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**Working Paper**

## Patent Data by Industry: Evidence for Invention Potential Exhaustion?

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CENTER DISCUSSION PAPER NO. 620

PATENT DATA BY INDUSTRY:  
EVIDENCE FOR INVENTION POTENTIAL EXHAUSTION?

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**Patent Data by Industry: Evidence for Invention  
Potential Exhaustion?**

Abstract

The ratio of patented inventions to real R&D expenditures (R&D), or to the number of scientists and engineers (S&E) engaged in R&D, has declined in all countries for which data are available over the 1969 to 1987 period. Not only have declines in these ratios taken place, but these declines have been large. By 1985-6 patent/R&D ratios were only 55, 44, 42, 40, and 75 percent of the 1972-3 levels for the U.S., U.K., Germany, France, and Japan respectively.

This paper examines data for these ratios for twenty-three industries for the 1969 to 1987 period in the five leading invention producing countries. The objective is to determine how much of the decline in these ratios can be attributed to changes in the "propensity to patent" (i.e., to changes in the proportion of inventions that are patented) and how much can be attributed to "invention potential exhaustion" (i.e., to a real reduction in invention made per unit of inventive effort.)

Changes in the ratio that are common across industries in a given country are likely to be due to changes in the propensity to patent. Invention potential exhaustion is likely to differ by industrial field and to have some international components; declines in the ratio that are common over countries within an industry suggest that invention potential exhaustion is the source. Tests showed that a considerable part of the decline in the ratios is a common decline over all industrial fields. However, significant industry effects common to several countries were also found. The paper discusses why some of these latter effects might also be due to changes in propensity to patent, however. More data are required to resolve the issue.

KEY WORDS: technology, invention potential

**Patent Data by Industry: Evidence for Invention  
Potential Exhaustion?**

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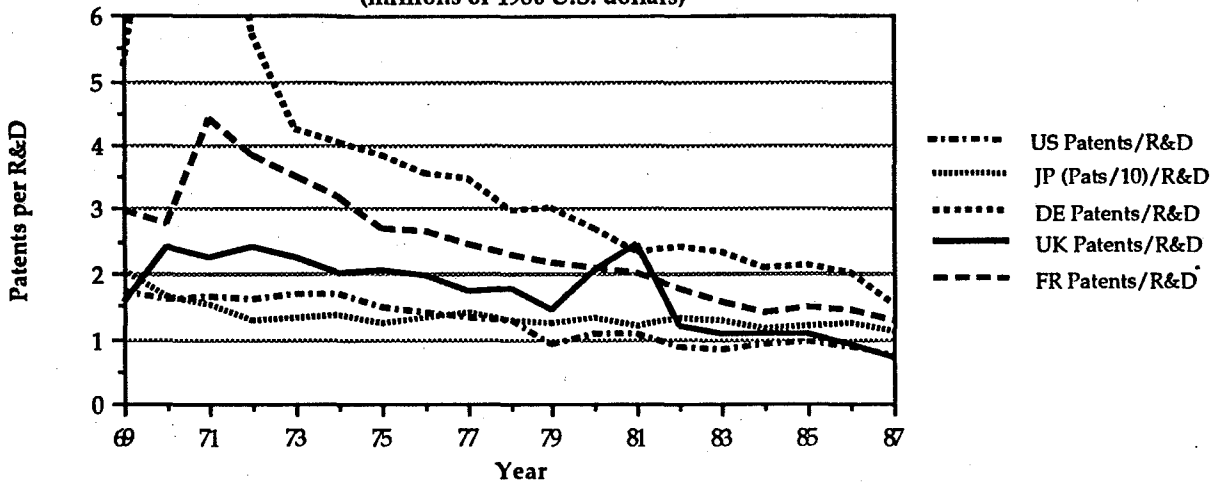
The ratio of patented inventions to real R&D expenditures (R&D), or to the number of scientists and engineers (S&E) engaged in R&D, has declined in all countries for which data are available over the 1969 to 1987 period. Figure 1 (below) depicts these ratios for the years 1969 to 1987 for the U.S., U.K., Germany, France, and Japan. Not only have declines in these ratios taken place, but these declines have been large. By 1985-6 patent/R&D ratios were only 55, 44, 42, 40, and 75 percent of the 1972-3 levels for the U.S., U.K., Germany, France, and Japan respectively.<sup>1</sup>

A number of explanations for the decline in these ratios have been put forward. Griliches (1984, 1989) lists several reasons for a decline in the "propensity to patent", i.e., in the proportion of inventions actually patented, and cites additional evidence that R&D "potency" (as measured by its productivity impact) has probably not declined in the U.S. in the 1970's.<sup>2</sup> In addition, simple versions of "optimal R&D" investment analyses suggest that the declines in this ratio probably do not constitute real changes in R&D potency. The optimal R&D investment strategy argument in its simplest form is that the level of R&D investment will adjust so as to keep the "marginal product" of R&D from falling. Since the real price of conducting R&D has apparently risen in the U.S., Germany, and Japan (see Figure 1), it appears unlikely that the marginal product of R&D has fallen and, by inference, it also appears unlikely that the real average product of R&D has fallen if average products are closely related to marginal products.<sup>3</sup>

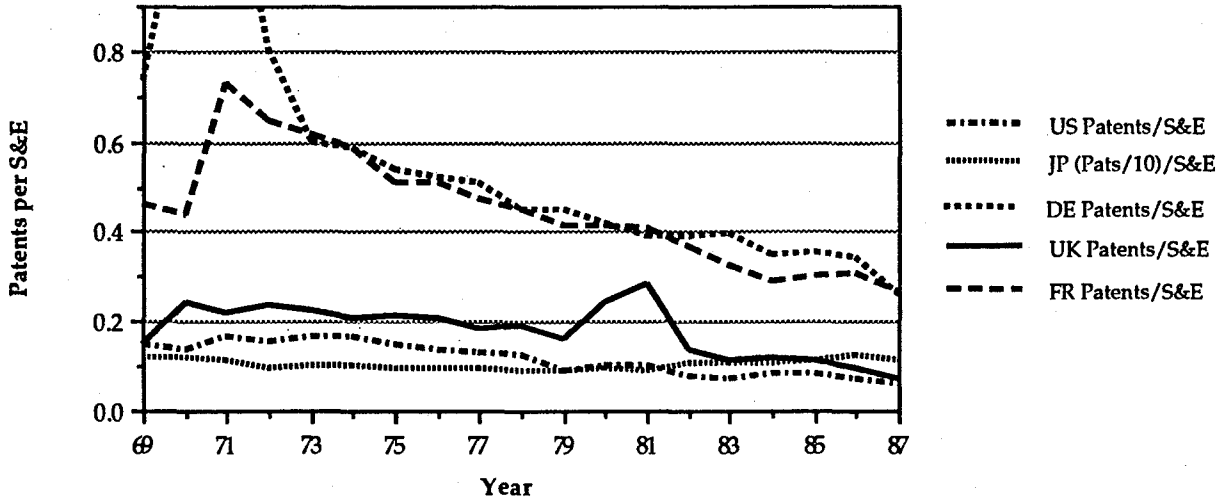
Evenson (1984) argued that since research activity entails considerable elements of "search" in the form of experimentation and trial and error activities, it is almost certainly subject to diminishing returns or

Figure 1

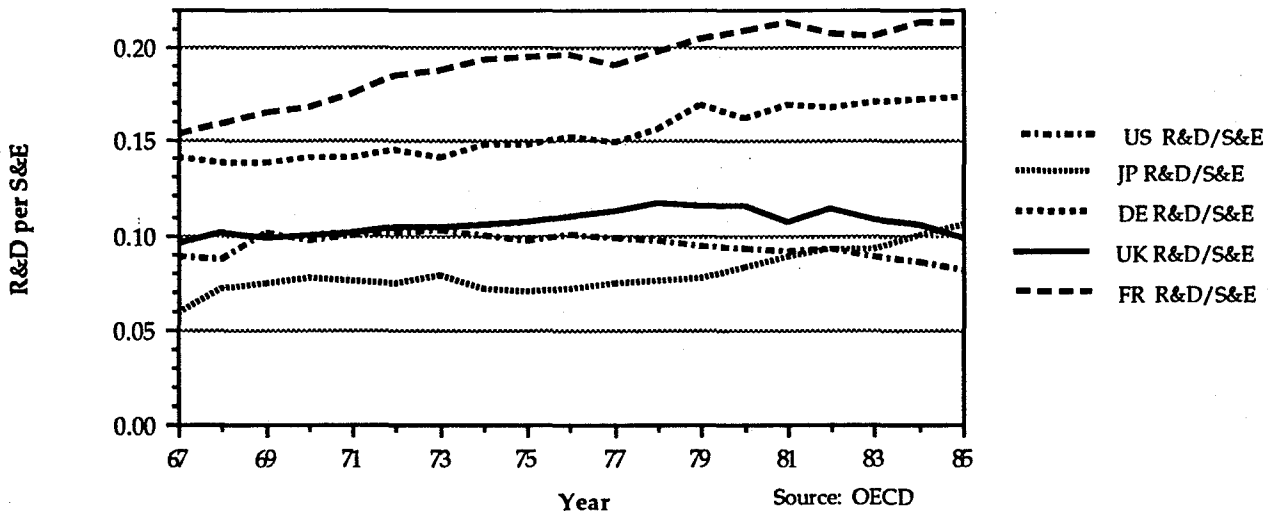
**Annual patents per R&D**  
(millions of 1980 U.S. dollars)



**Annual patents per S&E**



**Annual R&D per S&E**  
(millions of 1980 U.S. dollars)



Source: OECD

"invention potential exhaustion" (IPE). Furthermore, since R&D is time and sequence dependent, the relationship between average products and marginal products in the short-run is such that the optimal R&D argument, (even if one believed that private firms and public agencies were truly optimizing), could not be relied upon to rule out IPE. The underlying model for the IPE explanation also implies that there will be a "competition" explanation for declining patent/R&D (S&E) ratios associated with increases in the levels of inventive activity by foreign inventors under conditions of IPE. This competition effect is not, however, likely to be important under the "recharge" conditions required for constant R&D potency. (See Part I below.)

It is very difficult to distinguish between the IPE explanation (and the associated competition explanation) and alternative explanations utilizing aggregate national data as depicted in Figure 1 (i.e., aggregated over all industries and technology fields). The fact that the decline in these ratios is almost universal across countries (Evenson 1984) is favorable to the IPE (competition) explanation since this explanation does predict internationally correlated changes in average products of R&D.<sup>4</sup> Unfortunately some of the competing explanations also imply international correlations (see below).

Recently it has become possible to "concord" patent data to industry categories and thereby to compute patent to R&D and patent to S&E ratios for industries of manufacture in a number of countries.<sup>5</sup> This paper investigates whether these industry data provide additional insight into the problem of explaining changes in these ratios. The expectation is that this new data should be helpful in this regard since the IPE (and competition) explanations imply that IPE is likely to be industry-specific and highly correlated internationally, while some of the alternative explanations do not imply industry-specific effects and/or do not imply strong international correlations.

Part I of the paper discusses the basis for the competing explanations and the implications for tests using industry data. Part II provides a descriptive summary of patent and R&D data for the five major invention producing countries for the 1969-1987 period. A number of simple tests of alternative explanations are then reported. Part III reports a provisional effort to explore the "competition" and disclosure implications of the IPE explanation. Part IV discusses further data requirements and tests for further work on the topic.

### I. Explanations for Changes in Patent/R&D (S&E) Ratios

Explanation of changing patent/R&D (S&E) ratios can be treated in two categories: a) changes in the patent/invention ratios (propensity to patent) and b) changes in the invention/R&D (S&E) ratios (potency).

#### A. Changes in the "Propensity to Patent" (patents/invention)

Changes in the proportion of inventions that are patented to total inventions made will, of course, result in changes in the patent/R&D ratio even if no changes occur in the underlying potency factors. Griliches (1989) lists a number of these propensity to patent factors and concludes that they probably explain the major part of changes in the patent/R&D ratios. Propensity to patent factors can be divided into two categories: those that are country-, but not industry-specific and those that are country- and industry-specific.

##### 1. Country-, but not industry-specific factors.

A number of the propensity to patent factors are due to changes in administration and legal system costs that enter into the decision to patent. These include:

- a) Legal and administrative fees.
- b) Time lags between application and grant.
- c) Expected litigation and regulatory costs associated with patenting.

In addition, patent officials may change granting standards and changes in

budgets and staff may have additional unmeasured costs.

This set of cost factors can thus explain a falling patent/R&D (S&E) ratio across all industries within a country. Rising costs of this type will reduce the propensity to patent. These factors should affect all industries in a roughly proportionate way.<sup>6</sup>

## 2. Country and industry specific factors.

There are several propensity to patent factors that do have an industry specific component. (This is unfortunate for testing purposes because the IPE explanation is also industry-specific - see below.)

The first is that the distribution of inventions by value (profit advantage per unit times expected units sold over time) may differ by technology field or industry of manufacture. A rise in the costs of obtaining patents will reduce the patent/R&D (S&E) ratio by more in a field where a large proportion of inventions are small, low value inventions, than in a field where inventions tend to be confined to larger, high-valued inventions.

Patent law also requires that invention details be disclosed. Thus there is a "loss of secrecy" cost to firms that affects the propensity to patent. This cost is, to some degree, industry-specific.

In addition, the benefits to patent protection are also industry specific and changes in these benefits may well produce industry specific changes in propensities to patent. These benefits are roughly proportional to the expected "size" of the market (including the international market). That is, for a given invention with a particular expected "profit advantage" (per unit of product embodying the invention), growth in its market will change the likelihood that it will be patented. Tax treatment and trade policies will also affect benefits.

In addition to these factors a factor common to the propensity to patent explanations and the potency argument is the expected obsolescence factor. An



inventor will expect that the benefits of an invention will be eroded by subsequent inventions that are close substitutes (or imitations; see Mansfield 1986). Thus, as foreign inventors enter the field, a country's invention may be subject to more expected obsolescence and this may affect propensity to patent. (It also affects potency via competition effects; see below.)

#### B. Changes in Potency (the IPE Explanation) (Inventions/R&D)

Any discussion of R&D potency requires some specification of the discovery or invention function itself. Little empirical or analytic work on this topic is available. The "search model of invention" (Evenson and Kislev 1975, Lee 1982), in which invention is the outcome of directed search processes or "trial and error" activities, is one of the more reasonable specifications of invention functions. Induced innovation models typically have simply postulated standard convex functions and have given little or no thought to the invention process itself. Standard invention analysis usually treats invention as a single period or single "race" phenomenon (Nordhaus 1972, Wright 1985). In actuality, R&D is highly sequence- (and hence time-) dependent. Discovery in period  $t$  depends on what was discovered in period  $t-1$ . Because of this, inventions per unit of R&D will be greater if the R&D is conducted over  $n$  periods than if it is conducted in a single period. This fact has implications for the average and marginal product relationship.

It is difficult to conceive of invention functions that are not subject to diminishing returns in inventive activity.<sup>7</sup> Search models, even with internal learning from period to period, ultimately imply exhaustion of discovery potential unless some "recharge" process, exogenous to the invention process itself, occurs. Recharge can come from inventions in related fields (e.g., new materials inventions may recharge the invention function in telecommunications) or from advances in basic science (e.g., biotechnology invention functions are recharged by scientific discoveries). Actually,

advocates of constant R&D potency over time are implicitly specifying constant rates of recharge in all technology fields over time.<sup>8</sup>

The basic nature of the process is depicted in the schematic model in Figure 2. The figure depicts three periods in an invention sequence in a field of technology with no "recharge". The distribution  $f(X_1)$  depicts the distribution of potential inventions in the technology field that can be made in period one. This distribution is itself the product of past searches and discoveries and represents possible inventions (or invention potential) given the state of knowledge, methods and materials. Inherently the technology of invention, (implied in  $f(X_1)$ ), as of period 1 is given by this past history. If a number of inventors are actively seeking inventions, they will effectively be sampling from this distribution.<sup>9</sup> As total search (R&D) expands, a series of inventions will be produced. In the right hand panels of Figure 2 the  $Z$ 's represent the expected maximum values of  $x$  in samples of size  $n$  (proxied by R&D  $R_1$ ). As  $n$  ( $R_1$ ) increases, the expected value of  $Z$  rises. The optimal R&D in period 1,  $R_1$ , will be determined by the ratio of invention costs to values, i.e., where marginal cost = marginal benefits (where benefits are  $Z$ 's expressed in monetary units).

Thus at the end of period 1, the expected "marginal" invention will be valued at  $Z_1^*$ . Presuming no prior invention with value below  $\bar{X}_1$  and presuming that over the period each new invention is patented, total patents will be proportional to  $Z_1^* - \bar{X}_1$ . The average patent/R&D ratio for the period is depicted by the slope of the line  $a_1$ .<sup>10</sup>

The invention potential distribution in period two  $f(X_2)$  is determined by two factors, 1) the experience from period one invention and 2) "recharge" from other sources. In Figure 2, no recharge is presumed in the creation of  $f(X_2)$ . Invention in period one, however, reveals important information to

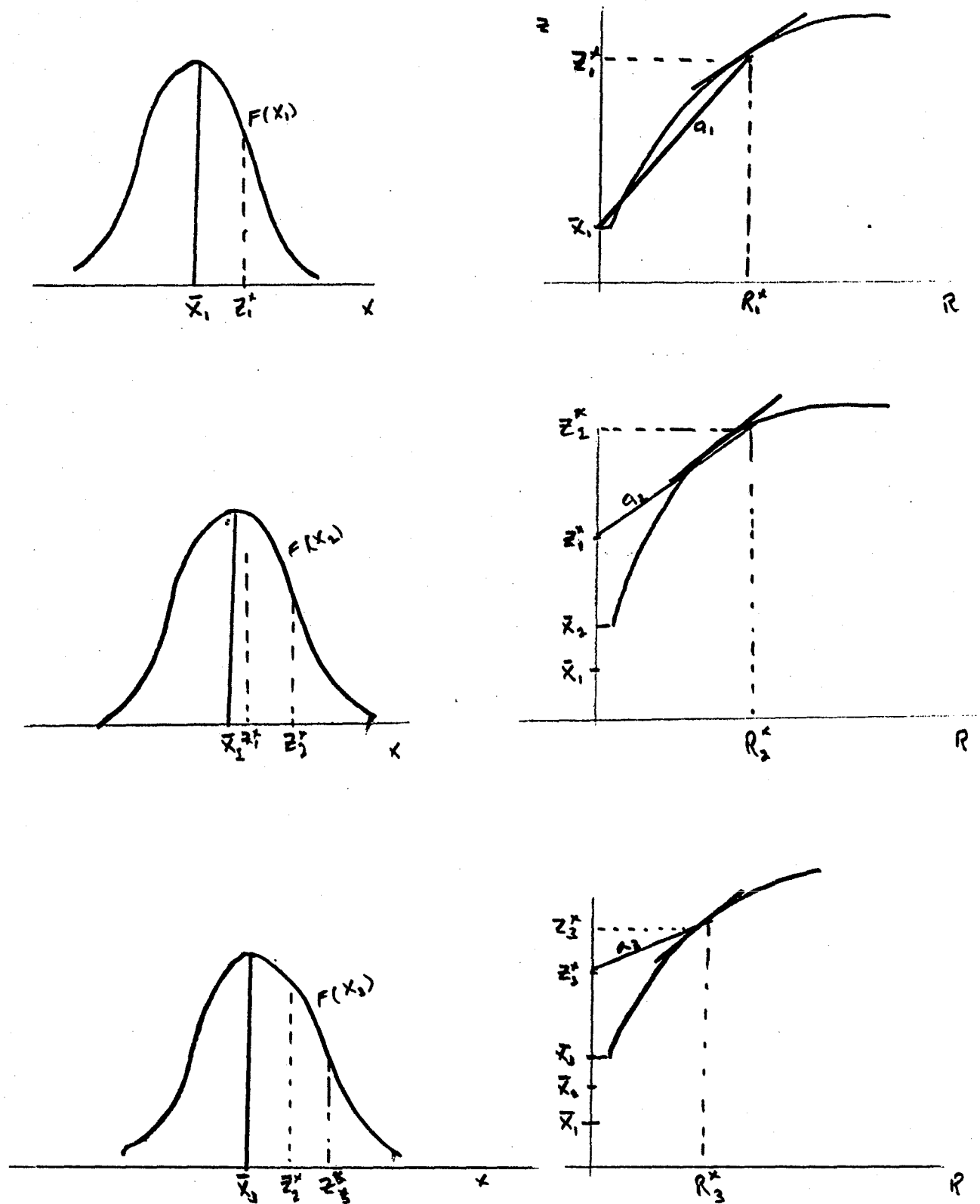


Figure 2 Sequential Invariant Search

inventors that they can utilize in period two. Given many different paths that invention might take, invention in period one helps to identify promising paths and unpromising (dead end) paths. (Note, therefore, that R&D in period one will alter the invention potential in period two even when it was not successful.)

Given the new period two distribution, inventors will undertake R&D up to  $R_2^*$  and achieve inventions up to  $Z_2^*$ . Again on the presumption that as incremental inventions are made they will be patented, inventions in period two will be proportional to  $Z_2^* - Z_1^*$  since inventions of value less than  $Z_1^*$  cannot be patented. The patent/R&D ratio will be the slope of the line  $a_2$ .

The same arguments apply to period three (and further periods). In period three further R&D will be performed ( $R_3^*$ ) and new inventions made ( $Z_3^* - Z_2^*$ ) and a new patent/R&D ratio (slope of  $a_3$ ) will be observed.

Under the presumption of no outside recharge this process will ultimately reach a state of "exhaustion". One can visualize a "meta" distribution of invention potential that is the envelope of the  $f(X_i)$  distributions and governs the ultimate inventions in this field. With no recharge, the  $\bar{X}_i$  will move to the right in smaller and smaller increments and the  $Z_i^*$  will move further out into the tails of the  $f(X_i)$  distributions and will also increase in smaller and smaller increments. The patent/R&D ratios will decline over time but it is quite possible that  $R_i^*$ , the optimal R&D level will not decline (at least not to zero) until the late stages of exhaustion. The relevant point here is that optimal R&D decisions do not prevent patent/R&D ratios from falling over time when IPE is taking place. Furthermore these patent/R&D ratios do measure the average product or average potency of R&D in a real sense. (There is some

possibility that patented inventions will be packed closer together in late stages of exhaustion. Patent laws and administration in most countries require an "inventive step" and this limits packing together.)

When recharge from another source occurs, the period to period shifts in  $f(X_i)$  will be greater. They will no longer be constrained by the original meta-function.<sup>12</sup> There is some level of recharge which would keep patent/R&D ratios constant and many observers seem to have an extraordinary degree of faith that this level of recharge in fact takes place. There is also a level of recharge that will raise these ratios. With low levels of recharge they will fall.

These models have complex implications for the effects of competition. Setting aside strategic behavior for the moment and allowing many differentiated inventions to actually have markets in a given technology field, a potential inventor will take into account the number of competing inventors (i.e., competing R&D or S&E) in assessing the likelihood of making an invention. In general, more competition will lead to lower expected and realized average products. Inventions themselves can be classified according to whether they are "frontier" or "derivative" inventions, where derivative inventions are modifications of frontier inventions to meet localized market conditions. Frontier inventions compete for the main national markets. In some technology fields, there is little differentiation in national markets and thus there is an international frontier. In other fields there are substantial differences in national frontiers because of different demand conditions.

The effects of foreign R&D and invention on expected potency (and obsolescence) in a given country depend on whether the foreign invention is derivative or frontier and on the degree of internationalization of frontier invention. Derivative inventive is often not eligible for patent protection. (The "utility model" or "petty patent" used in a number of countries is suited

to its protection) and this invention is generally not competitive. Derivative invention in the home country actually is stimulated by frontier invention in foreign countries.

Frontier R&D in a foreign country has two effects on R&D potency. The first, and probably the dominant, effect is that it is competitive and reduces the potency of R&D at home. The second is that it also constitutes additional identification of promising avenues and dead ends and "discloses" new invention opportunities (i.e., it can increase the changes in  $\bar{X}_i$  - see Figure 2). The competitive effect would be stronger, the more international are the frontiers. The disclosure effect would probably be stronger in somewhat more differentiated markets.

If a high level of recharge is taking place in a technology field, international competition effects will be minimal. This will also be true for the disclosure effects.

## II. Empirical Tests

The previous section reviewed three clusters of explanations for declining patent/R&D ratios:

- 1) Propensity to patent cost-side factors such as legal costs, changing granting standards, etc.
- 2) Propensity to patent-demand or benefit factors such as size of market.
- 3) Real potency or IPE factors.

The first set of factors can be regarded to be "country but not industry" specific. The second set of factors is also country and industry specific with implication for "country-pair" international correlations of changes. The third set of factors is also country and industry specific and also related to demand side factor (which determine R&D) and real technology supply factors such as recharges and disclosure. The IPE explanations also imply foreign competition and disclosure effects. Further, they imply general industry

international correlations.

A simple "country effects" statistical procedure thus cannot separate propensity to patent explanation from potency explanations because both have industry effects. It is nonetheless useful to apply tests to see whether common country-year effects across industry explains all of the decline (or rise) in patent/R&D (S&E) ratios. If this were to be the case it doesn't necessarily disprove the existence of IPE or potency effects (which could be there but not in an industry specific form), but it would be pretty strong evidence in favor of the first cluster of explanations.

If there are industry differences in changes (not levels) in patent/R&D (S&E) ratios, these could be due to demand side propensity to patent factors (cluster 2) or to potency factors. Evidence on patent/R&D (S&E) correlations between country pairs can be utilized to gain some further insights into alternative explanations. The potency or IPE explanations call for strong positive inter-industry correlations across countries but because of differences in the types of invention by industry, these should vary from industry to industry. Cost side propensity to patent effects should affect country pair correlations independently of industries. Demand side propensity to patent factors, (i.e., size of markets) will also provide industry differences in correlations and these will tend to be country-pair specific.

In the absence of demand type variables to control for demand or benefit type propensity to patent effects, it is difficult to draw strong conclusions regarding the IPE explanation. It is of some interest to explore, however, whether patent/R&D (S&E) ratios are related to past cumulated R&D in other countries as an indicator of possible competition and disclosure effects (recognizing that demand side propensity to patent variables are left out).

Thus the following simple tests will be undertaken in the following two parts of the paper. Part III will provide a descriptive summary of the data by

industry and will report tests to determine whether the first cluster of explanations can provide a full explanation for the decline in patent/R&D ratios.

Industry trends  $b_{ij}$  are estimated and reported for each industry and country:

$$1) \ln(P/S\&E)_{ijt} = a_{ij} + b_{ij}(YR) \text{ where } i \text{ is the industry, } j \text{ is the country}$$

These estimated trends,  $\hat{b}_{ij}$ , are then subjected to a simple analysis to see whether they are common to countries or industries.

$$2) \hat{b}_{ij} = \sum_j \alpha_j D_j + \sum_i \beta_i D_i$$

where  $D_j$  are country dummies and  $D_i$  are industry dummies.

An F test is then performed on the  $\alpha_i$  and  $\beta_i$  coefficients to determine whether there are industry effects and/or country effects.

Correlations of the patent/R&D (S&E) ratios between each country pair for each industry are also computed over the 1969-87 period. These correlations are then subjected to a similar country pair - industry effects analysis.

$$3) C_{ij}' = \sum_{jk} \alpha'_{jk} D_{jk} + \sum_i \beta'_i D_i$$

and a similar test on the  $\beta'_i$  and  $\alpha'_{jk}$  coefficients is made. These correlation tests are designed to indicate whether the second or third clusters of explanations are relevant. The second cluster of propensity to patent explanations will tend to produce country pair effects in correlations. IPE explanations will tend to be more industry specific.

Then a second set of industry trends is estimated for each country including year effects.

$$4) \ln(P/S\&E)_{ijt} = \sum_i \beta''_i D_i + b''_{ij} D_{ij}^* YR + \gamma \sum_t YD_t$$

where the YD are year dummies and the  $D_{ij} \times YR$  are industry trends.



These new industry trends, when pooled over countries have the same statistical implications as in (2). However, now the industry test can be performed for each country.

Part IV of the paper reports a provisional test of the competition and disclosure effects implied by the IPE explanations. This test is specified in a "meta-recharge" formulation (as opposed to an annual Patent/R&D (S&E) specification).

If a general meta invention function is governing invention, the relationship between patents and R&D (S&E) will be

$$5) \text{ PAT} \approx \ln(\text{R\&D}) \text{ or } \approx \ln(\text{S\&E}).$$

Accordingly if (6) is estimated

$$6) \text{ PAT}/\ln(\text{R\&D}) = a + b\text{YR}$$

The coefficient on YR in (6) will be zero if there is no recharge. This expression is the predicted no-recharge relationship between invention and R&D for a broad class of invention meta-functions (see Evenson & Kislev 1975, and Kortum 1990). To better approximate the meta-nature of the specification, this can be expressed in cumulated form.

$$7) \text{ CumPat}/\ln(\text{CumR\&D})_{ijt} = a_{ij} + b_{ij}^* \text{YR}$$

In this form, if there is recharge,  $b_{ij}$  will be positive.

Finally, taking (7) in logarithmic form and estimating for each industry  $i$ .

$$8) \ln(\text{CumPat}/\ln(\text{CumR\&D}))_{ijt} = \sum_i \sigma_i D_i + \sum_{ij} \beta_{ij} x_{ij} \text{YR}$$

provides a test as to whether there is recharge.

If the  $\beta_{ij}$  are zero, i.e., no country trends, there is no recharge. If the  $\beta_{ij}$  are one there is full recharge. This is because with full recharge the exhaustion "drag" caused by the logarithmic specification in (5) is fully offset.

Expression (7) can then be extended to

$$9) \ln(\text{CumPat}/\ln(\text{CumR\&D}))_{ijt} = \sum \sigma_{ij}^{**} D_{ij} + \sum \beta_{ij}^{**} D_{ij} \text{YR} + \delta_i \text{CumR\&DRow}_i$$

where CumR&DRow is cumulated R&D in the rest of the world. This tests for a competition effect. The coefficient on this should be negative if the  $\beta_{ij}^{**}$  trends are relatively low.

Finally, one can add a term to test for a disclosure effect

$$10) \approx \ln(\text{CumPat}/\ln \text{CumR\&D})_{ijt} = \sum \sigma_{jii}^{***} D_{ij} + \sum \beta_{ij}^{**} D_{ij} \text{YR} + \delta_i \text{CumR\&DRow}_i + \phi_i \text{LAGPATROW}_i$$

where LAGPATROW is lagged patenting in the rest of the world.

This specification is, of course, subject to possible bias because the rest of the world's R&D may be responsive to a country's patent/R&D ratio. Without demand data it is difficult to instrument this variable and test for simultaneity. The lagged patenting variable is also subject to some possible simultaneity bias. In spite of these possible biases, these estimates will be useful as indicators of the possibility of IPE effects.

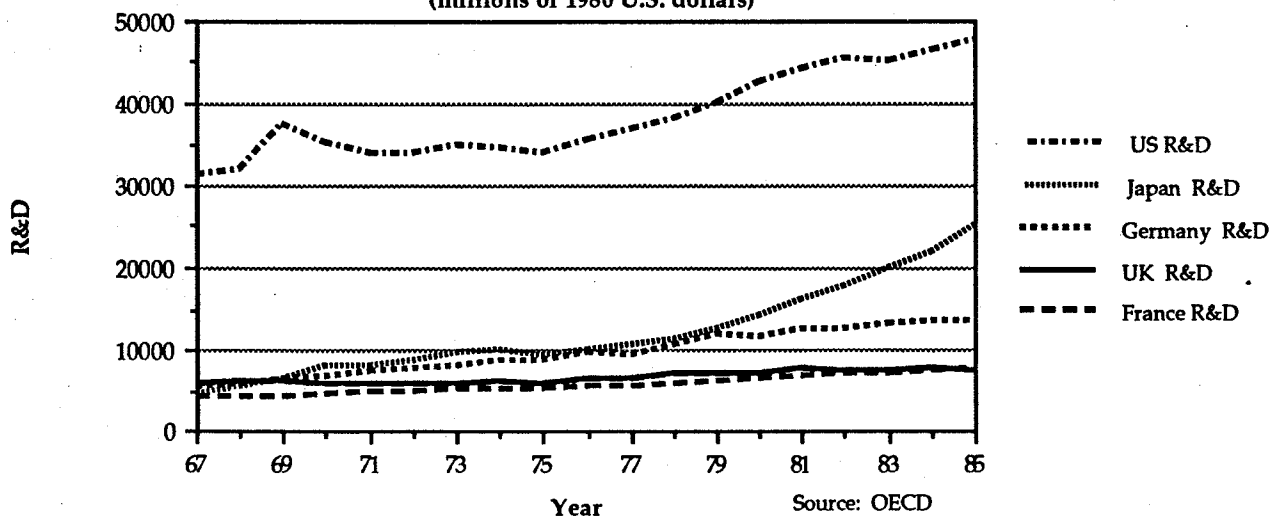
## II. Data Summaries and Simple Tests

### A. Aggregate Data

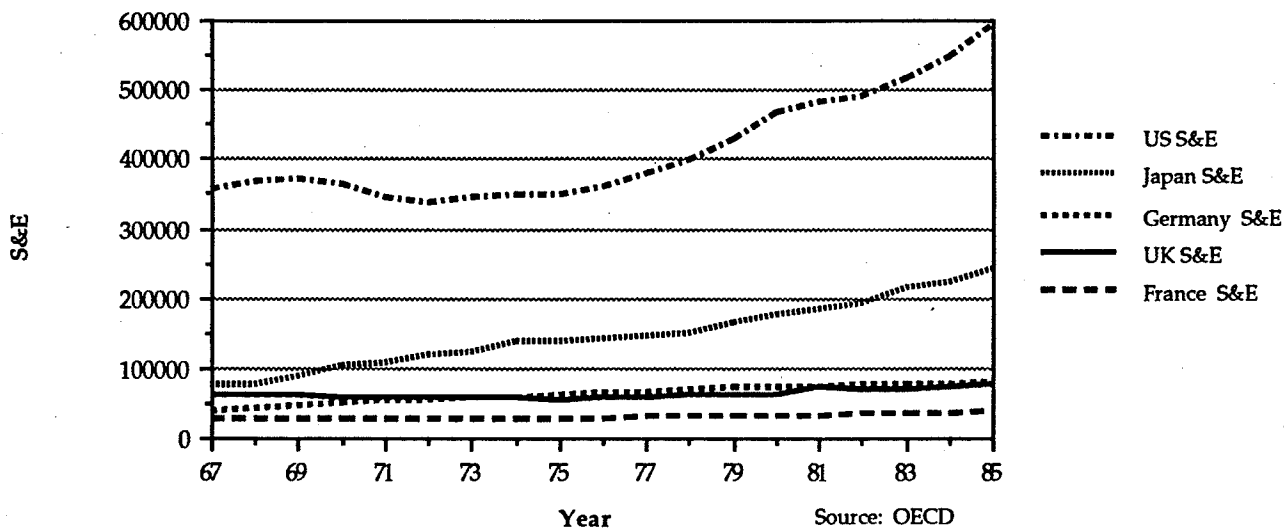
Figure 1 summarized patent and R&D data for five countries; the U.S., Germany, U.K. Japan, and France for the 1969-1987 period. These were the five leading market economies in terms of inventions over the period. The USSR was also a major invention producer but its patent system is not comparable to the Western system shown here. Japan's patent system also differs from other Western systems to some degree and data from Japan are not utilized in this section. Figure 3 summarizes R&D data, total patents and scientific and engineer data for these countries.

Patents reported are patents granted to national inventors in the year reported.<sup>12</sup> There are some differences in patent laws that occurred during

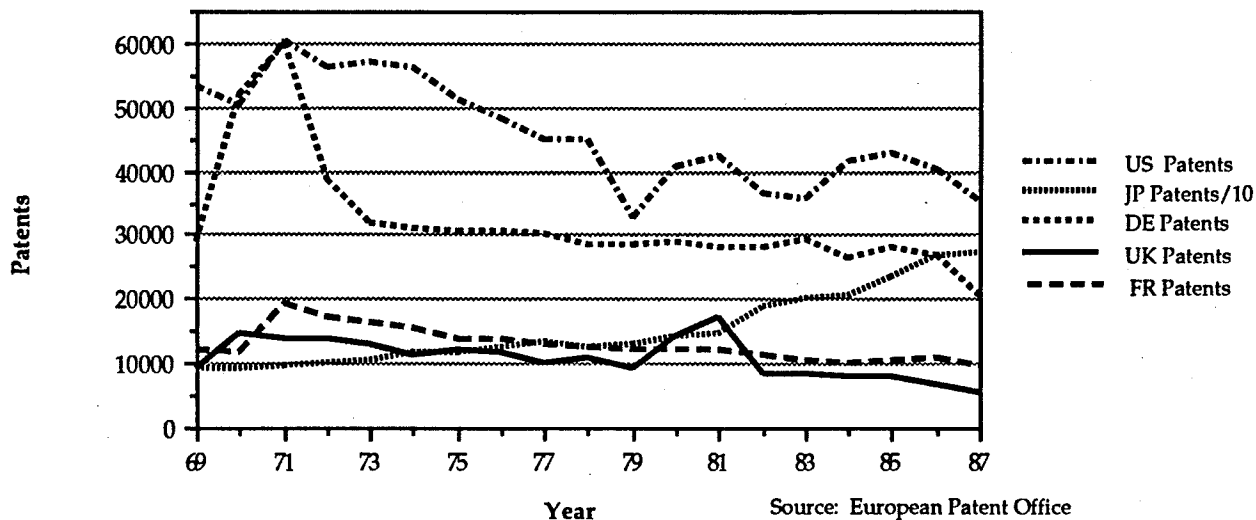
### Annual R&D expenditures (millions of 1980 U.S. dollars)



### Annual scientists and engineers



### Annual domestic patents



the period. This is evident in patent numbers for Germany in the first few years of the series and in the U.S. after 1981 and in France in the first two years of the series. It is clear from a simple reading of the figure that there are a number of country-year effects in the patent data.

The R&D data expressed in 1980 million U.S. dollars (converted at official exchange rates in 1980, but deflated by country) show much smoother patterns and probably are relatively error-free. Note that there is roughly a two year lag between patent application and R&D built into these comparisons since patent applications lag grants by approximately 2 years in these countries. It should be noted, however, that a fairly substantial proportion of R&D is undertaken after a successful invention occurs. Griliches et al, 1987, concluded that the relationship between R&D spending and patenting is approximately contemporaneous. It should further be noted that approximately twenty percent of the inventions patented in the U.S. were not assigned to corporate entities at the time of patent grant. (This is probably roughly the case for other countries as well.)<sup>13</sup> These "independent" inventions were probably based on R&D activities that were not actually included in the R&D data reported here. U.S. data indicate, however, that the proportion of patents granted to independent inventors has been constant since 1960.

The S&E data are subject to the same problems of comparability to patents as are the R&D data. Since they are in manpower units, problems of exchange rate conversion are not a potential source of error. There may be a certain degree of non-comparability from country to country, but no attempt is made to interpret inter-country differences (or even inter-industry differences) in the patent/R&D(S&E) ratios in this paper. The focus is on rates of change in the ratios. These, of course, are affected by changes in the R&D/S&E ratio. This ratio is depicted in Figure 1 and is of some interest. The R&D/S&E ratio (and

thus the real cost of doing R&D) has risen considerably in Japan (from a low base in 1967) and in France and Germany as well. It has not risen significantly in the U.S. or the U.K.

Tables 1, 2 and 4 report three indicators by industry for the five countries. Table 1 reports estimated trends in the Patents/R&D ratio (the  $\hat{b}_{ij}$  in (1)). Table 2 reports comparable trend estimates for the Patents/S&E ratio (the difference in the two is the trend in the R&D/S&E ratio). Tests of country and industry effects in these trends. <sup>are reported.</sup> Table 4 reports country pair-wise correlation in the time series for the Patent/R&D ratios.

Table 1 shows that most industry trends in the Patent/R&D ratio are negative. The U.S. and German (DE) trends are all negative. France and the U.K. each have two positive trends. For Japan, however, ten of the 23 industries exhibit positive trends. Japan differs from the other countries, however, in two important respects. First, its patent system differs in that it restricts the number of "claims" in a patent to one.<sup>14</sup> Thus its patents tend to be "smaller" than are those in the other four countries where there is no similar restriction. More importantly, however, Japan has only recently emerged from a highly imitative-adaptive invention phase of economic growth where it has achieved rapid "catch-up" growth.

Table 2 shows essentially the same pattern exhibited in Table 1. It shows positive trends in 12 industries for Japan. Changes in the R&D/S&E ratios have not altered the industry pattern significantly.

These correlation could be due entirely to country effects which happen to be correlated by country. Thus it is useful to test for country and industry effect in trends (and correlations). Table 3 reports a simple test. The estimated trends from Tables 1 and 2 are pooled and regressed on country and industry dummy variables. If trends are common across all industries this

Table 1  
 Coefficients of a Regression of Log (Patents/R&D)  
 on Industry Dummies and Industry Trends  
 (Only Trend Coefficients are Reported - T-Statistics in Parentheses)

Industry	LOG(PATENTS/R&D)				
	US	JP	DE	GB	FR
02 Mining	( . )	.036123 ( 4.33)	-.11045 (-11.37)	-0.1347 (-16.41)	-0.0392 ( -6.84)
03 Electric Machinery	-.02284 ( -4.12)	-.00184 ( -0.22)	-.08951 ( -9.21)	-.03003 ( -3.66)	-.03421 ( -5.96)
04 Electronic Equipment	-0.0354 ( -6.38)	0.00494 ( 0.59)	-.08095 ( -8.33)	-.09126 (-11.11)	-.08726 ( -15.2)
05 Chemicals	-.06504 (-11.72)	-.01193 ( -1.43)	-.06674 ( -6.87)	-.09615 (-11.71)	-.09484 (-16.52)
06 Drugs	-0.0136 ( -2.46)	.013496 ( 1.62)	-.05647 ( -5.81)	-.10859 (-13.22)	-.05665 ( -9.87)
07 Petroleum Refinery	-.04356 ( -7.85)	-.01530 ( -1.84)	-.10440 (-10.74)	-.04181 ( -5.09)	-.05546 ( -9.66)
08 Aerospace	-0.0421 ( -7.6)	( . )	-.08585 ( -8.84)	-.06693 ( -8.15)	-.07646 (-13.32)
09 Motor Vehicles	-.05703 (-10.28)	-.05217 ( -6.26)	-.07572 ( -7.79)	-.03310 ( -4.03)	-.09036 (-15.74)
10 Ships	( . )	( -8.43)	.025556 ( 2.63)	.039688 ( 4.83)	-.01898 ( -3.31)
11 Other Transport	-.09073 (-16.35)	.040937 ( 4.91)	-.11454 (-11.79)	( . )	-.16150 (-28.13)
12 Ferrous Metals	-.09866 (-17.78)	-.01778 ( -2.13)	-.04335 ( -4.46)	-.00315 ( -0.38)	-.11771 (-20.51)
13 Non-ferrous Metals	-.06724 (-12.12)	.032479 ( 3.9)	-0.0855 ( -8.8)	-.07317 ( -8.91)	-.08899 ( -15.5)
14 Fabricated Metals	-.04050 ( -7.3)	-.03104 ( -3.72)	-.20405 ( -21)	-.03661 ( -4.46)	-.09088 (-15.83)
15 Instruments	-.09332 (-16.82)	-.05173 ( -6.21)	-.09755 (-10.04)	-.00136 ( -0.17)	-.07944 (-13.84)
16 Office Machinery	-.05287 ( -9.53)	.025938 ( 3.11)	-.10546 (-10.85)	-.10483 (-12.76)	-.05088 ( -8.86)
17 Other Machinery	-.07475 (-13.47)	-.03462 ( -4.15)	-.10873 (-11.19)	-.05541 ( -6.75)	-.05089 ( -8.87)
18 Food, Drink, Tobacco	-0.0632 (-11.39)	-.03022 ( -3.63)	-.16281 (-16.76)	-.04286 ( -5.22)	-.07366 (-12.83)
19 Textile - Clothing	-.01736 ( -3.13)	.001493 ( 0.18)	-.11782 (-12.13)	.056630 ( 6.9)	.018768 ( 3.27)
20 Rubber - Plastics	-.03838 ( -6.92)	-.09599 (-11.52)	-.13459 (-13.85)	-.03469 ( -4.22)	-.08533 (-15.04)
21 Stone, Clay, Glass	-.04697 ( -8.46)	-.04093 ( -4.91)	-.12624 (-12.99)	-.01334 ( -1.63)	-.03421 ( -5.96)
22 Paper, Printing	-.06818 (-12.29)	.014840 ( 1.78)	-.07617 ( -7.84)	-.00669 ( -0.82)	-0.0644 (-11.23)
23 Wood Furniture	-.05695 (-10.26)	.005096 ( 0.61)	-.09269 ( -9.54)	-.01595 ( -1.94)	-.06729 (-11.72)
24 Other Manufacturing	-.04592 ( -8.27)	.030253 ( 3.63)	-.04785 ( -4.92)	-.02975 ( -3.62)	.029765 ( 5.19)

Table 2

Coefficients of a Regression of Log (Patents/S&E)  
on Industry Dummies and Industry Trends  
(Only Trend Coefficients are Reported - T-Statistics in Parentheses)

Industry	LOG(PATENTS/S&E)				
	US	JP	DE	GB	FR
02 Mining	( . )	.061687 ( 7.09)	-.03538 ( -3.17)	-0.0741 ( -9.58)	-.02584 ( -4.7)
03 Electric Machinery	-0.0290 ( -4.14)	.014452 ( 1.66)	-.07711 ( -6.92)	-.03504 ( -4.53)	-.02883 ( -5.24)
04 Electric Equipment	-.04238 ( -6.04)	0.01853 ( 2.13)	-.06855 ( -6.15)	-.07964 ( -10.29)	-.06434 ( -11.69)
05 Chemicals	-.04681 ( -6.67)	.002472 ( 0.28)	-.05802 ( -5.2)	-.07095 ( -9.17)	-.06857 ( -12.46)
06 Drugs	-.02784 ( -3.97)	.048853 ( 5.62)	-.03311 ( -2.97)	-0.0797 ( -10.31)	-.02213 ( -4.02)
07 Petroleum Refinery	-.03522 ( -5.02)	.004499 ( 0.52)	-.03017 ( -2.71)	-.02990 ( -3.86)	-.03954 ( -7.19)
08 Aerospace	-.04782 ( -6.82)	( . )	-0.0473 ( -4.25)	-.06486 ( -8.38)	-.06387 ( -11.61)
09 Motor Vehicles	-.04910 ( -7)	-.03089 ( -3.55)	-.06506 ( -5.84)	-.03681 ( -4.76)	-.04902 ( -8.91)
10 Ships	( . )	-.07198 ( -8.28)	-.11184 ( -10.03)	.021831 ( 2.82)	0.02989 ( 5.43)
11 Other Transport	-.03690 ( -5.26)	.053187 ( 6.12)	.018696 ( 1.68)	( . )	-.09578 ( -17.4)
12 Ferrous Metals	-.07301 ( -10.41)	.019144 ( 2.2)	0.00997 ( 0.89)	-.01092 ( -1.41)	-.06475 ( -11.77)
13 Non-ferrous Metals	-.04876 ( -6.95)	.050158 ( 5.77)	-.05256 ( -4.72)	-.04340 ( -5.61)	-.06092 ( -11.07)
14 Fabricated Metals	-.03811 ( -5.43)	-.00289 ( -0.33)	-.12315 ( -11.05)	-.04579 ( -5.92)	-.06500 ( -11.81)
15 Instruments	-.12190 ( -17.38)	-.02390 ( -2.75)	-.04110 ( -3.69)	.013187 ( 1.7)	-.07321 ( -13.3)
16 Office Machinery	-.06307 ( -8.99)	.044860 ( 5.16)	-.09566 ( -8.58)	-.12038 ( -15.55)	-0.0663 ( -12.06)
17 Other Machinery	-.08142 ( -11.61)	-.02408 ( -2.77)	-.11932 ( -10.7)	-.05461 ( -7.06)	-.06919 ( -12.57)
18 Food, Drink, Tobacco	-0.0489 ( -6.98)	-.01082 ( -1.25)	-.12400 ( -11.12)	-.06098 ( -7.88)	-.05182 ( -9.42)
19 Textile - Clothing	-.00611 ( -0.87)	.025657 ( 2.95)	-.06105 ( -5.48)	.044011 ( 5.69)	-.02326 ( -4.23)
20 Rubber - Plastics	-.04463 ( -6.36)	-.07261 ( -8.35)	-.10620 ( -9.53)	-.05916 ( -7.64)	-.06606 ( -12)
21 Stone, Clay, Glass	-.03679 ( -5.25)	-0.0086 ( -0.99)	-.06555 ( -5.88)	-.00845 ( -1.09)	-.02844 ( -5.17)
22 Paper, Printing	-.07313 ( -10.43)	.036690 ( 4.22)	-0.0838 ( -7.52)	-.04148 ( -5.36)	-.06120 ( -11.12)
23 Wood Furniture	-.06042 ( -8.61)	-.02178 ( -2.51)	-.13344 ( -11.97)	-.05118 ( -6.61)	-0.0806 ( -14.65)
24 Other Manufacturing	-.06567 ( -9.36)	.019025 ( 2.19)	-.00478 ( -0.43)	-.02468 ( -3.19)	-.03163 ( -5.75)

TABLE 3  
RESULTS OF REGRESSING THE ESTIMATES FROM TABLE 1 and 2  
ON INDUSTRY AND COUNTRY DUMMIES, AND TESTS FOR JOINT SIGNIFICANCE

	LOG(PATENTS/R&D)	T	LOG(PATENTS/S&E)	T
<b>INDUSTRY</b>				
03	.0140	( 0.575)	-.0164	(-0.802)
04	-.0083	(-0.342)	-.0325	(-1.594)
05	-.0173	(-0.711)	-.0336	(-1.648)
06	.0053	( 0.218)	-.0081	(-0.396)
07	-.0024	(-0.100)	-.0113	(-0.555)
08	-.0046	(-0.190)	-.0301	(-1.471)
09	-.0120	(-0.494)	-.0314	(-1.540)
10	.0449	( 1.846)	-.0117	(-0.572)
11	-.0155	(-0.638)	.0026	( 0.126)
12	-.0065	(-0.266)	-.0092	(-0.450)
13	-.0068	(-0.280)	-.0164	(-0.802)
14	-.0309	(-1.273)	-.0403	(-1.971)
15	-.0150	(-0.618)	-.0347	(-1.697)
16	-.0080	(-0.327)	-.0454	(-2.223)
17	-.0152	(-0.626)	-.0550	(-2.693)
18	-.0249	(-1.024)	-.0446	(-2.183)
19	.0380	( 1.564)	.0106	( 0.518)
20	-.0283	(-1.166)	-.0550	(-2.693)
21	-.0027	(-0.110)	-.0149	(-0.727)
22	.0095	( 0.393)	-.0299	(-1.463)
23	.0041	( 0.169)	-.0548	(-2.681)
24	.0370	( 1.521)	-.0068	(-0.334)
<b>COUNTRY</b>				
US	-.0474	(-2.544)	-.0221	(-1.413)
JP	-.0088	(-0.473)	.0305	( 1.946)
DE	-.0920	(-4.942)	-.0409	(-2.612)
GB	-.0382	(-2.052)	-.0150	(-0.957)
FR	-.0620	(-3.329)	-.0262	(-1.672)

F-tests:	DF	F-value	Prob>F	F-value	Prob>F
Industries	(22,88)	1.36	.1577	1.78	.0312
Countries	( 5,88)	13.36	.0001	13.04	.0001

F-tests Excluding Japan

Industries	(22,66)	1.75	.0424	1.79	.0364
Countries	( 4,66)	10.48	.0001	3.27	.0166



Table 4

Coefficients of a Regression of Pairwise Correlation Coefficients  
on Industry Dummies and Country-Pair Dummies  
and Tests for Joint Significance

UNADJUSTED					
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INDUSTRY	LOG(PATS/R&D)	T	LOG(PATS/S&E)	T	
I03	.0533	( 0.276)	.0135	( 0.072)	
I04	.2144	( 1.110)	.0618	( 0.330)	
I05	.4901	( 2.536)	.1585	( 0.846)	
I06	.0857	( 0.444)	-.0250	(-0.134)	
I07	.2694	( 1.394)	.0531	( 0.283)	
I08	.2851	( 1.312)	.1359	( 0.645)	
I09	.3755	( 1.944)	.3530	( 1.885)	
I10	-.1570	(-0.731)	-.0163	(-0.078)	
I11	-.1984	(-0.913)	-.2085	(-0.990)	
I12	.1958	( 1.013)	-.1309	(-0.699)	
I13	-.0040	(-0.021)	-.0738	(-0.394)	
I14	.4642	( 2.403)	.3788	( 2.023)	
I15	.2220	( 1.149)	.1611	( 0.860)	
I16	.1728	( 0.895)	.1963	( 1.048)	
I17	.4208	( 2.178)	.4594	( 2.453)	
I18	.5560	( 2.877)	.4843	( 2.587)	
I19	-.2910	(-1.506)	-.1821	(-0.973)	
I20	.5537	( 2.866)	.6067	( 3.240)	
I21	.3242	( 1.678)	.1896	( 1.013)	
I22	-.0620	(-0.321)	.0397	( 0.212)	
I23	.0078	( 0.040)	.3774	( 2.015)	
I24	-.2120	(-1.097)	.0105	( 0.056)	
COUNTRY-PAIRS					
US_JP	.0084	( 0.047)	-.2657	(-1.553)	
US_DE	.5993	( 3.414)	.4009	( 2.357)	
US_GB	.2114	( 1.198)	.2944	( 1.722)	
US_FR	.4971	( 2.832)	.5337	( 3.138)	
JP_DE	-.0319	(-0.190)	-.0868	(-0.533)	
JP_GB	-.2482	(-1.470)	-.3523	(-2.153)	
JP_FR	-.0253	(-0.151)	-.2718	(-1.667)	
DE_GB	.2590	( 1.539)	.2449	( 1.502)	
DE_FR	.4926	( 2.937)	.3860	( 2.375)	
GB_FR	.3038	( 1.806)	.3472	( 2.129)	
F-tests:					
	DF	F-Value	Prob>F	F-Value	Prob>F
Industries	(22,182)	4.2225	.0001	3.5256	.0001
Country-Pairs	(10,182)	10.4949	.0001	15.7996	.0001

would give support to the cluster one propensity to patent explanations. For the Patents/R&D ratios, the F test for industry effects is weak, although dropping Japan from the regression improves it substantially. The comparable tests for the Patent/S&E ratios provide stronger evidence for ratio changes associated with industries.

Table 4 reports simple correlation coefficients in the time series between countries of the Patent/R&D ratio by industry. These correlations are predominately positive except for those in which Japan is part of the pair. Thus, except for Japan, it is quite clear that these data show strong correlations in the decline in these ratios between countries (and between industries).

Table 4 also reports similar F tests for the country pairwise correlation coefficients. Again if these were simply due to correlations of country effects the country-pairs dummy variables would explain all variations in correlation coefficients. The F tests show quite clearly that there are strong country pair correlations except for comparisons with Japan, but that there are also a number of positive industry effects as well. (These would be stronger excluding Japan.) Thus, there is support for explanations that go beyond the simple propensity to patent explanations. The correlation evidence suggests that there are also explanations that go beyond the cluster time propensity to patent explanation.

A further set of tests were undertaken based on (3) where year dummies, industry dummies and industry trends were included in regressions for each country. Table 5 reports F tests for industry trend coefficients indicating industry trend effects in each country. These show quite clearly that industry effects exist in these ratios.

#### **IV. Tests for Competition and Disclosure Effects**

Table 6 summarizes tests of competition and disclosure effects based on

**Table 5: F Tests on Industry Trends with  
Year Dummy Variables by Country**

	Log Pats/R&D			Log Pats/S&E		
	DF	F-Value	Prob > F	DF	F-Value	Prob > F
U.S.	(21,340)	30.27	.0001	(21,340)	15.52	.0001
Japan	(22,357)	20.06	.0001	(22,357)	19.51	.0001
Germany	(23,374)	35.48	.0001	(23,374)	23.79	.0001
G.B.	(22,357)	38.99	.0001	(22,357)	28.34	.0001
France	(23,374)	64.94	.0001	(23,374)	25.67	.0001

Table 6: Tests of Competition and Disclosure Efforts: 5 Countries

Data 1969-1987. Dependent Variable:  $\ln(\text{CumPAT}/\ln(\text{CumS\&E}))$

Industry	Country Trends										CumRow S&E(S9)	CumRow S&E(S10)	LAGPAT Row(S10)
	Specification (8)					Specification (10)							
	U.S.	Germany	U.K.	France	Japan	U.S.	Germany	U.K.	France	Japan			
02 Mining	na	.090	.088	.095	.158	na	.744	.664	.975	.864	-.004120	-.0003982	.008288
03 Electric Machinery	.110	.071	.097	.088	.160	.877	1.48	1.02	1.68	1.33	-.0000210	-.0000271	.0000338
04 Electronic Equipment	.112	.080	.105	.092	.181	.306	.447	.477	.502	.562	-.0000024	-.0000201	.0000201
05 Chemicals	.118	.071	.099	.085	.138	.656	.963	1.00	1.05	.851	-.0000118	-.0000147	.0000652
06 Drugs	.149	.093	.113	.115	.187	.231	.398	.399	.434	.453	-.0000094	-.0000102	.0002333
07 Petroleum Refinery	.121	.072	.094	.096	.158	.168	.289	.302	.303	.354	-.0000164	-.0000161	-.0000961 <sup>N</sup>
08 Aerospace	.107	.066	.087	.079	na	.135	.209	.222	.354	na	-.0000018 <sup>N</sup>	-.00000149 <sup>N</sup>	-.0001293 <sup>N</sup>
09 Motor Vehicles	.114	.084	.105	.092	.125	.398	.705	.749	na	.677	-.0000111	-.0000136	.0000505
10 Ships	na	.075	.108	.096	.117	na	.351	.357	.381	.159	-.0000341	-.0000652	.0007695
11 Other Transport	.108	.069	na	.074	.178	.124	.121	na	.125	.317	-.0000860	-.0000219 <sup>N</sup>	-.0000999 <sup>N</sup>
12 Ferrous Metals	.107	.079	.099	.086	.153	.421	.562	.567	.662	.521	-.0000265	-.0000514	-.0008249
13 Non-ferrous Metals	.110	.062	.089	.086	.172	.464	.726	.737	.765	.643	-.0000599	-.0001000	.000232 <sup>N</sup>
14 Fabricated Metals	.114	.074	.103	.089	.161	.362	.676	.764	.718	.641	-.0000333	-.0000511	.0000744
15 Instruments	.112	.083	.109	.085	.145	.135	.175	.199	.179	.214	-.0001769	-.0000024	-.0000111 <sup>N</sup>
16 Office Machinery	.116	.079	.098	.086	.208	.199	.421	.468	.462	.583	-.0000587	-.0000076	.0000417
17 Other Machines	.111	.071	.101	.089	.131	.337	.471	.567	.562	.437	-.0000716	-.0000105	.0000186
18 Food, Drink, Tobacco	.114	.060	.106	.087	.139	.452	.679	.658	.711	.562	-.0000228	-.0000406	.0006892
19 Textile - Clothing	.112	.068	.099	.085	.143	neg	neg	neg	neg	net	+.0000329	+.000122	-.000231
20 Rubber - Plastics	.111	.070	.103	.082	.132	.279	.500	.539	.523	.436	-.0000913	-.0000330	.0002167
21 Stone, Clay, Glass	.112	.074	.107	.091	.150	.442	.674	.678	.707	.567	-.0000442	-.0000608	.0003409
22 Paper, Printing	.110	.069	.101	.079	.149	.202	.433	.451	.446	.460	-.0000026	-.0000410	.0005075
23 Wood, Furniture	.106	.066	.094	.072	.124	.318	.613	.630	.622	.487	-.0000023	-.0001745	.0000916 <sup>N</sup>
24 Other Manufacturing	.115	.079	.108	.085	.129	.398	.636	.624	.642	.432	-.0000089	-.0000586	.0000079 <sup>N</sup>

specification (8), (9), and (10). Country x industry trend coefficients are reported for both specification (8) and (10). Coefficients on the competition variable, cumulated S&E in the rest of the world CumS&Erow are reported for specification (9) where it is simply added to specification (8) and for specification (9) where the disclosure variable, lagged patenting in the rest of the world (LAGPATORW) is also included (and its coefficient reported).

Recall that the industry country trends in specification (8) reflect a combination of exogenous recharge, competition and disclosure effects. If these coefficients are zero it means that the period to period invention distribution  $f(X_i)$  are not shifting. Full diminishing returns are thus setting in. If these coefficients are one the period to period shifts are sufficient to fully offset the diminishing returns implied by the search distribution built into the dependent variable.

In specification (10) where competition and disclosure effects are present, the trend coefficients are ostensibly measuring only the pure recharge effect which is itself composed of internal period to period shifts in  $f(X_i)$  within the meta-function of  $h(X)$  and exogenous shifts in the meta-function (i.e., exogenous to the industry R&D process).

Table 6 provides considerable support for the basic model and for the IPE explanation. The trend coefficients in both specifications are generally between zero and one and they are uniformly higher in specification (10) where competition and disclosure are held constant. The competition effect is negative in all industries except one. The disclosure effect is positive in all but 6 industries.

In general the total trends for specification (8) are low and positive. They are highest for Japan. Variation by industry is not great. The "net recharge" trend coefficients from specification (10) are all higher (except for textiles and clothing). They show much more variation by industry and a high

degree of correlation across countries. If these coefficients can be interpreted as net recharge coefficients, they indicate that the industries with highest net recharge are electrical machinery and chemicals, both of which have approximately full recharge. Industries with high recharge (above .5) include motor vehicles, ferrous metals, non-ferrous metals, fabricated metals, food, rubber, plastics, stone and glass, wood and furniture.

The competition effects are negative (except in textiles which is generally anomalous) and the effect varies by industry.

Does this constitute support for the IPE explanation? It does unless one can argue for large biases that would create this negative correlation. One source of bias might be that rest of world S&E is itself responding to the observation countries S&E through competition perceptions. This would presumably be a negative response, i.e., the more home S&E, the less Row S&E. If this were so it would bias the coefficients in Table 6 in a positive direction.

If, on the other hand, all countries in the world were reducing S&E investments as they observe Pat/S&E ratios declining in other countries this would produce the negative correlation reported in Table 3. But this itself is consistent with the IPE hypothesis and to the competition hypothesis.

Specification (10) seeks to add a "recent disclosure" effect to specification (9) by adding a variable measuring lagged (by one year) patents granted in the rest of the world. This variable is intended as a measure of recent inventions that might stimulate invention in the observation country. Thus, it is expected to have a positive sign. As Table 6 indicates, 17 of the 23 industry coefficients for this variable are positive, (15 significantly so), lending support to this interpretation. Again, this variable could also have other interpretations. A high (low) level of recent patenting relative to cumulated R&D could reflect propensity to patent effects that might be

internationally correlated. It could also signal high recharge abroad that is channeled to the observation country (this is not very different from the disclosure explanation however).

#### IV. Directions for Further Work

The IPE explanation is by no means trivial from a policy perspective. If potential productivity growth in the leading invention economies is significantly lower because of IPE effects, this has obvious implications and ramifications for welfare and policy. This paper has not satisfactorily sorted out the alternative explanations and measured real IPE or potency declines in invention (and of course, it has not attempted to address the invention-productivity link). Its chief purpose was to examine whether relatively simple propensity to patent explanations for the decline in patent/R&D(S&E) ratios could easily explain the phenomenon.

There are substantial indications that the simple explanations will not suffice. Clearly there are industry specific trend effects. The competition-disclosure evidence points to some IPE effects although they are surely not the complete explanation. Indeed, given that propensity to patent effects can be quite complex, it may be quite difficult to distinguish propensity to patent explanations from IPE explanations.

It does appear that more explicit modeling of demand side factors that affect both propensity to patent and investment in R&D will be required to make further headway. This conclusion is quite obvious and reflects the Schmookler (1966) perspective on demand factors in invention. Good international data on value added, production and related data by industry are available. In addition a feature of the Yale-Canada Concordance that enables patents to be assigned to Industries of Manufacture and Industries of Use will enable further richer specification of demand side factors.

It is hoped that this paper has offered some evidence to further the task of attaining a better understanding of an important phenomenon.

## FOOTNOTES

1. Data on patent/R&D(S&E) ratios are available for some countries for a longer period. These computations, based on Table 1, attempt to avoid some anomalies in the data (see Part II).
2. Griliches does acknowledge the possibility of potency decline. Indeed, U.S. data on R&D impacts do show a decline from 1972 to 1976.
3. Simple production functions do not allow average products to decline while marginal products rise in the region of efficient production
4. The phenomenon of productivity slowdowns in the 1970s and the recognition of "rust-belt" or "sunset" industries in a number of economies also suggest technology exhaustion.
5. See Appendix 1 for a discussion of the Yale-Canada concordance.
6. Virtually all patent offices process patent applications in chronological order and do not discriminate by technical field.
7. Nordhaus (1972) discusses cauchy (fat-tailed) distribution of potential inventions as one type of invention not subject to diminishing returns.
8. The tenacity with which the view of constant recharge is held is quite remarkable. It appears to be in part due to the widespread reliance on constant time trends in much modeling. Macroeconomic analyses, for example, assess economic performance against constant time trends.
9. This may be very sophisticated sampling. Post R&D determines the distribution of  $(X_1)$  and governs the design of experiments and trials in the current period.
10. Actually, given market conditions, there is room for a number of inventions to be embodied in marketable products so there is not a single winner at the end of the period.
11. The inventive step requirement determines a minimum "distance" between inventions. It is quite plausible that in the high potency stages of invention, patented inventions are less closely packed together along the value index and that they become more closely packed together as exhaustion occurs. This would indicate a reduction in the average value of patents over time. Pakes and Schankerman (1984) do not find evidence for declining value of patents. Declines in propensity to patent, will also affect average value of patented inventions. However, minimum distances imposed by inventive step and novelty requirements will also prevent average patent values from falling during exhaustion.
12. The meta-function itself will shift as recharge occurs.
13. The R&D and S&E data are from OECD STI files. R&D conversions were made using 1980 standard exchange rates.
14. Data on independent inventors are not presently available for countries other than the U.S.
15. This has been changed recently.



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