Other Evidence from Patent Statistics

5.1 Patenting by Experienced and Inexperienced Patentees

The next analysis that we undertake is to examine the shift in patenting by type of firm. The "regulatory capture" hypothesis suggests that the increase in patenting activity, far from being an exogenous event, may have been the product of lobbying by the firms who thought that it would better their strategic position. Consistent with other studies (Bartel and Thomas, 1987; Thomas, 1990), established U.S. firms—with substantial patent practices and well-organized lobbying efforts—may have pushed for these changes to strengthen their competitive position viz-a-viz smaller firms.

In this case, the increase in patenting activity may be concentrated in these firms, as they sought to exploit the advantages that strong patent position gave them. Particularly striking, practitioner accounts suggest, has been the growth of litigation and threats of litigation between large and small firms. Examples may include the dispute between Cetus Corporation and New England Biolabs regarding taq DNA polymerase and that between Texas Instruments and LSI Logic regarding semiconductor technology (these and other examples are discussed in Chu, 1992; Rutter, 1993). Several observers argue that the proliferation of such threats may be leading to transfers of financial resources from some of the youngest and most innovative firms to more established, better capitalized concerns. Even if the target firm feels that it does not infringe, it may choose to settle rather than fight. It either may be unable to raise the capital to finance a protracted court battle, or else may believe that the publicity associated with the litigation will depress the valuation of its equity.

This hypothesis suggests that the greatest growth in patenting will occur in established firms who are already active in patenting. To examine this implication of the regulatory capture hypothesis, we examine the composition of patentees in recent years. In particular, we rank the firms into five cohorts on the basis of their patenting activity between 1979 and 1984. We then examine how many patents have been awarded to firms in the various cohorts in subsequent years. We compare these patterns to those of earlier years, using patents awarded between 1969 and 1974. The results suggest that, contrary to the regulatory capture hypothesis, the role of newer and less frequent patentees has actually increased.

To undertake this analysis, we use a data-set compiled by researchers at Case-Western University and the National Bureau of Economic Research. This database links the first assignee of each U.S. patent award through 1993 to a CUSIP or other identifier. Assignees that are subsidiaries or joint ventures are linked up to their parent firms.

We first examine the extent to which new firms that have not patented during the previous six year period (1969 through 1974 and 1979 through 1984) are active patentees. For each subsequent year, we calculate the ratio of the number of patents awarded to entities (i.e., not including awards to individuals) that had not previously patented to the total number of patent awards in that year. In Figure 11, we arrange the observations by years after these six-year periods (which we dub the "cohort periods"). For instance, "Year 1" is 1975 for the 1969-74 analysis and 1985 for the 1979-84 analysis. In each case, new firms are more active patentees in the later period. For instance, entities that had not patented in 1969 through 1974 represented 9 percent of the patents in 1978; while those that had not patented in 1979 through 1985 represented 14 percent of the patents in 1988. The late 1980s and early 1990s, rather than seeing an decrease in activity by new patentees, actually had increasing representation.

One possible explanation for this pattern is that it reflects the extent of merger activity and new firm formation during this period. Because the 1980s saw considerably more new firm formation and mergers than the 1970s, it may be that the increasing share of patents issued to new patentees simply reflects the greater economic and innovative activities by these entities. New firms may have been less likely to undertake patenting activities, but there were simply many more of them.

To at least partially address this possibility, we look at the evolution of patenting by firms that had already filed for patents in the two cohort periods. This analysis will not be influenced by shifts in merger activity or new firm formation. We divide the patentees in the two six-year periods into five quartiles, which range from the most to the least active firms in patenting. The quartiles are constructed so that each has the same number of patents: thus, the quartile containing the most active patentees has many fewer firms than the quartile with the least active patentees.

We then look in Figure 12 at the ratio of patents in subsequent years by the quartile least active in patenting to the quartile most active. While the relative share of patenting by the least active quartile declined sharply in the 1970s, in the 1980s the share actually increased. Thus, once again we see that the most marginal patentees appear not to have diminished during this period, but actually increased. This is inconsistent with the view that the large firms pushed for and exploited the change in the patent system to benefit themselves.

5.2 Comparing Applications and Grants

If the value of patenting is rising in the United States (as is predicted by the *friendly court hypothesis*) researchers will have an increasing incentive to seek patent protection even on inventions which are of questionable patentability. Under this scenario, such questionable applications will increase as a fraction of all patent applications. Assuming that patent examiners reject a constant fraction of questionable applications, we would expect to see a declining share of patent applications eventually granted.[17]

To examine this issue we use U.S. Patent and Trademark Office statistics on patents granted by country of inventor (dated by year of application) and on patent applications by country of inventor. We calculate, in each year from 1972 to 1993, the percentage of applications that had been granted by the end of 1995.[18]

Figure 13 plots the percentage of patent applications eventually granted, by year of application and country of inventor. The "application yield" has been fairly constant since the early 1980's for U.S. inventors. There is little evidence of a decline since 1982, as predicted by the friendly court hypothesis. On the other hand, there has been a recent decline in the yield for foreign inventors. Since the friendly court hypothesis predicts a declining yield on patent applications from all sources, we find this second fact somewhat puzzling.

5.3 Patent Renewals

Another source of evidence is from data on patent renewals. Public Law 96-517 required all U.S. patents issued from applications filed after December 1980 to pay renewal fees at four, eight and twelve years after the issue date. (Alternatively, the patent holders can let the awards expire prematurely.) Such fees have been in force for over forty years in many European countries (Pakes and Simpson, 1989). The changing patterns of patent renewals might be helpful in distinguishing between our hypotheses.

Statistics on renewal rates in the United States have recently been compiled and analyzed by Brown (1995). He finds that renewal rates have generally fallen in the 1990s. For instance, the percentage of U.S. patents for which fourth year renewal fees were paid fell from 84 percent in 1991 to 79 percent in 1994. Of those eligible for an eighth year renewal, the fraction actually renewed fell from 74 percent in 1991 to 66 percent in 1994. Patents in the United States from other countries display a similar decline.[19]

Although the trends in patent renewals are unambiguous, the implications are not so clear-cut. It is unclear whether a strengthening in patent protection (such as the friendly court hypothesis suggests has occurred) will lead to an increase or a decrease in the renewal rate. If firms can quickly discover whether patents are worthwhile, they may increasingly file for awards on even marginal discoveries, and then let many of them expire. (If we view a patent as an option, a rise in the variance of patent value may lead an increasing willingness to file for patents on "out of the money" patents–i.e., patents that are likely not to be renewed.) If, on the other hand, firms find it difficult to assess which patents are worthwhile until very late in their legal life, an increase in patent strength may lead to a greater willingness to renew awards.

The fertile technology hypothesis, on the other hand, predicts a decline in renewal rates as the faster flow of new inventions leads to a higher obsolescence rate. (This effect is captured in the model below). Thus, if anything, the evidence on declining renewal rates weakly favors the fertile technology hypothesis.

6 The R&D Puzzle

In exploring what caused the unprecedented increase in U.S. patenting—one indicator of research output—it is natural to ask what happened to research inputs. Our analysis of various dimensions of the patent data has led to a tentative conclusion that U.S. patenting jumped due to improvements in the management or automation of the innovation process itself. We now subject that tentative conclusion to evidence on research effort. We begin by examining what a simple model predicts about the link between research productivity and research effort.

6.1 A Model of Research Effort

The general equilibrium model, distilled from Kortum (1997), generates a baseline in which patenting is constant while research effort and productivity grow at constant rates. The baseline captures the U.S. trends in these three indicators of technological change prior to the mid 1980's. To reproduce the recent jump in patenting, along the lines suggested by the fertile technology hypothesis, we perturb the baseline by introducing a permanent positive shock to research productivity. We use the model to trace out the dynamic response of patenting and research effort to the research–productivity shock.

The core of the model is a production function for output Y, a production function for inventions I, and an equation for how inventions raise productivity A. The total labor force L is allocated between goods production and research R. The distinctive feature is that in the invention production function, due to a fishing–out phenomenon, ever–increasing research effort is required to generate a constant stream of new inventions. We assume that all inventions are patented.[20] The equations are set in continuous time (with the time subscript suppressed):

$$Y = (L - R)A, \tag{5}$$

$$I = \phi R A^{\frac{-1}{\lambda(1+\gamma)}}, \tag{6}$$

and

$$\dot{A}/A = \lambda I, \tag{7}$$

where $\phi > 0$ is a research productivity parameter, $1 > \lambda > 0$ is a parameter of the size distribution of inventions, and $\gamma > \frac{\lambda}{1-\lambda}$ is a parameter indicating research spillovers (the parameter restrictions rule out certain perverse behavior).

We assume that the labor force grows at rate $n > 0$.[21] To complete the model, we assume that research satisfies a free entry condition (the cost of doing research is just offset by the value of the inventions that are discovered),

$$IV = RW, \tag{8}$$

for $0 < R < L$, where V is the expected value of an invention and W is the wage (the price of output is unity). The expected value of an invention (not conditioning on the size of the inventive step) is determined by equating the flow of profits from the inventions plus capital gains to the opportunity cost of holding the asset which includes the chance that a new invention makes it obsolete,

$$\frac{\lambda}{1+\lambda} Y + \dot{V} = (\rho + I)V, \tag{9}$$

where ρ is the discount rate and $\frac{\lambda}{1+\lambda}$ is the expected share of revenues retained by the inventor (assuming the inventive step is drawn from a Pareto distribution with parameter

$1/\lambda$). The wage is simply output per worker net of revenues paid to the research sector:

$$W = \frac{1}{1+\lambda} A. \tag{10}$$

The dynamics of this model are governed by a single state variable, $x \equiv LA^{\frac{-1}{\lambda(1+\gamma)}}$, capturing the relevant information about both the size of the market and the productivity of research. After some manipulation of the equations above, it can be shown that the state variable satisfies the differential equation,[22]

$$\dot{x}/x = \frac{\rho + n\gamma}{\gamma} - \frac{\phi\lambda}{\gamma} x, \tag{11}$$

for $x > x_L \equiv \frac{\rho}{\lambda\phi}$. The later restriction implies that $R > 0$ and thus ensures that equation (8) holds. Given x, research intensity is simply

$$R/L = \frac{\lambda(1+\gamma)}{\gamma} - \frac{\rho(1+\gamma)}{\gamma\phi} x^{-1} \tag{12}$$

and the rate of invention is

$$I = -\frac{\rho(1+\gamma)}{\gamma} + \frac{\phi\lambda(1+\gamma)}{\gamma} x. \tag{13}$$

Starting from any initial condition $x_0 > x_L$, the state variable converges to a constant $x^* \equiv \frac{\rho+n\gamma}{\phi\lambda}$. In steady state, the rate of invention is $n(1+\gamma)$, productivity growth is $\lambda(1+\gamma)n$, output growth is $[1+\lambda(1+\gamma)]n$, and research intensity is $R/L = \frac{\lambda(1+\gamma)n}{\rho+n\gamma}$.

To be concrete, we calibrate the model using the vector of parameter values chosen in Kortum (1997): $\rho = .07$, $\gamma = 9$, $\lambda = .03$ and $n = .03$. These parameters generate a steady state with output growing at almost four percent, productivity growing at almost one percent, a hazard rate (for the returns on an invention) of thirty percent, and research intensity of 2.6 percent. The prediction for research intensity is reasonable, depending on how research intensity is measured.[23]

We analyze the response of research intensity to a rise in research productivity ϕ, as implied by the fertile technology hypothesis. We consider a one-time unexpected permanent increase in research productivity. According to the steady state equations, such a change will not have a permanent effect on the level of research intensity. As for the transitory effect, the initial impact of a jump in research productivity is that research intensity, conditional on the state variable x, rises as indicated by equation (12). The increase in research productivity also leads to a steepening of the $\dot{x}/x$ equation (11). This sets in motion a period during which the state variable x falls and research intensity declines to its original level. The rate of patenting is temporarily higher not only because of greater inventive output for any given level of research activity but also because of greater research activity. Eventually, however, research intensity and patenting both return to their original levels.

The model makes a clear prediction: a permanent rise in research productivity leads to a transitory rise in patenting and generates a transitory period of higher research intensity. How large is the effect on research intensity? Based on the parameters above, suppose the economy is initially in a steady state and that research productivity jumps by 30 percent (this will produce a 30 percent jump in patenting conditional on research intensity). Research intensity is predicted to jump up initially by about 0.2 percentage points (i.e. from 2.6 percent to 2.8 percent) and then to slowly decline (these results are essentially the same whether research intensity is measured in terms of employment or expenditure). Although the increase in research intensity is modest relative to the associated forty percent jump in patenting, it is a large enough change to be noticeable given the relative smoothness data on research intensity.[24] We now compare this prediction to the data.

6.2 Evidence on Research Effort

Research intensity did rise rapidly, as expected, in the 1980s, but it has flattened in the 1990s even as patenting has continued to surge.

We consider two alternative measures of research intensity in France, Germany, Japan, the United Kingdom, and the United States. The first, shown in Figure 14, is research scientists and engineers employed in business enterprises relative to the labor force. The second, shown in Figure 15, is R&D expenditures financed and performed in business enterprises relative to GDP (both measured in local currencies). These measures correspond to R/L and WR/Y, respectively, in the model above.[25]

The two measures tell a similar story: in the 1990s research intensity has been either flat or declining, after having risen sharply in the 1980s. The United States is not an outlier in this respect: research intensity has declined less than in Germany but more than in France and the United Kingdom. For all countries but the United States, the pattern in Figure 15 is strikingly similar to the pattern of source-country effects in Figure 6. In contrast, U.S. R&D intensity has dipped as the United States has become a more potent source of patents.

Research intensity in the United States began to increase about 5 years before patenting started to rise. Twelve years later, research intensity began to decline as patenting continued to rise. If a shock to research productivity has driven the increase in patenting, then the behavior of research intensity in the past few years is anomalous. Alternatively, the behavior of research effort is evidence against the view that the continued rise in patenting is driven by a jump in research productivity.

What about the other variant of the fertile technology hypothesis, that the management of R&D has improved? As Rosenberg and Spencer note, "Firms are restructuring, redirecting and resizing their research organizations as part of a corporate-wide emphasis on the timely and profitable commercialization of inventions combined with the rapid and continuing improvement of technologies in use" (1964, p. 4). Consider the simplest formalization of this view, which is that effective research input is $R' = (1-b)R$ where b is the fraction of researchers who are not producing commercially viable inventions. An extreme view is that b is the fraction of researchers doing basic research with no foreseeable payoff to the firm. Better management of research corresponds to a reduction in b. Replacing R with R' in equation (6), we see that a decline in b is identical to an increase in research productivity ϕ. Therefore this variant implies that we should see a rise in research spending as well.

7 Conclusion

We began with the puzzle of why patenting in the United States by U.S. inventors has suddenly risen so much. Our initial conjecture, which we termed the friendly court hypothesis, was that the upswing resulted from changes in the legal environment for patents in the United States. We also considered two competing views, which we identified as the fertile technology and regulatory capture hypotheses. We explored several different dimensions of the patent data in search of evidence to either support or challenge the different hypotheses.

The key findings that emerge from our analysis are as follows:

- the recent surge in domestic patenting is particular to the United States.
- foreign patenting in the United States has increased since 1985, but was also increasing prior to that.
- patenting abroad by U.S. inventors has risen roughly in parallel to U.S. domestic patenting.
- decomposing international patenting patterns shows that the United States has not become a more attractive destination for patents.
- the recent increase in patenting was experienced broadly across the spectrum of different technologies.

- the growth of biotechnology and software patenting alone does not explain a large fraction of the overall increase.
- compared to earlier periods, in the late 1980s new and less established patentees are more aggressively exploiting the patent system.
- the fraction of domestic patent applications eventually granted by the U.S. Patent and Trademark Office has declined very little.
- the intensity of research effort has not risen at the same time that patenting has surged.

We seek to determine which explanation is consistent with all these facts. We question the simple variant of the friendly court hypothesis, since it suggests that the United States would show up as a more attractive destination and that the percentage of patent applications granted would fall. We question the regulatory capture hypothesis, since the share of patenting by smaller firms has recently increased, rather than fallen. We question the view that technological opportunities have driven the jump in patenting since it is not highly concentrated in particular technologies.

By a process of elimination, our analysis leads us to conclude that the increase in patenting has been driven by changes in the management of innovation, involving a shift to more applied activities. Looked at from the bright side, the jump in U.S. patenting both at home and abroad seems to indicate a real burst of innovation. The one piece of evidence to temper this rosy picture is that research investment has flattened in the 1990s.

Footnotes

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1. The data are from the U.S. Bureau of the Census (1976), Federico (1964), WIPO (annual issues), and tabulations of the U.S. Patent and Trademark Office. From 1900-1950 we proxy for U.S. domestic patent applications by multiplying (in each year) total U.S. applications by the fraction of total U.S. grants that were to domestic inventors (the fraction of patents granted to domestic inventors varied between about 85 and 90 percent over the years 1900-1950).

2. To distinguish between the variants of the fertile technology hypothesis, suppose that R&D is described by a process of random search as in Kortum (1997). The first variant of the fertile technology hypothesis corresponds to a stochastic improvement in some of the search distributions from which researchers draw their discoveries. The second and third variant correspond to an increase in how frequently researchers draw from the search distributions. We hypothesize that the effect of the former will be highly concentrated in certain emerging technologies, while the effect of the latter will be spread more evenly across the entire spectrum of technologies.

3. This section is based on Adelman (1987), Harmon (1991), Lerner (1995), Merges (1992), Tripp and Stokley (1995), and Wegner (1993).

4. Such comparisons can be misleading since the mixture of cases may have been different: firms may have altered their licensing and litigation practices over the four decades. Nonetheless, the magnitude and speed of the shift suggests that it cannot be attributed entirely to the changes in the mix of cases.

5. These countries account for a vast majority of the world's patents. The data were assembled from "Industrial Property Statistics," WIPO (annual issues). Adjustments were made to correctly count patents in the European countries following the introduction of the European Patent in 1978. Starting in 1985 WIPO has made these adjustments in their standard tables. Prior to 1960, the data are from Federico (1964).

6. Note the different scale for Japan's domestic applications. Okada (1992) finds that Japanese domestic patents contain only 20 percent as many claims of invention on average as do foreign patents in Japan.

7. The restriction that the value of patent protection does not depend on the source of the invention is a simple working hypothesis. It is in the spirit of the 1880 Paris Convention (which stated that foreign inventors should be treated the same as domestic inventors). There are, however, several arguments for why the restriction will not hold exactly. First, the value of patent protection is likely to be lower in foreign countries either because imitation of non-patented inventions is slower or because courts are biased against foreign patent holders in infringement cases. Estimates of imitation rates in Eaton and Kortum (1996, 1997) imply that patent protection is less valuable to foreign than to domestic inventors. Second, translation fees and the expense of dealing with patent agents abroad raises the

cost of obtaining foreign protection relative to the cost of obtaining patent protection locally. Third, the cost structure and timing for obtaining foreign patent protection is more complicated than what we have modeled. There are some fixed costs of applying for a patent that are unrelated to the number of countries in which protection is sought. Lundberg and Woessner (1993) document these fixed costs as well as other fees that are paid to extend the option of obtaining foreign protection beyond the usual one-year window. Putnam (1997) develops a dynamic model of the decision to seek foreign patent protection that incorporates these timing considerations.

8. The 110 thousand patent applications in the United States in 1982 imply a rate of invention of $110/.70 = 157$ thousand. If this rate of invention generates a 9 percent obsolescence rate, we can infer that there are 1.74 million markets. Given U.S. GDP of $3.24 billion in 1982, we obtain a potential market size of $1.78 million per invention per year.

9. The model implies that the value of inventive output (given optimal patenting decisions) is $47 billion, only somewhat above actual U.S. company funded R&D in 1982 of $40 billion. Only five percent of the value of inventive output is due to the value of patent rights, as expected given the slight difference in imitation rates between patented and unpatented inventions. Pakes and Schankerman (1986) compare their estimates of the value of patent rights to expenditure on R&D and report a figure closer to six percent.

10. Eaton et. al. (1997) estimate a similar model assuming a Poisson error and where the t subscript ranges over technologies (patent classes) rather than years. Here, because the cell counts are rather large, the Poisson assumption is easily rejected.

11. The estimation is performed in SAS using PROC GLM.

12. The parameterization that we choose follows that used in the analysis of categorical data by log-linear models (Bishop, Fienberg, and Holland, 1975; Christensen, 1990).

13. For example, in the case of destination-country effects (where there is only one dimension),

$$\prod_{n=1}^{5}(\hat{D}_n)^{1/5} = e^{(1/5)\sum_{n=1}^{5}\ln \hat{D}_n} = e^0 = 1,$$

where $\hat{D}_n$ is the estimate of D_n.

14. In the data with technology assignments we do not actually know the residence of the inventor, but we do know the country in which patent protection was first sought, i.e., the "priority" country. It turns out that U.S. priority is a good proxy for U.S. residence of the inventor. We therefore conduct the analysis using U.S. priority patents.

15. The technology assignments are available at an even more detailed level. For this analysis we decided that the more detailed classifications would generate problems due to changes in their definitions over time.

16. The figure suppresses the number of classes containing only one or two patents. In the 1980-'85 period there were 229 such classes and in the 1986-'91 period there were 929 such classes. We do not emphasize these numbers because they include patents that were not assigned to a proper IPC class for one reason or another, which is essentially a peculiarity of the data set.

17. We thank Mehmet Yorukoglu for suggesting that we examine this issue.

18. For application years 1991, 1992, and 1993 we adjust upward the number of patents granted to account for an estimate of how many are likely to be granted after 1995.

This estimate, which reflects the lag in the examination process, was based the application years of patents granted in 1993, reported in WIPO (1993).

19. The renewal rate began to decline after 1990, but the first year of decline is difficult to interpret because renewal fees rose by 70 percent effective in November 1990. The decline since 1991 is not likely due to changing renewal fees since fees have been constant in real terms since 1990.

20. The form of the invention production function is derived from a search-theoretic model in Kortum (1997). To facilitate studying the dynamics of the model, we ignore complications arising from the search-theoretic approach and instead follow the simpler quality-ladders framework developed in Grossman and Helpman (1991). We also ignore the patenting decision (by implicitly setting the cost of patenting to zero) since our goal here is to derive implications of the fertile technology hypothesis.

21. We interpret the labor force to be effective units of labor available to the economy so that its growth is driven by increases in either population, labor force participation, or human capital per worker.

22. The steps are: (a) log differentiate the state variable and plug in equation (7) to get $\dot{x}/x = n - I/(1+\gamma)$; (b) combine equations (5), (6), (8), and (10) to obtain (i) $I = \phi x - \frac{Y}{(1+\lambda)V}$ and (ii) $x = \frac{LA}{(1+\lambda)V\phi}$; (c) log differentiate (ii) from step (b), plug in equation (9), and equate the result to the result from step (a) to get $\frac{\lambda Y}{(1+\lambda)V} = \rho + (1 - \lambda - \frac{1}{1+\gamma})I$; (d) plug the result from (c) into result (i) from step (b) to get $I = -\frac{\rho(1+\gamma)}{\gamma} + \frac{(1+\gamma)\lambda\phi}{\gamma}x$; and (e) plug the result of step (d) into the result from step (a) to get equation (11).

23. Actual research intensity in the United States, as measured by employment in business enterprises, is currently only 0.6 percent (see Figure 14). Research intensity

as measured by spending (R&D financed and conducted in business enterprises relative to GDP) is currently about 1.5 percent in the United States (see Figure 15). Another measure of research intensity is R&D financed and conducted in business enterprises relative to the sales of R&D-performing companies, which currently exceeds three percent (National Science Board, 1996). According to the model, the level of research intensity as measured by spending is

$$WR/Y = \frac{\lambda(1+\gamma)\phi x - (1+\gamma)\rho}{(1+\lambda)\phi[\gamma - \lambda(1+\gamma)]x + (1+\lambda)\rho(1+\gamma)},$$

which in a steady state reduces to $\frac{\lambda(1+\gamma)n}{(1+\lambda)(\rho+n\gamma-\lambda n(1+\gamma))}$. The parameters above generate steady-state research intensity of 2.6 percent using the expenditure definition, the same as for the employment definition.

24. Our calibration of the model produces a rather small response of research intensity to a research-productivity shock. Here, we explore an alternative in which the inventive step is larger. Holding $\lambda(1+\gamma)$ and n fixed (so that steady-state output and productivity growth are unchanged) we raise λ from 0.03 to 0.1 and lower γ from 9 to 2. In the new calibration, research spillovers are smaller, but the average invention represents a ten percent (rather than a three percent) improvement over its predecessor. In order to produce roughly the same level of research intensity as in the original calibration, we introduce an imitation rate of 20 % (which is equivalent to raising the discount rate ρ from 0.07 to 0.27). (Note that these parameters are consistent with those used for the calibration in section 3.2, except that the cost of patenting is implicitly set to zero). With this calibration, a thirty percent research-productivity shock leads to a doubling of research intensity.

25. The data on research employment and R&D expenditure are from OECD (1995) and Main Science and Technology Indicators (magnetic tape). The data on GDP and the workforce are from Summers and Heston (1991), version 5.6.

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A Appendices

A.1 Patent Policy Abroad

Patent policy has also been the focus of reform efforts elsewhere. But as this appendix describes, these efforts have been distinguished more by the intention to undertake radical changes than the actual realization.

A.1.1 Europe

The origins of the patent system have been traced by Kaufer (1989) back to thirteenth century, when Germanic rulers in the Tyrolean region made awards for mining discoveries. [This section is drawn in large part from Epstein, Laurie, and Elder (1994), Paterson (1992, 1994, 1995), and Wegner (1993).] This approach soon diffused to Venice, which codified the first patent law in 1474. While Venice's economic importance faded soon thereafter, its patent code formed the basis for both the British and French systems.

The most direct ancestor of European patent law, however, was the German Patent Act of 1877. This measure, the first patent law for the newly-unified German state, incorporated for the first time the "first-to-file" principle: patent awards should be granted not to the party who first makes a discovery, but to the one whose patent application is received first in the patent office. Another distinctive feature—the publication of pending applications—was not introduced until much later. In 1964, the Dutch patent office began unilaterally publishing patent applications (in Dutch) 18 months after they were filed, whether or not they had been examined yet. The German and Japanese governments, arguing that they did not want to put their researchers at a disadvantage, rapidly followed suit.

The German industrial leadership of that era lobbied very aggressively for harmonization of patent rules across countries. The Paris Convention, which began being negotiated in 1880 and was signed by all major European nations in 1883, provided that each of the signatory countries would treat domestic and international patentees equally. It also stipulated that all applicants would have one year after filing domestically to undertake international patent applications. Finally, it stated that patent awards would be made to those who were first to file for inventions. (This latter provision prevented the United States from signing the agreement until 1903, when it was removed.)

One of the first priorities of the European Economic Commission in the 1950s was the development of a common European system of intellectual property protection. This resolve led to the 1963 Strasbourg Convention, which established the guiding principles for European patent policy. These broad goals, however, were not implemented until nearly fifteen years later.

Over a decade of subsequent negotiations was needed until the first concrete agreement, the Convention on the Grant of European Patents (EPC), was signed. When the agreement came into force in 1978, the process of granting patents in European nations changed somewhat. Much of the examination and issuance of patents shifted to a regional body, the European Patent Office (EPO). After approving an application, this body could grant a "bundle" of national patents: by 1995, the EPO could grant patents in 17 nations (Paterson, 1995). The EPO's patent examining procedures reflected those widely accepted in Europe at the time: e.g., making awards to those first to file for discoveries, publishing applications after 18 months, and granting awards for twenty years from the application date.

At the same time, the EPC agreement had important limitations. Most seriously, the patentee who wished to enforce his "bundle" of national patents could not pursue infringers in any centralized venue. Rather, he was required to sue in the courts of the nations where the infringements took place. Individual nations differed in how they interpreted these patent awards: e.g., the extent to which prior publication invalidated patents, or the patentability of software programs. While the EPC agreement encouraged nations to adhere to the standards laid out by the EPO, there was no requirement to do so.

A much more far-reaching reform was called for by the Convention for the European Patent for the Common Market. This agreement was signed in 1975, amended in 1985 and 1989, but has not yet implemented. The convention called for the EPO to award a single, European Community-wide patent. These awards would be enforceable in regional patent courts run by the European Community, with a centralized appellate court that would have the final say in all disputes. This effort to create a truly pan-European patent system, however, was only ratified by three countries in the two decades after it was originally negotiated (Paterson, 1995). The likelihood that it will be implemented in the near future appears low.

A.1.2 Japan

The Japanese patent law was introduced early in the Meiji era. [This section is based on Forstner (1993), Linck and McGarry (1993), Lindgren and Yudell (1994), Takenaka (1992, 1994) and Wegner (1993).] Many of the elements of the patent system were modeled after the German system. These included awarding patents to the party who was "first to file" and avoiding jury trials in adjudicating patent cases.

Particularly after World War II, the Japanese aggressively incorporated elements of foreign patent laws that they felt would help their industries "catch up" with technological leaders overseas. Among the key features were:

- the weaker novelty requirements of the American patent law, introduced in 1959. (By way of contrast, in many European nations, a single scientific publication is sufficient to disqualify a patent application.)
- the Dutch and German practice of publishing patent applications eighteen months

after filing, first allowed in 1971.

- the American system for protecting chemical products, introduced in 1986.

While these features were adapted from elsewhere, the Japanese system in practice was quite unique. In particular, the Japanese Patent Office (JPO) granted until 1988 only very narrow patents, typically with only one claim. This enabled firms to engage in a practice known as "patent flooding": the filing of numerous very narrow patents around the edges of a rival's patent (or application). Furthermore, firms could file oppositions to rival's patent applications before they were granted. The competitor's patent would not issue until this lengthy procedure was resolved.

The prosecution of infringements of one's patents was also ineffective. A U.S. General Accounting Office survey (1993) estimated that patent cases took between 50 percent and 300 percent longer to be resolved in Japan than in the United States. Cases were frequently heard in a series of up to several dozen brief hearings, each punctuated by a break of several months. Judges often exerted strong pressure on the parties to settle. Meanwhile, the courts, lawyers, and even expert witnesses charged fees to the plaintiffs in patent cases as a percentage of the damages claimed. This led plaintiffs to be more cautious in making damages claims. Over the course of the 1980s, these features of the Japanese patent system led to increasing protests by U.S. firms.

Formal negotiations over these issues were begun as part of the Structural Impediments Initiative (SII) talks in July 1989. These negotiations were designed to address a wide variety of impediments to free trade. The discussion of intellectual property issues in the joint report a year later, however, was confined to a general recommendation to speed the processing of patents through the JPO.

Two additional agreements were signed in 1994. In January 1994, Japan agreed to allow U.S. firms to file patent applications in English, as long as they were promptly translated into Japanese. (The United States already allowed Japanese applicants the reciprocal privilege.) The United States agreed in turn to implement the just-signed GATT agreement. In August 1994, Japan agreed to:

- allow applicants to request accelerated patent examinations.
- abandon the system of pre-grant oppositions (all other developed countries with this system, such as Germany, had previously abandoned it).
- streamline the hearings on oppositions filed after the patent was awarded.
- stop threatening firms that refused to license patents with compulsory patent licenses to rivals.

These moves have been criticized by observers, however, for their emphasis on changing the process of the Japanese Patent Office, rather than the substance of the examination and enforcement process. Many observers have argued that the reforms to date are unlikely to have much real impact.

A.1.3 International Efforts

A desire to establish a worldwide approach to patent awards inspired extended negotiations in the 1960s. [This section is based on Chaudhry and Walsh (1995), Tripp and Stokley (1995), and Wegner (1993, 1996).] These led in turn to the 1970 Patent Cooperation Treaty. This agreement systematized the timing of international patent filings, and made it easier to file for awards in multiple countries. Its impact on the differing structure of patent examination procedures and awards, however, was quite minimal (Cartiglia, 1994; Peterson, 1993).

More recent harmonization efforts started in 1984, when diplomatic efforts were begun by the United Nations' World Intellectual Property Organization (WIPO). In a series of meetings over the course of the 1980s, diplomats strove to design a workable framework for a global intellectual property protection system.

The fruits of these negotiations was the draft patent harmonization treaty released in December 1990. Among the key features of the proposed agreement were that applicants would have a grace period, as today, to file for international patent protection. They would only be required, however, to file a single application (in the inventor's native language, and later in English translation). The patent applications would be reviewed by a central office, which would include examiners from the various nations. The patent applications would be published eighteen months after the original application date.

The WIPO effort foundered, however, after encountering resistance from several nations, who objected to changing their patent systems to correspond to the proposed treaty. Particularly detrimental was Commerce Secretary Ron Brown's announcement in January 1994 that the United States would not abandon the "first-to-file" requirement. (The decision was made despite a largely favorable recommendation from the President's Advisory Committee on Patent Law Reform in 1992.) Since then, the WIPO effort has been largely dormant.

Several features of the draft WIPO agreement, however, were incorporated into the December 1993 GATT agreement (also known as the Uruguay Round agreement). There had been seven previous GATT agreements since World War II, but none had addressed intellectual property issues. The 1993 agreement, signed by over 100 nations, included provisions known as the Trade Related Aspects of Intellectual Property (TRIPs) agreement. This agreement established minimum standards for intellectual property protection, and insisted that the terms offered foreign and domestic patentees be equal. (Similarly, there could not be discrimination by class of technology.) Among the specific provisions for patents were that awards had to be made for twenty years from the filing date.

A.2 Identifying Biotechnology and Software Patents

Identifying biotechnology and software patents is difficult. These patents tend to be assigned to a variety of subclasses, often mixed in with other awards. We thus define biotechnology and software awards in two steps. First we identify firms specializing in the fields of biotechnology or software. We realize that we are consequently only examining a fraction of awards. Many biotechnology awards have been made to universities and major pharmaceutical companies, and many software awards to integrated computer hardware and software firms such as IBM. There seems little reason to expect, however, that the classification of patent awards to dedicated firms should differ from that of awards to established concerns. Second, we identify the international patent classes used most frequently by the biotechnology and software firms that we identify. Total patenting in this set of international patent classes is our proxy for biotechnology and software patents. We now turn to the details of these two steps.

A.2.1 Identifying Biotechnology and Software Firms

We identify biotechnology and software firms using two sources. In both cases, we use the records of Venture Economics to identify venture-backed firms. Venture Economics, a unit of Securities Data Company, compiles information from institutional venture investors. We include those firms in their classes 4000, "Biotechnology" and 2700, "Software." Many software firms—with small product development costs and modest working capital needs—do not, however, receive venture financing. We supplement the list of software firms with those active and research companies in Compustat whose primary industry assignment is (or was) in industry classes 7371, "Computer Programming Services," 7372, "Prepackaged Software," and 7373, "Computer Integrated Systems Design." This search leads to the identification of 350 biotechnology and 248 software firms. [To be included in Compustat, a firm must have made a public filing with the U.S. Securities and Exchange Commission. Neither of these data sources capture the many private software firms that have not received financing from institutional or public sources. Our goal, however, is to create a representative sample of firms whose technological focus is on software.]

We identify patents assigned to these firms using a CD-ROM database prepared by the USPTO (USPTO/OPDLP, 1990 and 1991). This includes both awards to publicly and privately held firms. We include awards to these firms' subsidiaries, joint ventures, and R&D limited partnerships. We identify name changes, joint ventures, subsidiaries, and research and development limited partnerships from a variety of reference sources (Corporate, 1993; National Register, 1992; NCBC, 1990a and 1990b; Oryx, 1992; Predicasts, 1993). We obtain information on the classification of each patent, as well as its award date, using BRS Information Technologies' PATDATA database (1986). These searches generate a total of 1661 biotechnology awards and 245 software patents. [A related question is the period over which to examine the patents. In a few cases, there are very early awards to these firms. These are almost invariably cases where a firm changed its technological focus over time: e.g., a firm that shifted from computer hardware manufacturing to software. In the case of biotechnology, we employ all awards after 1980, the year of the seminal Diamond v. Chakrabarty decision. In software there is no single clear-cut decision that opened the floodgates for patenting. Instead, we note that in the sample the pace of patenting of these firms is trivial prior to 1986. This observation is corroborated by the more general patterns documented by Soma and Smith (1989). We consequently use this as our first year. The biotechnology sample includes all awards through September 1992; the software sample through December 1993.]

A.2.2 International Patent Classes

We then identify which International Patent Classifications (IPCs) these software and biotechnology patents fall into. We will then look at the changing share of all awards in these classes, to determine if the overall shifts are driven by the surge of innovation in these areas. Because the IPC scheme has not widely used in economic research, in this section of the appendix we explain its construction and usage. [This discussion is based in part on Lerner (1994).]

Patent classifications are determined through a careful process. [This discussion is based on USPTO (1992).] A supervising primary examiner reviews the incoming patent applications, and assigns each to one of the over 100,000 U.S. patent subclasses. This classification determines which examining group reviews the application. A patent examiner in the assigned group then evaluates the proposed patent. To assess the novelty of the application, he searches previous patents issued in the original and related subclasses, as well as various other databases. At the time of award, the patent examiner assigns the patent to one or more U.S. patent subclasses. The examiner has a strong incentive to classify these patents carefully, because he uses these classifications in his searches of the prior state-of-the-art. To insure the accuracy of the classification and to maintain consistency across examining groups, an official known as a "post classifier" reviews the classification of all issuing patents.

At the same time as the examiner assigns the patent to U.S. patent subclasses, he also assigns it to one or more International Patent Classification (IPC) subclasses. The IPC system had its origin in the Council of Europe's 1954 "European Convention on the International Classification of Patents for Invention." The classification has been managed by an international (rather than a purely European) agency since 1969. Since that year, U.S. patents have been classified according to both the U.S. and IPC schemes (WIPO, 1981).

The IPC and U.S. classification schemes differ in three respects. First, the quality of the classification schemes differs. The World Intellectual Property Organization carefully guards the integrity of the IPC classification scheme through periodic reviews. While the USPTO goes to considerable pains to insure that patents are placed into the proper subclasses, it devotes limited attention to the arrangement of the U.S. subclasses: the U.S. classification has not had a systematic overhaul since 1872 (USPO, 1966). The power to introduce subclasses lies with the patent examiners, who can develop and locate "informal" subclasses with little review (USPTO, 1984). Second, the principles that motivate the two classification schemes differ. As the U.S. Patent Office stated shortly after it began reporting IPC classifications: "It is well recognized that the two systems are conceptually different; the U.S. system being based primarily on structure and function while the International Classification is primarily industry and profession oriented" (1973, p. 154.3).

Thus, the IPC scheme reflects the economic importance of new inventions, as opposed to the technical focus of the U.S. scheme. Finally, the first four levels of the IPC classifications are nested. This is in contrast with the U.S. system, where 435/40 is a subset of 435/39, which is in turn a subclass of 435/34, but 435/41 is not a subclass of any of these (USPTO, 1993).

Figure 1: Patents by U.S. Inventors

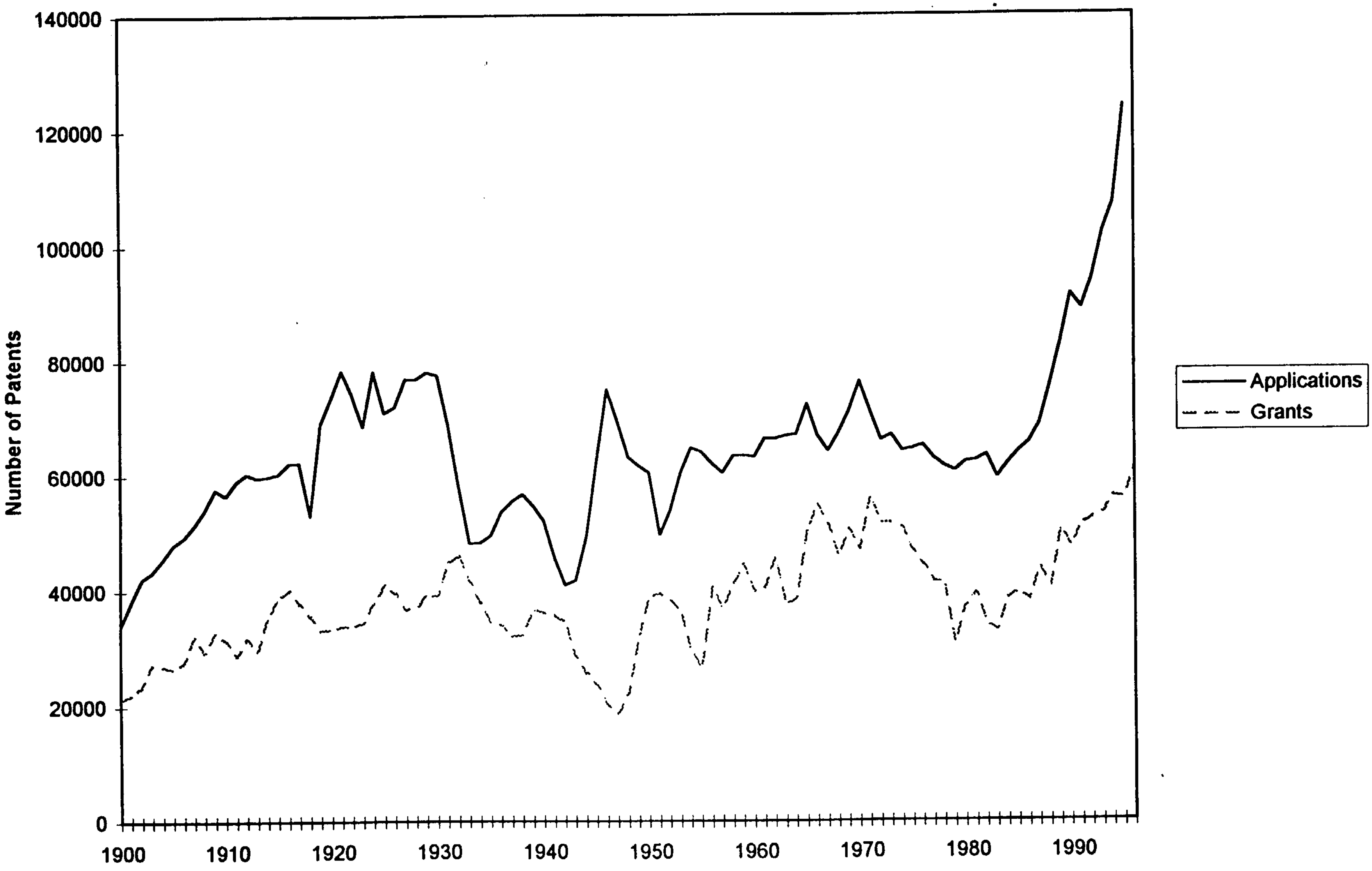


Figure 2: Domestic Patent Applications

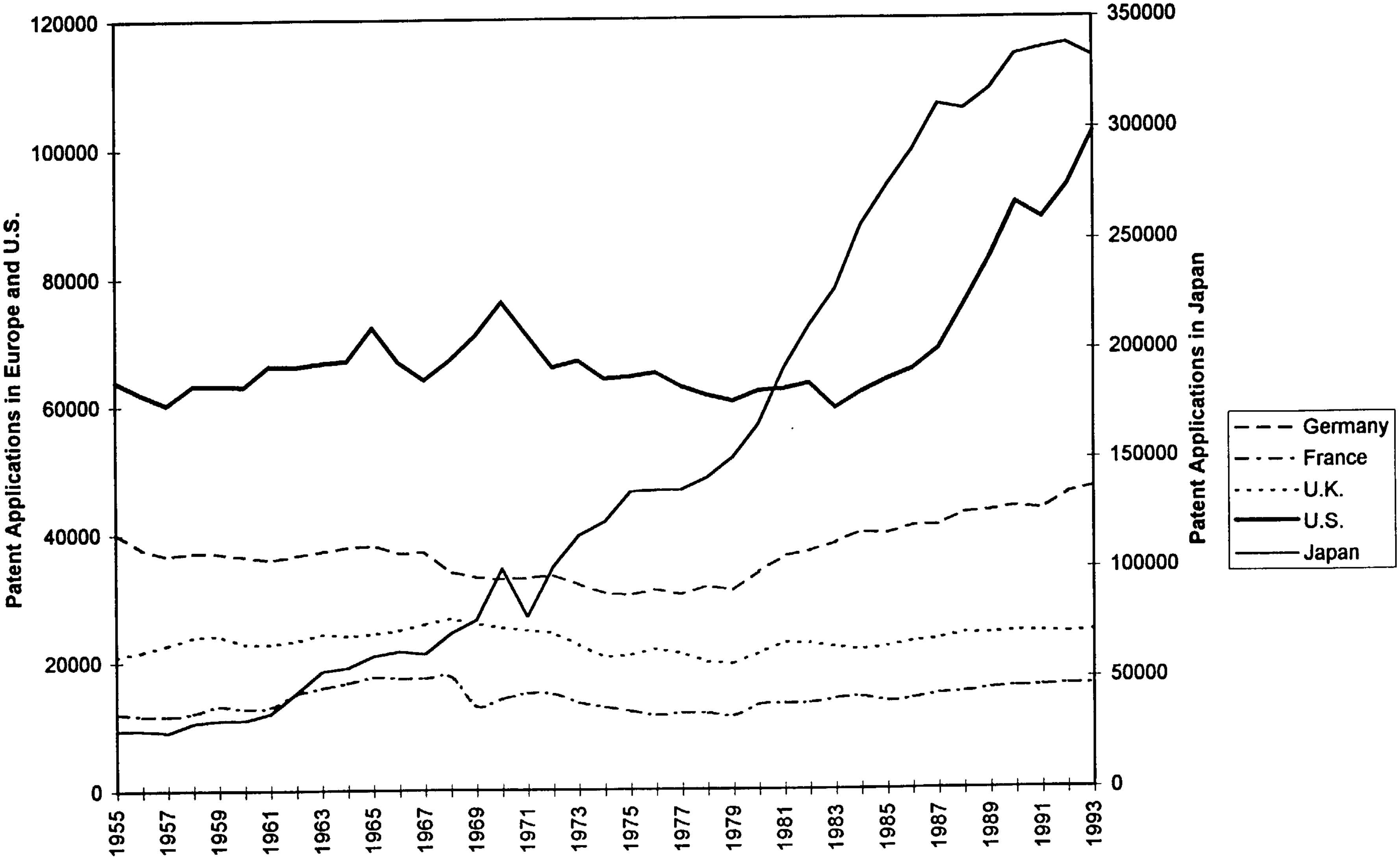


Figure 3: Foreign Patent Applications in the United States

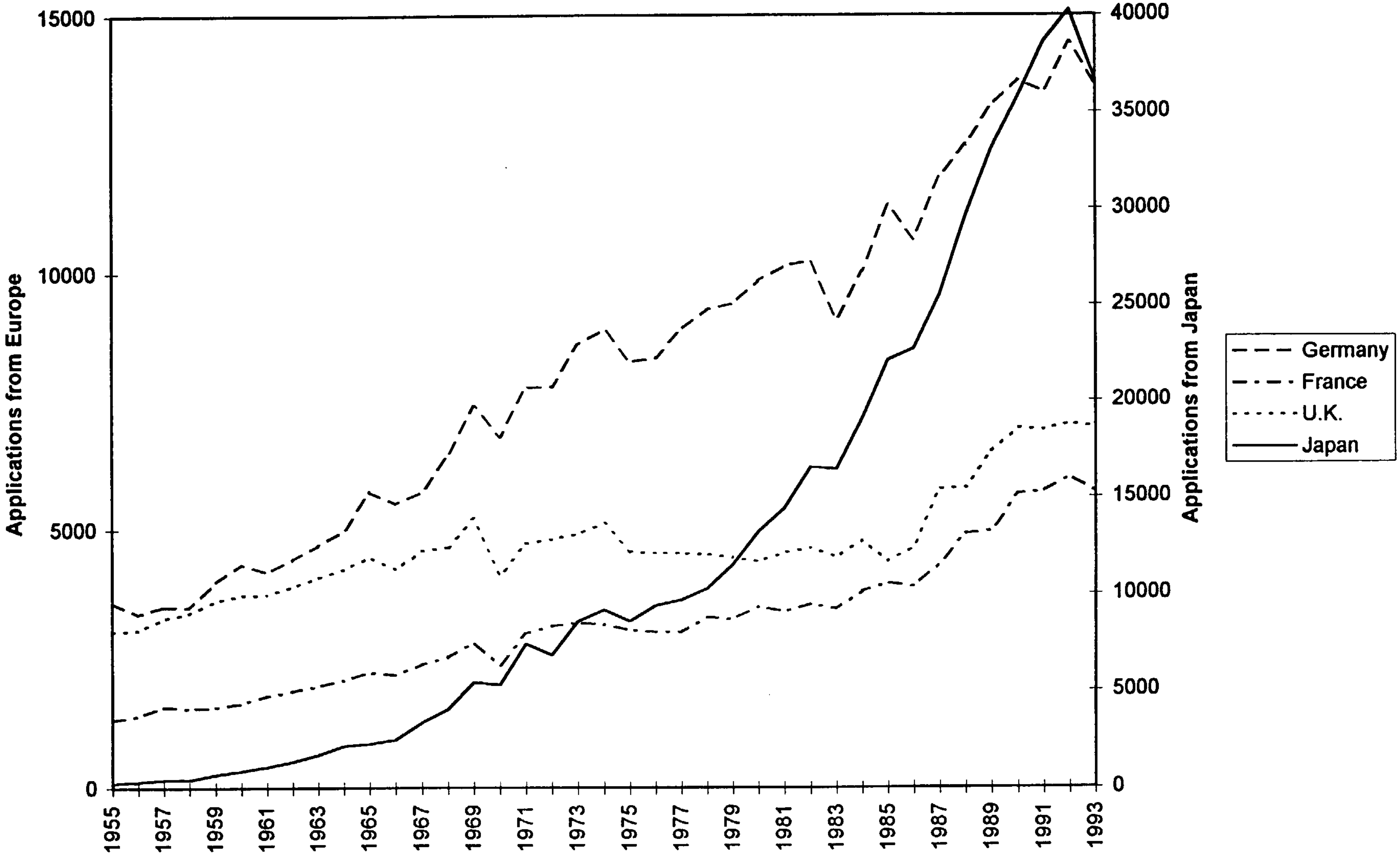


Figure 4: U.S. Patenting Abroad

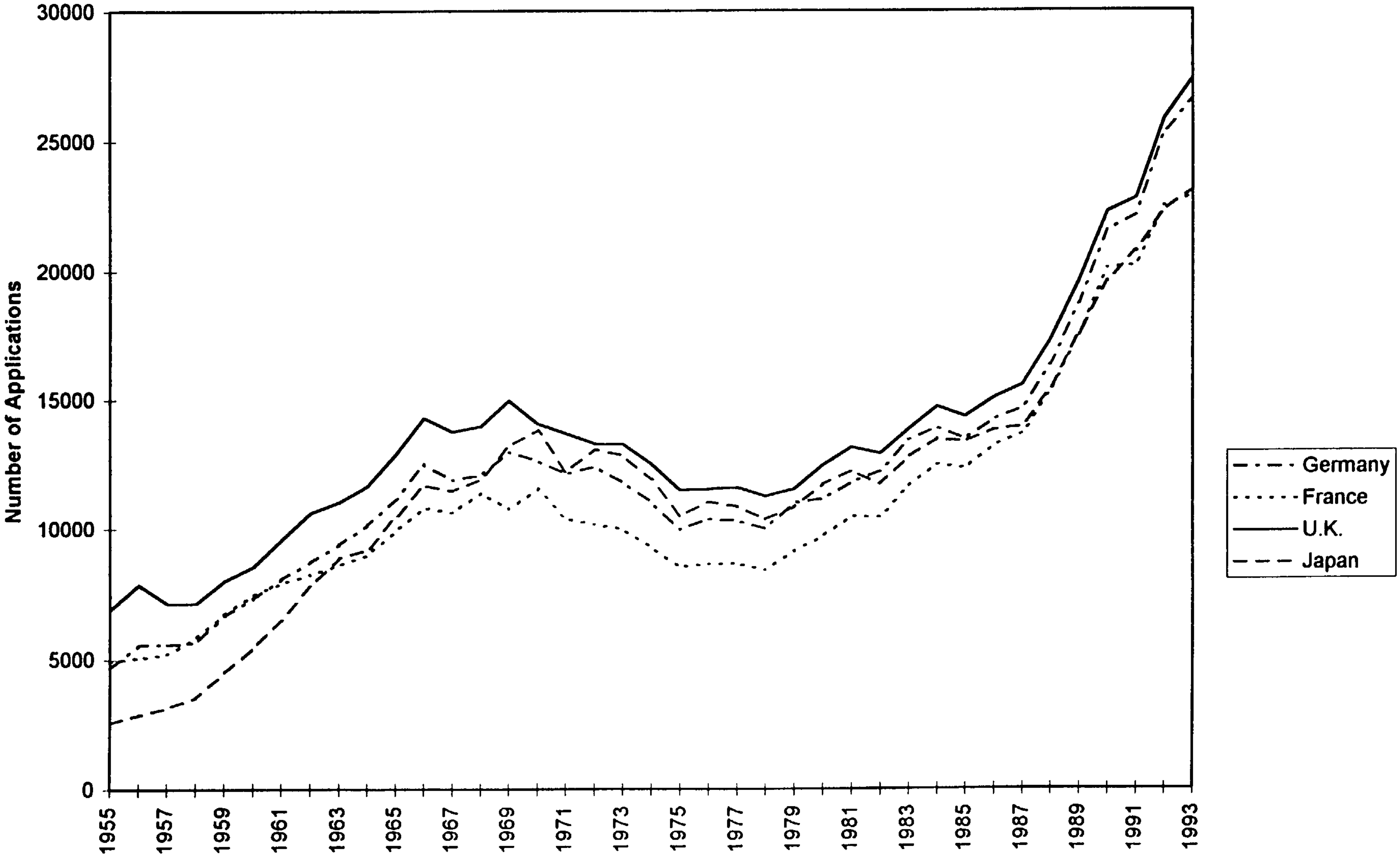


Figure 5: Decomposition of U.S. Domestic Patenting

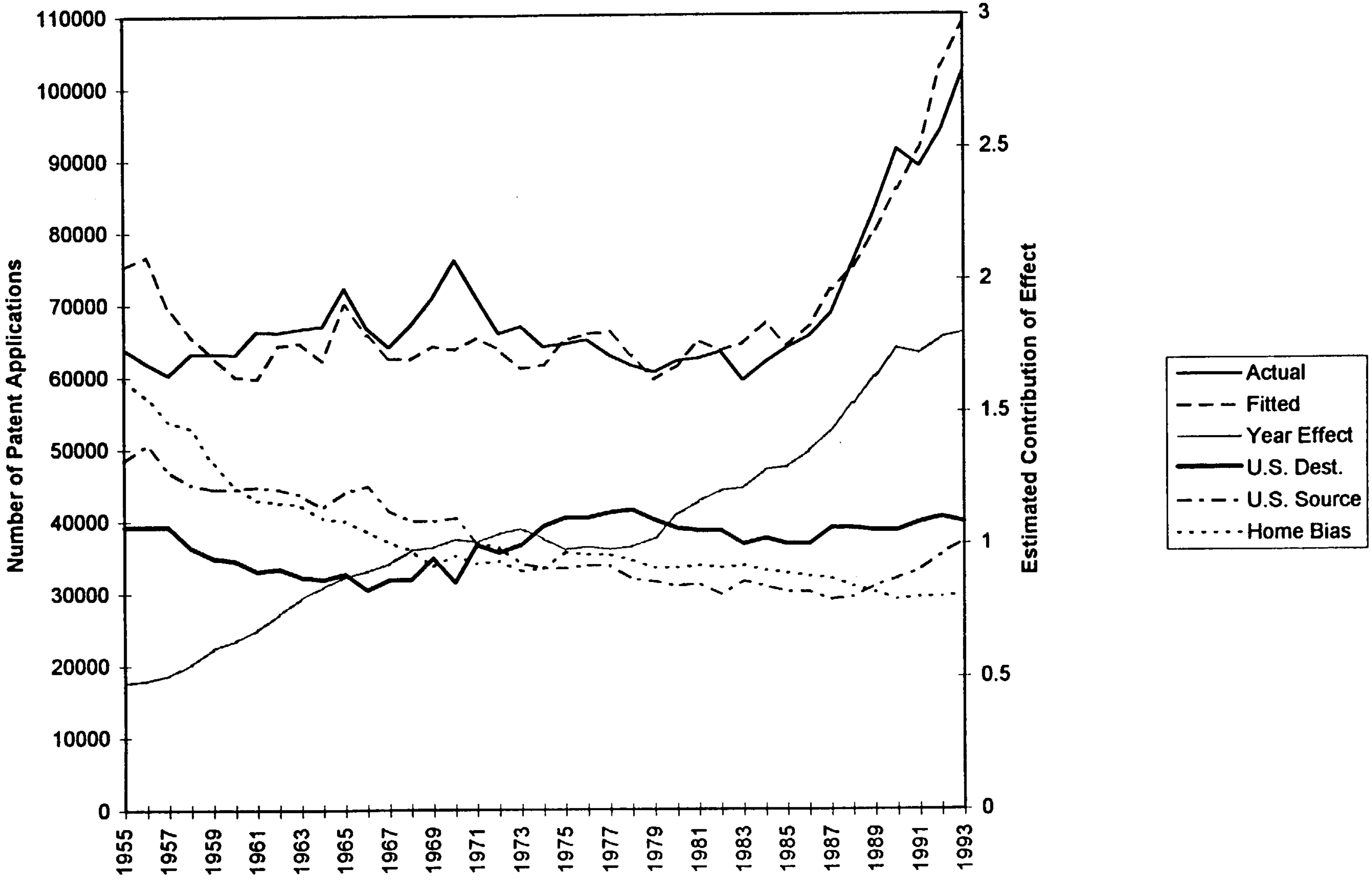


Figure 6: Estimated Source-Country Effects
(normalized to 1982=1)

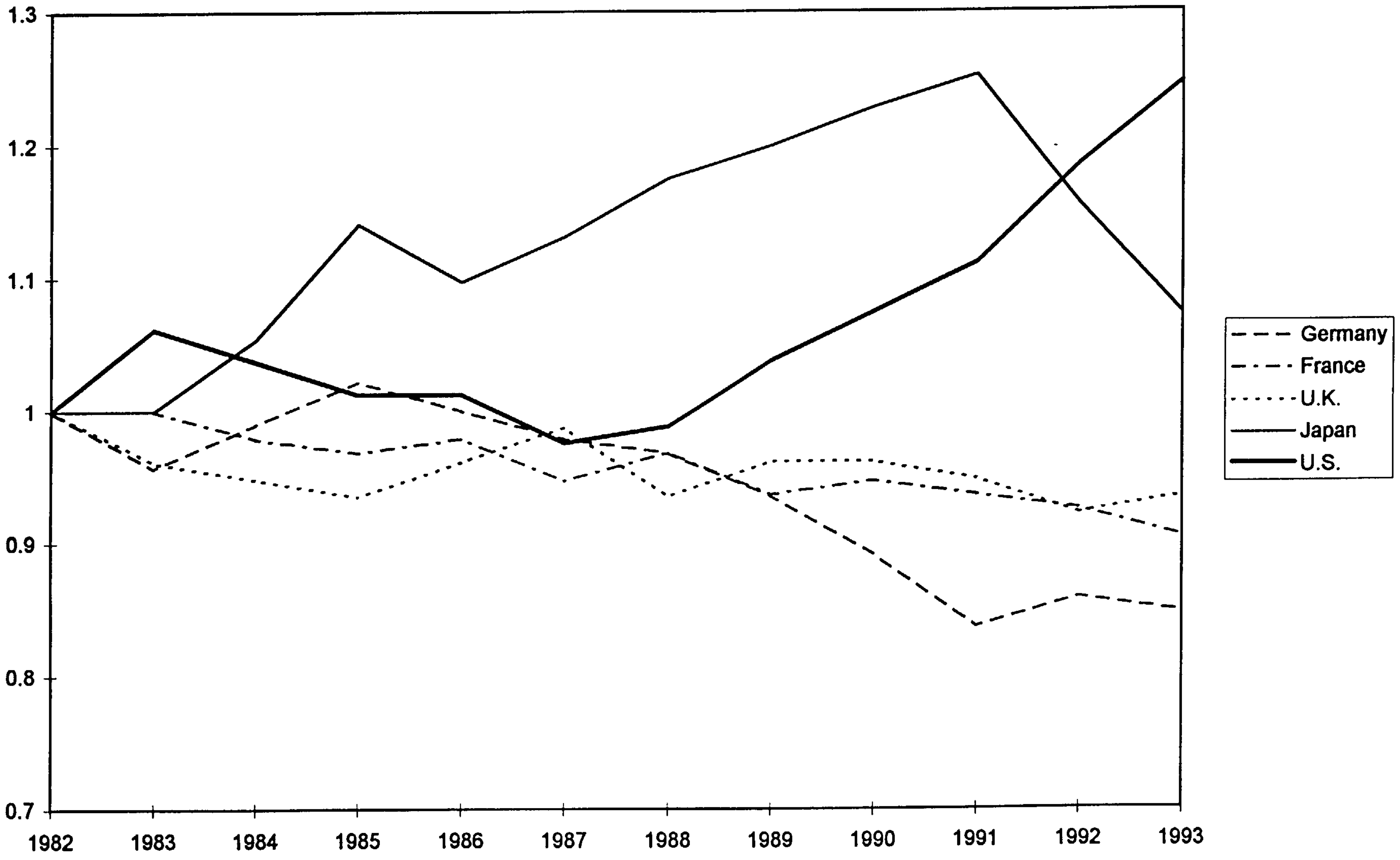


Figure 7: Estimated Destination-Country Effects
(normalized to 1975=1)

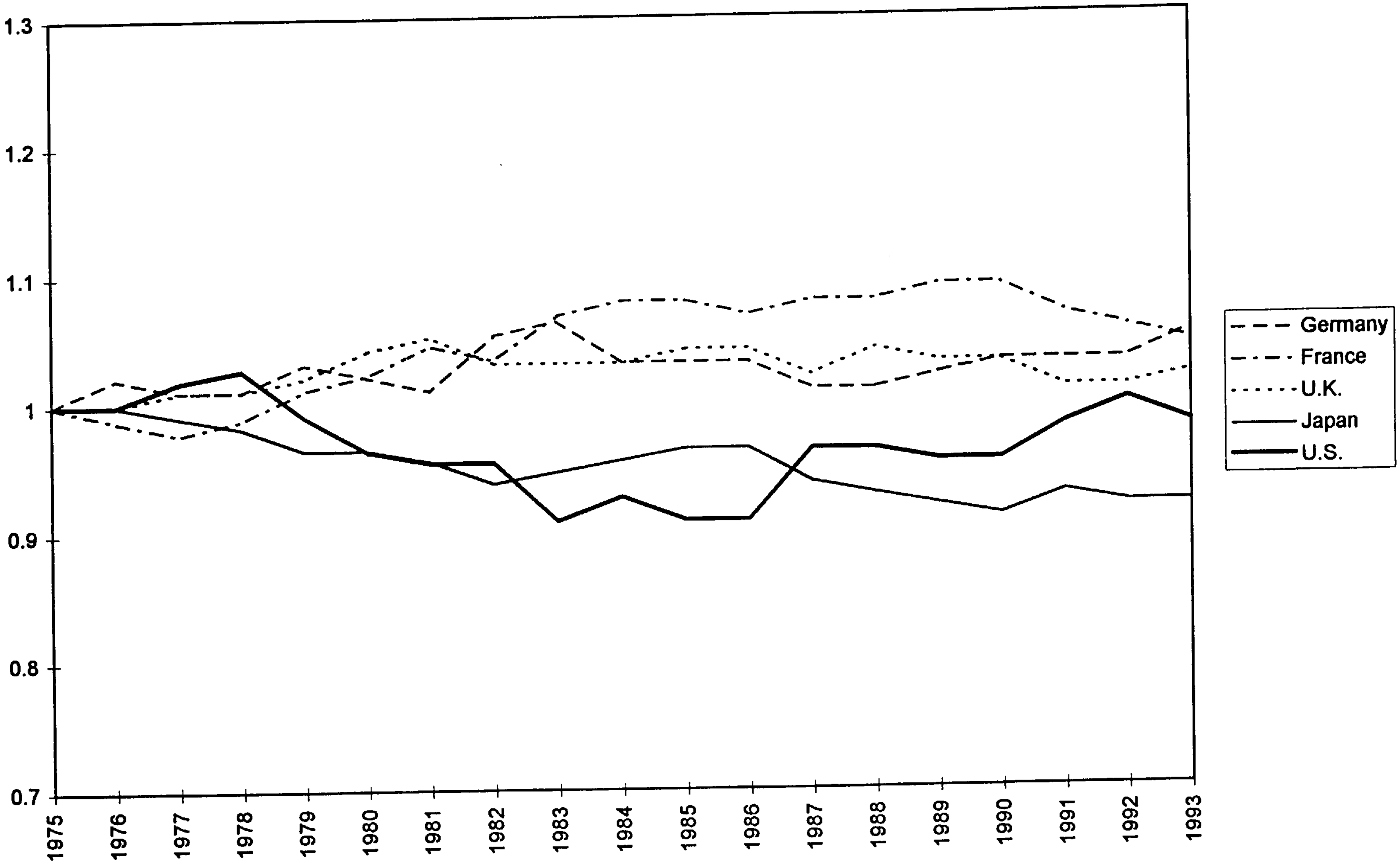


Figure 8: The Size Distribution of Technology Classes

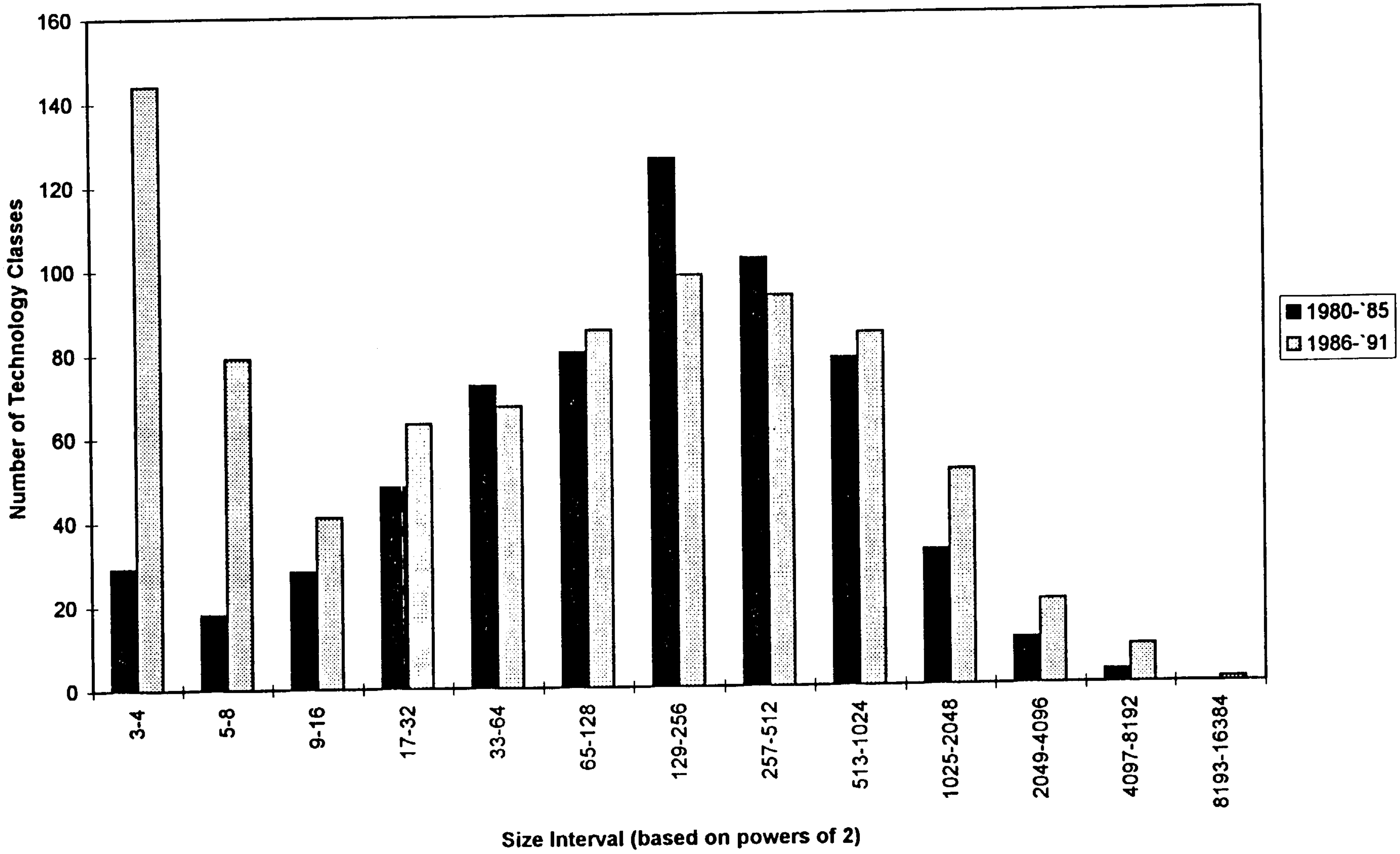


Figure 9: The Distribution of Patenting Growth Across Technologies

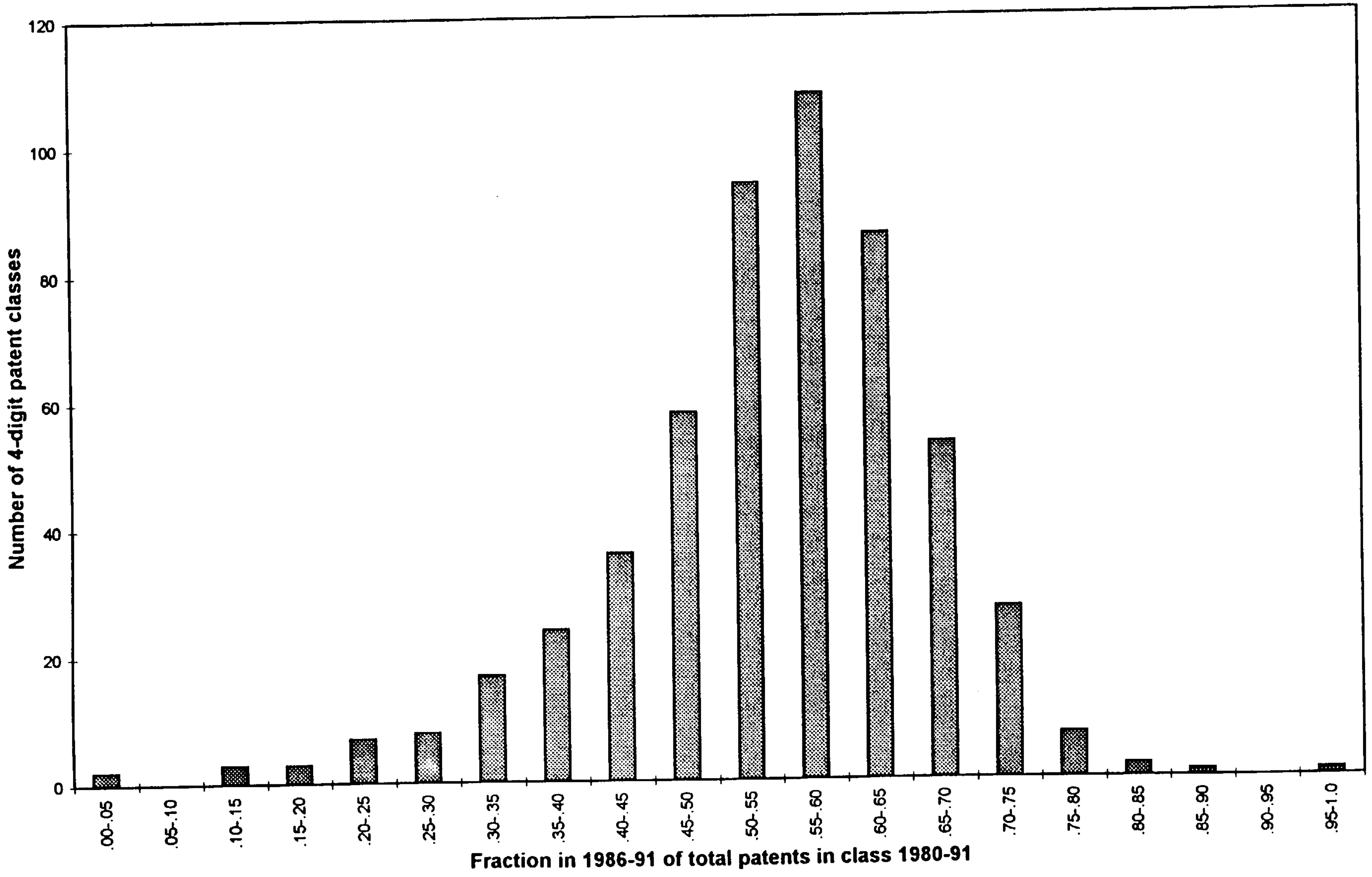


Figure 10: Patenting in Biotech and Software

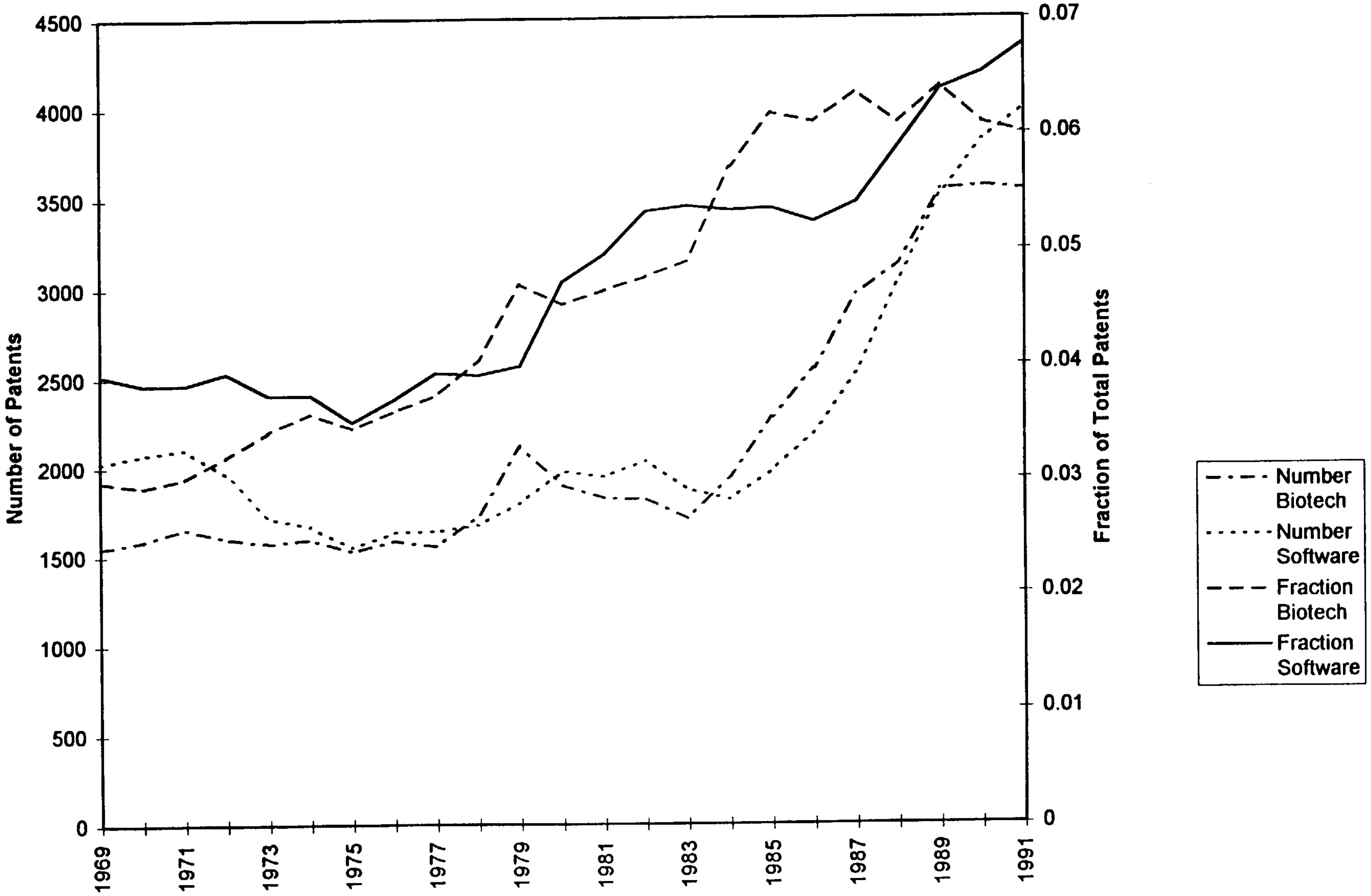


Figure 11: Patenting by Inexperienced Patentees

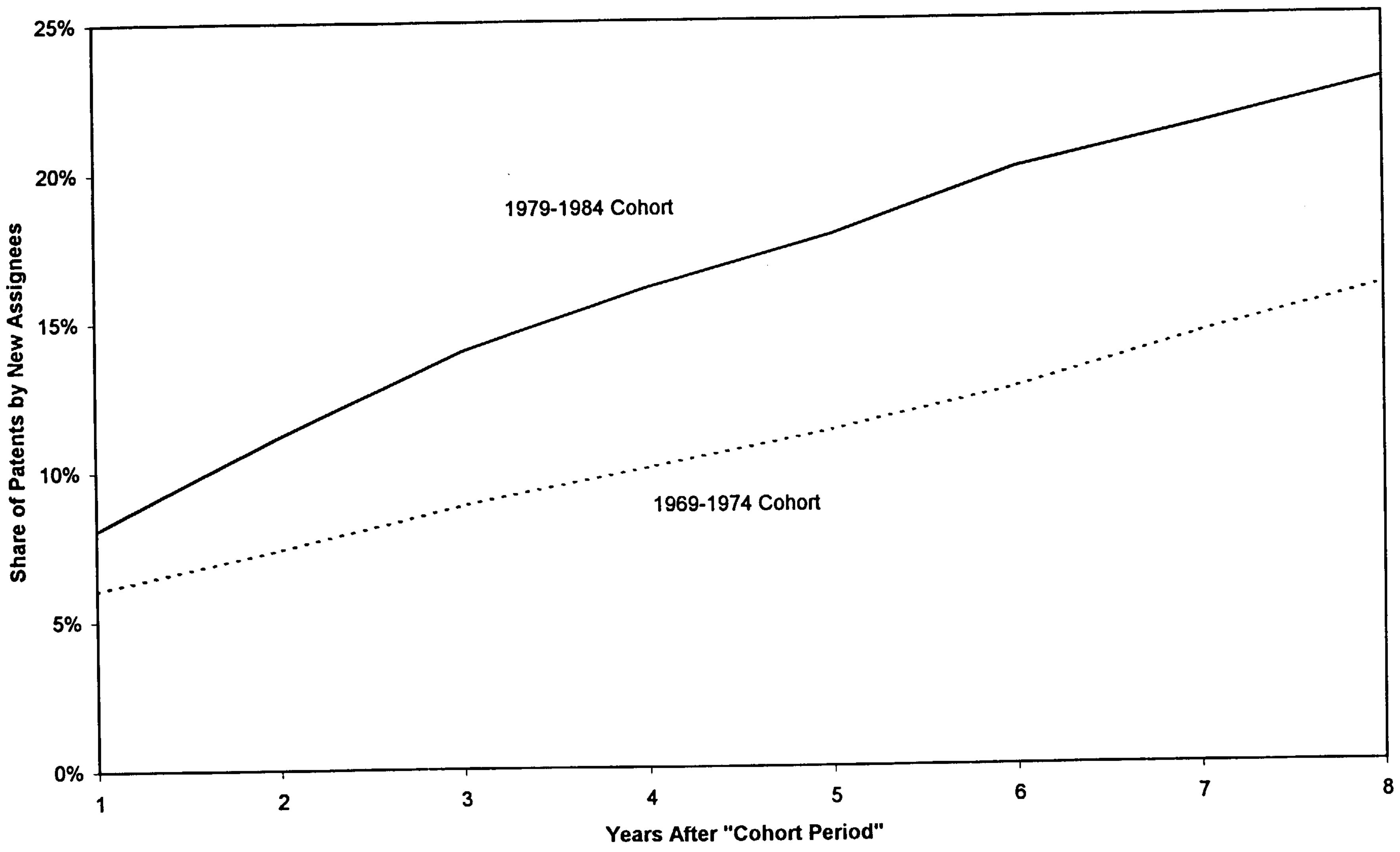


Figure 12: Patenting by Least Experienced Relative to Most Experienced

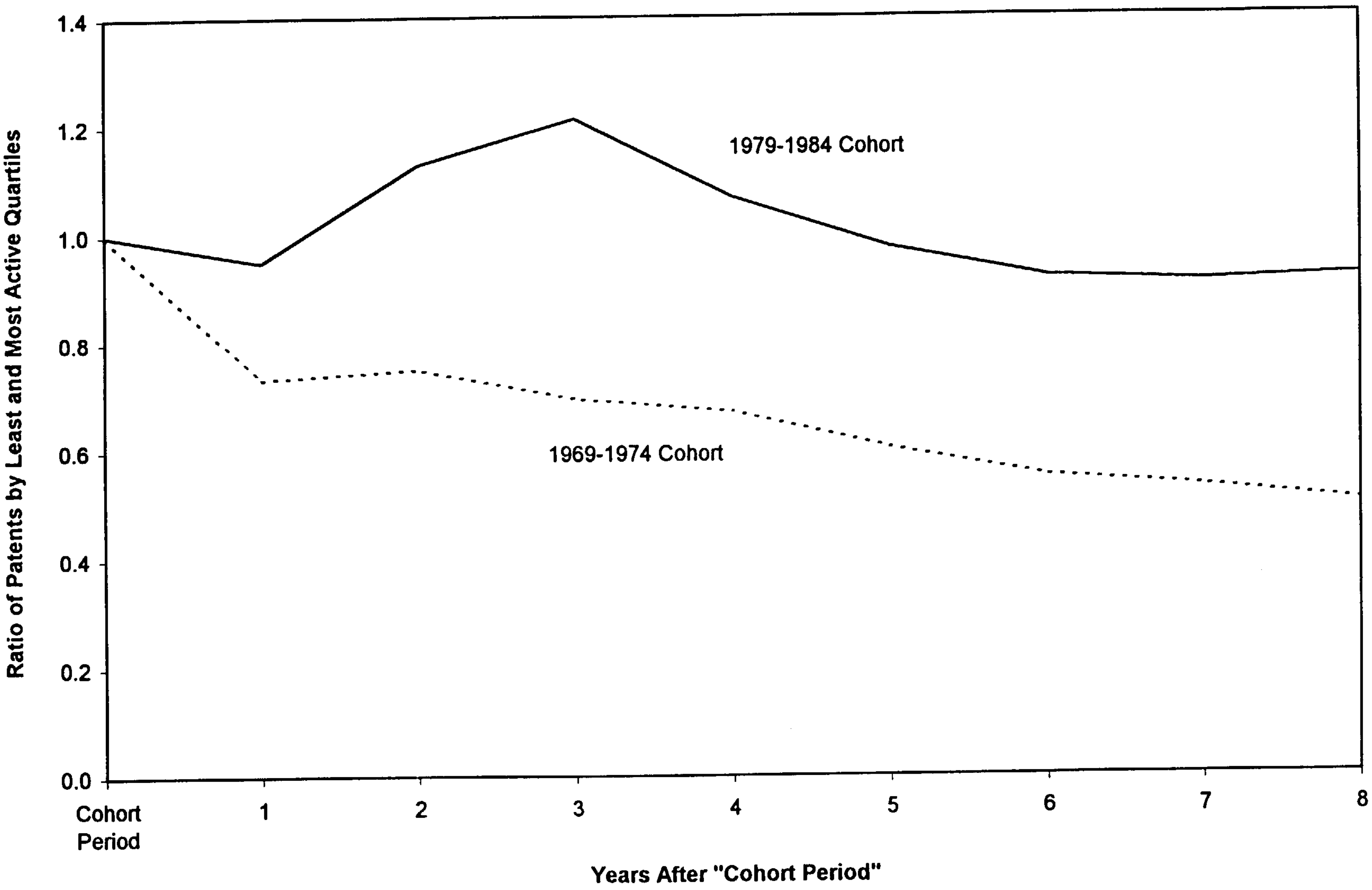
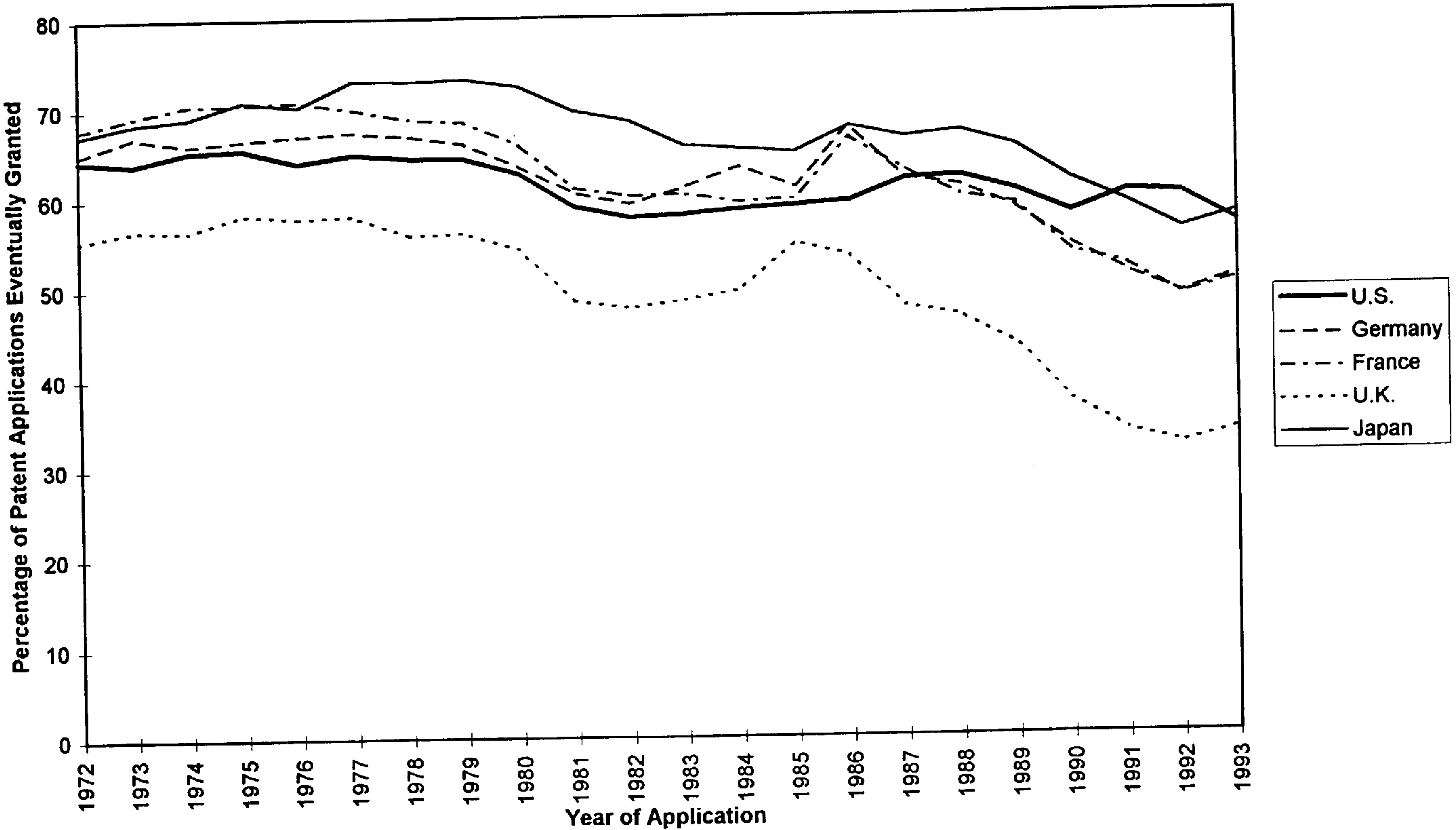


Figure 13: U.S. Patent Grants Relative to Applications by Residence of Inventor



(1991-1993 data includes patents expected to be granted after 1995)

Figure 14: Research Scientists and Engineers Relative to the Labor Force (employed in business enterprises)

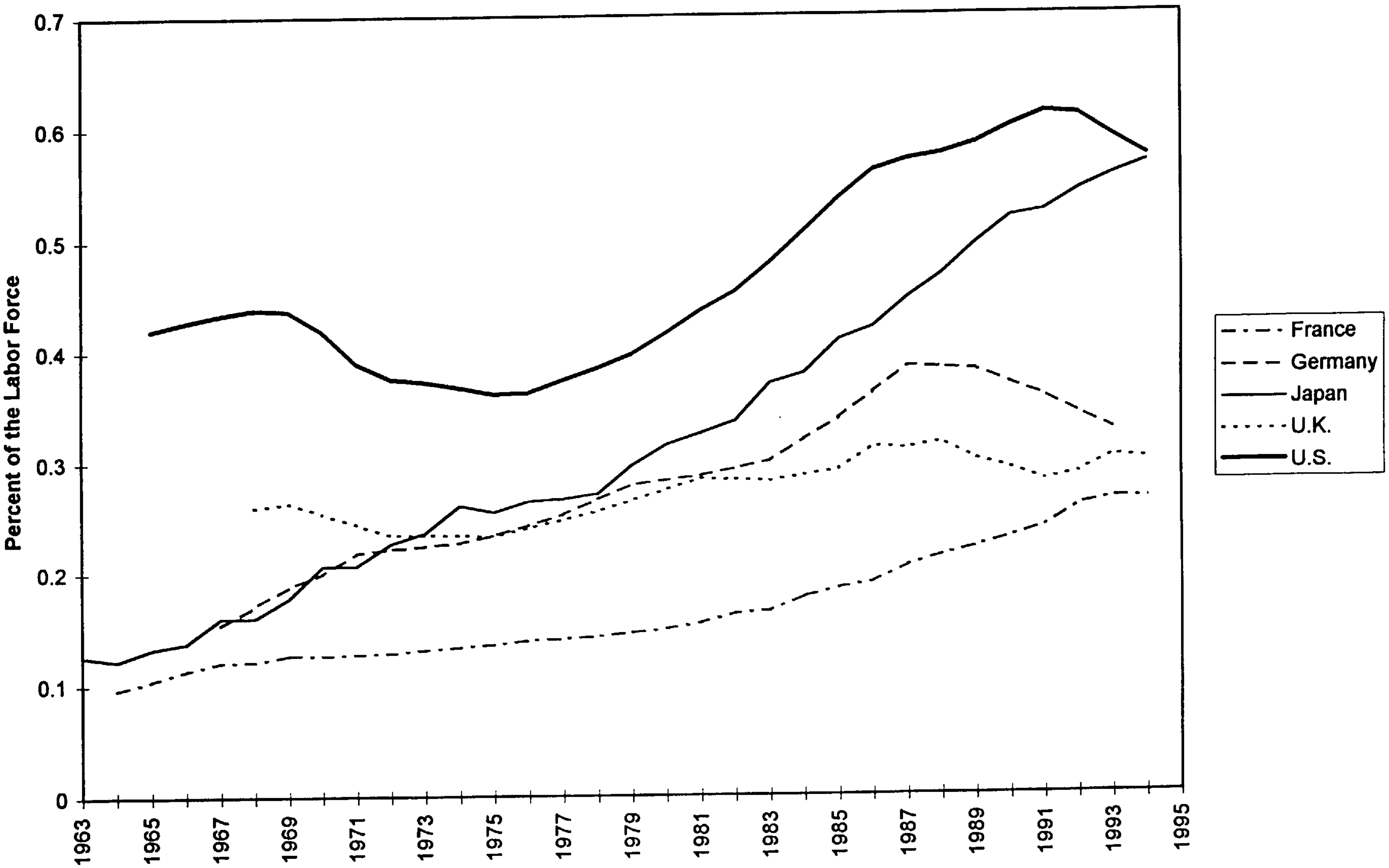


Figure 15: R&D Relative to GDP
(financed and performed in business enterprises)