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ESTIMATES BY TECHNOLOGY FIELD USING PATENT RENEWAL DATA

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ABSTRACT

This paper presents quantitative estimates of the private value of property rights conferred by patent protection for different technology fields and countries of ownership. The measures are derived from parametric estimation of a model of patent renewal, using a new data set on patent renewals in France during the period 1969-1987. The results show that patent protection is a significant, but not the major, source of private returns to inventive activity and that its importance varies sharply across technology fields. The paper quantifies the equivalent subsidy to R&D generated by the patent system, characterizes variations in the value of patent rights across technology fields, countries of ownership and time, and explores the determinants of those differences.

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This paper provides empirical estimates of the importance of the patent system as a source of economic returns to inventive activity. In the literature on intellectual property rights, and from a public policy perspective, two central questions are whether the patent system is a quantitatively important incentive mechanism and whether its importance varies across different, broadly defined technology areas (Levin, Klevorick, Nelson and Winter 1987). Patents are one of several alternative devices to appropriate the gains from invention, and the decision to patent presumably rests on the comparative effectiveness of these devices. To a first approximation, the private value of the patent system can be measured by the incremental returns from inventions protected by patents, above and beyond the gains that would be appropriable by the second-best means.

The basic empirical difficulty is that there are no active markets in patents where direct valuation of patent rights can be observed. The available evidence on the importance of patent protection is based exclusively on survey data (Taylor and Silberston 1973; Mansfield, Schwartz and Wagner 1981; Levin, Klevorick, Nelson and Winter 1987). This literature points to two main conclusions: first, that patents are not the exclusive or even primary device for protecting inventions in most industries, and second, that reliance on patents is much greater in some industries (especially pharmaceuticals) than in others.

This paper contributes econometric evidence to the discussion. The empirical analysis is based on the model of patent renewal developed by Schankerman and Pakes (1986). In most countries patentees are required to pay annual fees in order to maintain patent protection. On the assumption that the renewal decision is based on the private returns generated by the patent right, patent renewal data can be used to infer the private value of patent protection. The analysis in this paper is based on a new and extensive data set on patent renewals, containing virtually all patents applied for in France during the period 1969–1982. The renewal data are disaggregated both by technology field and country of origin, which allows one to investigate variations in the importance of patent rights across these dimensions.

Patent renewal data can only inform about the private value of patent rights. Nonappropriable (social) returns are presumably not relevant to, and hence cannot be revealed by, the patentee's renewal decision. Beyond that limitation, however, two important points should be kept in mind in interpreting results based on patent renewal data. First, there is an important distinction between the valuation of the patent system before and after the decision to patent (ex ante and ex post valuation). The renewal decision is required only after the decision to apply for a patent. As Horstman, MacDonald and Silvinski (1985) emphasise, the patent application itself reveals private information about the invention. Once this information has been disclosed, it may be very difficult to appropriate rents without patent protection. Hence, the willingness to pay to maintain patent protection after disclosure will be greater than before the decision to patent is taken. On this account, the estimates in this paper represent an upper bound to the private returns generated by the patent sytem ex ante. On the other hand, Judd (1989) has emphasised that the patent system may generate private returns by discouraging competition at the invention stage merely by offering the possibility of a patent, even if no patent is actually taken out by the winner. Hence patent renewal data may not fully capture the private gains due to strategic responses and may underestimate the private value of the patent system.

The paper is organised as follows. Section 1 describes the data set. The patent renewal model and stochastic specification are summarised in Section 2. Section 3 presents the empirical results for the four technology fields (pooling the countries of origin). This material includes parametric estimates of the patent renewal model (Section 3.1), the distributions of the value of patent rights (Section 3.2), computations of the equivalent subsidy to R&D conferred by patent protection (Section 3.3), and movements over time in patent counts and patent values (Section 3.4). Section 4 presents the empirical results allowing for differences across countries of origin within each technology field. This material includes parametric estimates of the model and the implied differences in mean value across countries of origin and over time (Section 4.1), and some evidence on the determinants of these variations (Section 4.2). Concluding remarks summarise the main empirical findings.

Section 1. Description of the Data Set

The data set was constructed from computerised files of individual patents from the French Patent Office (see Schankerman 1990 for details). The data cover all patent applications in France during the period 1969-1987, disaggregated in three dimensions: the technology field to which the patent is assigned, the country of origin, and the date the patent application is filed (cohort). For each technology field/country cell, the data set contains the number of patent applications per cohort, the number of patents granted per cohort during each of the years subsequent to application cohort date, and the number of patent renewals per cohort at each available age.

Each patent is assigned by the patent examiner to one primary technology group according to the International Patent Classification (IPC). Assignment is based on the function of the invention (e.g., conveyer belts would be classified as industrial transport apparatus), which may differ both from an industry of origin and industry of use criterion. The patent is identified by the country of the owner (normally but not always the inventor), which I refer to hereafter as country of origin. The countries of origin include Germany, France, the United Kingdom, Japan, and the United States. The raw data contain seventeen technology groups that account for the bulk (over 90 percent) of patent applications in France. For this paper the groups are consolidated into four major technology fields: pharmaceuticals, chemicals, mechanical, and electronics. This categorisation is designed to capture the broad distinctions between patents based on fundamentally different types of technologies.

Information on patent renewal fees was obtained directly from the French Patent Office. Renewal fee schedules were changed frequently during the sample period, but the prevailing schedule applied to all patents regardless of cohort, technology field, or country of origin. The renewal fees start at very low levels and rise monotonically as the patent ages. By age nineteen (the last age in the sample) the renewal fee is about $400 per patent (in 1980 U.S. dollars).[1]

The pattern of renewal rates varies across technology fields and countries of origin, but certain features do emerge. To conserve space, Figure 1 presents the age path of renewal rates for each technology field, averaged over countries of origin excluding Japan. Figure 2 provides the renewal rates for patents from Japan. There is substantial attrition as patents age, with about fifty percent of patents dropping out before they reach age ten. This general feature holds for all technology fields and countries of origin. For all countries of origin, except Japan, renewal rates for pharmaceuticals and chemicals are generally higher than for mechanical and electronics patents. The differences summarised in Figure 1 are particularly clear for France and the United Kingdom, while for Germany and the United States the renewal patterns are very similar across technology fields (not shown in the figure). This ranking of technology fields is sharply reversed for patents of Japanese origin, where renewal rates are highest in electronics and lowest in pharmaceuticals. The differences in renewal patterns across countries of origin are presented in Figures 3-6. In each technology field the renewal rates are much higher for patents from France and Japan than for the other three countries. Japan particularly stands out in the mechanical and electronics fields.

These rankings of renewal curves provide some limited information about the value of patent rights, without resorting to parametric estimation of the patent renewal model. In a study of nonparametric methods for patent renewal data, Pakes and Simpson (1989) develop a test of the null hypothesis that the value distributions for different groups of patents are identical. The test is based on a comparison between the mortality rates at each age in different groups of patents (facing the same renewal fee schedules). I apply this nonparametric (chi-square) test to variations among countries of origin and technology fields. Let π_{ac}^{ij} denote the mortality rate at age a for patents from cohort c, where i and j represent the country of origin and technology field respectively. The null hypothesis that the value distributions do not differ across technology fields is equivalent to the restriction H_0: $\pi_{ac}^{ij} = \pi_{ac}^{j}$ for all i. To test for differences across countries of origin, the null hypothesis is H_0: $\pi_{ac}^{ij} = \pi_{ac}^{i}$ for all j.

Table 2 summarises the test results. Under the null hypothesis, the expected value of the χ_d^2/d statistic is unity. The hypothesis that the value distribution is the same for all technology fields is rejected decisively for each country of origin (Panel A). The hypothesis that the value distribution is the same for all countries of origin is also strongly rejected for each technology field (Panel B). These results show that there is both within-technology field and within-country of origin variation in value distributions.[2] The parametric specification of the patent renewal model in Sections 2 and 4 will allow for differences in these dimensions.

Prior to 1968 there was no effective screening of patent applications in France. The French Patent Office was not legally bound to impose substantive criteria of acceptability, and all patent applications that met certain minimal procedural guidelines were granted. In 1968 a new patent law imposed substantive criteria and instructed the French Patent Office to enforce them. Table 1 shows that this patent reform was associated with dramatic changes in grant rates (computed as the ratio of cumulated grants from a given cohort to the number of patent applications for that cohort). Two facts are of particular importance. First, there was a very sharp decline in the grant rate over time for each technology field and country of origin. Second, there are systematic rankings of technology fields and countries of origin in terms of grant rates. Reading across the rows in the table, the ranking of technology fields (in descending order) is pharmaceuticals, chemicals, electronics, and mechanical. This ranking holds for each country of origin and the differences in the grant rates are large. Reading down the columns, the typical ranking countries of origin (within a given technology field) is Japan, France, Germany, the United States and the United Kingdom.

These findings yield two testable implications. First, if the decline in grant rates reflects more stringent screening that weeds out low value patents, it should raise the mean value of patent rights in the population of granted patents over time. Second, higher grant rates for a country of origin within a given technology field should be associated with a larger mean value of patent rights, provided the patent screening criteria do not depend on which country is applying for the patent.[3] These hypotheses are investigated in Section 4, using estimates of mean value from the patent renewal model.

Section 2. Model of Patent Renewal

The empirical work is based on the model developed by Schankerman and Pakes (1986). Consider an agent who holds a patent. Let c denote the cohort of the patent and a denote the age of the patent. In order to keep the patent in force the patentee must pay an annual renewal fee, and failure to pay terminates patent protection permanently. The renewal fee varies with the age and possibly the cohort of the patent. Let $\{C_{ac}\}_{a=1}^{M}$ denote the sequence of renewal fees (in real terms) at different ages. The (annual) economic returns to holding the patent at age a (in real terms) is denoted by R_{ac}. These returns include any economic benefits to the patentee that would not have accrued in the absence of the patent protection. The sequence $\{R_{ac}\}_{a=1}^{M}$ is assumed to be known with certainty by the patentee at the time the patent is applied for (when patent protection begins). The decision problem is to maximise the discounted value of net revenues accruing to the patent by choosing an optimal age at which to stop paying the renewal fee. Formally, the agent chooses the lifespan of the patent, T, to

$$\underset{T\epsilon(1,\ldots,M)}{Max} V(T) = \sum_{a=1}^{T} \beta^{a}(R_{ac} - C_{ac}) \tag{1}$$

where β is the discount factor and M is the statutory limit to patent protection. Provided the sequence of net revenues $\{R_{ac}-C_{ac}\}$ is non-increasing in age, the condition for renewal of the patent at age a is that the annual returns to holding the patent cover the renewal fee,

$$R_{ac} > C_{ac} . \tag{2}$$

Since renewal fees are increasing in age, a sufficient condition for this renewal rule to be optimal is that the returns to holding a patent decay over time.[4]

If the sequence of returns were the same for all patents in a given cohort, then patents would be cancelled at the same age and the renewal curve would be degenerate. Since this is not consistent with observed renewal curves, the model allows patents in a given cohort to differ in their initial revenues (representing them as random draws from some distribution), but assumes that the sequence of decay rates is the same for all patents. Under these assumptions, the condition for renewal of a patent at age a can be written: $R_{oc} > C_{ac} \prod_{t=1}^{a} d_{tc}^{-1}$ where $d_{tc} = 1-\delta_{tc}$. Let $F(R_{oc};\theta_c)$ be the distribution function of initial revenues, where θ_c denotes a vector of parameters that characterises the distribution and may be different across cohorts of patents. Then the proportion of patents in cohort c that is renewed at age a, P_{ac}, is

$$P_{ac} = \int_{z_{ac}}^{\infty} dF(R_{oc};\theta_c) = 1 - F(z_{ac};\theta_c) \tag{3}$$

where $z_{ac} = C_{ac} \prod_{t=1}^{a} d_{tc}^{-1}$. Given an assumed functional form for the distribution of initial revenues, equation (3) provides the relationship between the sequence of renewal proportions predicted by the model and the unknown parameters (the vector θ_c and $\{\delta_{ac}\}$). The estimation problem is to choose those parameter values that make the predicted renewal proportions as "close" to the observed proportions as possible.

On the basis of a comparison among alternative functional forms, the lognormal specification for $F(R;\theta)$ is used.[5] The data set contains four dimensions that must be incorporated in the parameterisation of the model. Denote the country of origin by i, the technology field by j, the cohort by c, and the age of the patent by a. Assume that initial revenues distribute lognormally and let lower case letters denote the logarithm of upper case ones. Then we have $r_{oc}^{ij} \sim N(\mu_c^{ij},\sigma_c^{ij})$ where $N(\cdot,\cdot)$ designates the normal distribution. In logarithmic form, the decision rule is to renew a patent at age a if and only if $r_{oc}^{ij} \geq \ln C_{ac} - \sum_{t=1}^{a} \ln d$ Equivalently,

$$\frac{r_{oc}^{ij} - \mu_c^{ij}}{\sigma_c^{ij}} \geq \frac{-\mu_c^{ij} + \ln C_{ac} - \sum_{t=1}^{a} \ln d_{tc}^{ij}}{\sigma_c^{ij}} \equiv z_{ac}^{ij} \tag{4}$$

The left hand side of (4) has a standard normal distribution, so the proportion of patents that has dropped out by age a is given by

$$P_{ac}^{ij} = \int_{z_{ac}^{ij}}^{\infty} d\Phi(.) = 1 - \Phi(z_{ac}^{ij}) \tag{5}$$

where $\Phi(\cdot)$ is the standardised normal distribution function. This implies the general form of the model,

$$y^{ij}_{ac} = \frac{-\mu^{ij}_{c} + \ln C_{ac} - \sum_{t=1}^{a} \ln d^{ij}_{tc}}{\sigma^{ij}_{c}} \tag{6}$$

where $y^{ij}_{ac} = \Phi^{-1}(1 - P^{ij}_{ac})$.

Given only data on renewal rates for each of the cells defined by the four dimensions, one cannot allow the parameters for the lognormal distribution and decay rates to be completely free. Some simplification of the parameterisation in (6) is required. The model is estimated separately for each technology group, so <u>all</u> parameters are allowed to vary across technology groups. I also permit the mean value of patent rights for any given technology group to differ across cohorts and countries of origin. For the lognormal distribution, the mean of initial revenues depends on μ and σ but the coefficient of variation depends only on σ.[6] The procedure followed here is to allow for the parameter μ to be specific to the cohort and country of origin, but to maintain a common value of σ. This is equivalent to allowing for a proportional rescaling of initial revenues of all patents in a given cell – the mean may differ but the coefficient of variation is common. Section 3 reports the empirical work based on data pooled across countries of origin for each technology group – that is, imposing the constraint $\mu^{ij}_{c} = \mu^{j}_{c}$ for all i. Section 4 explores the empirical differences across countries of origin, permitting μ to be freely parameterised. The decay rate is assumed to be common to different countries of origin within a given technology group and constant over time. However, the decay rate is permitted to differ in 1974 and 1980 in order to capture the impact of the major oil price shocks during those years. These effects are year-specific and apply to any patent that is in force during those years, regardless of patent age.[7]

The stochastic specification allows for two disturbances. The first is an error term in the renewal rule (4), ϵ_{ac}, that is assumed to have zero mean and constant variance, σ_ϵ^2. The second disturbance is a binomial sampling error in the observed renewal proportion, v_{ac}. The variance of the sampling error is given by $P_{ac}(1-P_{ac})/A_c$ where A_c is the number of patents in cohort c. This is introduced because some observed renewal rates are based on cells with relatively few observations (especially recent cohorts in pharmaceuticals).[8] Letting u_{ac} denote the composite disturbance and incorporating these specifications, the model can be written

$$y_{ac}^{ij} = \frac{1}{\sigma^j} [-\mu_c^{ij} + \ln C_{ac} - (\text{Age}-D1-D2)\ln(1-\delta^j) - D1 \ln(1-\delta_{74}^j) - D2 \ln(1-\delta_{80}^j)] + u_{ac} \tag{7}$$

where

$$D1 = \begin{cases} 1 \text{ if } C < 1974 \text{ and } a+c > 1974 \\ 0 \text{ elsewhere} \end{cases}$$

and

$$D2 = \begin{cases} 1 \text{ if } C < 1980 \text{ and } a+c > 1980 \\ 0 \text{ elsewhere} \end{cases}$$

Note that δ is the baseline decay rate applicable in all years except 1974 and 1980, and δ_{74} and δ_{80} are the year-specific decay rates. Because the composite disturbance is heteroskedastic, equation (7) is estimated by generalised nonlinear least squares.[9,10]

Section 3. Empirical Results by Technology Field

3.1 Estimates of the Patent Renewal Model

Table 3 presents the empirical results for different versions of the model, separately for each technology field (pooled across countries of origin). To facilitate discussion, I focus first on a comparison across different specifications, and then turn to the parameter estimates in the preferred specification and compare across technology field. Regression (1) for each technology field refers to the model with a constant decay rate and no cohort-specific variation in μ (i.e. $\mu_c^j = \mu^j$ for all c, which is called the no-effects model). Regression (2) allows for a completely free sequence of cohort effects in μ, $\{\mu_c^j\}_{c=1}^N$, and is called the fixed effects model. The null hypothesis that there are no cohort effects in μ is rejected in each technology group. The computed test statistic T1 varies between 3.5 and 5.5 depending on the technology group, compared to a critical value at the 0.05 level of 1.75 (2.18 at the 0.01 level). This implies that significant changes have occurred in the mean value of patent rights during the period 1969-1982 in all technology groups. These changes are discussed in more detail in Section 3.4.

Regression (3) refers to the fixed effects model that allows for the decay rate to differ during the years of the large oil price changes, 1974 and 1980. The null hypothesis that the decay rate does not change during these years is strongly rejected in each technology group. The computed test statistic T2 is around ten or more, compared to a critical value at the 0.05 level of 3.0 (4.6 at the 0.01 level). Since the parameters δ_{74} and δ_{80} represent year effects (regardless of patent age), this evidence reflects the fact that the dropout rate for all cohorts of patents was abnormally high during 1974 and 1980. Interpretation of these oil price effects is discussed later in this section.

Consider next the comparison of parameter estimates across the technology groups. For this purpose I focus on the model with cohort effects in μ and oil price effects in δ, but the conclusions all hold for the model without oil shocks. In all technology fields the parameters estimates have the expected sign and are statistically significant (δ in pharmaceuticals and chemicals being a marginal exception). The estimates of σ indicate that the distribution of initial revenues exhibits both substantial dispersion and skewness. The degree of dispersion is illustrated by the coefficient of variation, which varies from 2.6 in pharmaceuticals to 16.2 in electronics. The degree of skewness is illustrated by the ratio of the mean to the median of initial revenues, which for the lognormal is $\exp(\frac{1}{2}\,\sigma^2)$. This ratio varies from 2.4 in pharmaceuticals to 16.2 in electronics. Note also that differences across technology fields in μ are positively correlated with those in σ, so that technology groups with higher mean and median levels of initial revenues also have greater dispersion and skewness. The estimates of the rate of decay in returns from holding patents also vary substantially across technology groups. The rates of decay in the pharmaceutical and chemical sectors are similar to each other and rather low, on the order of 5 percent per year, but in the mechanical and electronics technology fields the decay rate is between 10 and 15 percent.

In summary, a sharp picture emerges from these results. The key empirical finding is that the parameters segregate the technology groups into two distinct categories. The first, comprised of pharmaceuticals and chemicals, is characterised by comparatively low values of μ, σ and δ. The distribution of initial returns to holding a patent in these sectors exhibits low median and mean returns, less dispersion and skewness, and a slow rate of decay in privately appropriable returns. The second field, composed of mechanical and electronic patents, is characterised by larger values of μ, σ and δ. The distribution in these sectors exhibits higher median and mean returns, a greater degree of dispersion and skewness, and a much faster rate of obsolescence.[11] The implications of these parameters for the distribution of the value of patent rights are considered in Section 3.2.

The estimates of the decay rates for 1974 and 1980 provide strong evidence that the oil price shocks reduced the value of the stock of patents in force. The point estimates of δ_{74} imply that the contemporaneous returns to holding a patent declined by between 39 and 65 percent in 1974, and the estimates are precise. The decline associated with the second oil price shock in 1980 is somewhat smaller but still substantial, varying between 21 and 39 percent. These parameters may seem unreasonably large, but it is important to remember that they measure the effect on current returns to holding a patent, not the discounted value of the stream of returns. The parameters can be used to deduce the impact on the discounted value of returns - that is, on the value of the patent rights (see Appendix 1 for the method). In this form the estimates of δ_{74} and δ_{80} imply that the oil price shocks reduced the discounted value of patent rights for the stock of patents in force by about 24 percent in 1974 and 18 percent in 1980. The estimated impact is almost identical in each of the four technology groups.[12]

To put this finding in perspective, note that the average decline in Tobin's-Q for the manufacturing sector in five major OECD countries was about 21 percent in 1974-75 and 13 percent in 1980-81 (see Chan-Lee 1986). Hence, the econometric evidence from the patent renewal model indicates that the downward revaluation of the stock of patent rights due to the oil price shocks was large, roughly similar to (if not greater than) the observed decline in the stock market valuation of (physical and intangible) capital at the manufacturing level.

As described in Section 1, the ranking across technology fields by patent renewal rates is very different for patents applied for by Japan than for other countries of origin. To check whether the inclusion of Japan affects the two-way grouping of technology fields, the fixed effects model with and without oil price effects was re-estimated on data excluding patents from Japan. The results (not reported to conserve space) show that the exclusion of Japan does not change the key finding that there are two distinct categories - pharmaceuticals and chemicals in one, mechanical and electronics in the other - or the main characteristics of the parameters in each category. The main effect of excluding Japan is to lower the estimate of μ. The estimate declines by about 0.15 in the pharmaceuticals, chemicals and mechanical groups, but by about 1.0 in electronics. Since the mean value of initial revenues is a (exponential) function of μ, these results suggest that Japanese patents in France are more valuable than those from other countries, especially in electronics where the difference may be very large. To address this issue more fully, Section 4 presents empirical estimates of the model allowing for differences across all countries of origin.

3.2 Estimates of the Value of Patent Rights

In this section the parameter estimates from Table 3 are used to derive the distribution of the value of patent rights. The net present value of patent rights for a single patent is $V = R_0 \Sigma_{t=1}^{T^*}[(1-\delta/(1+i)]^t$ where R_0 is the initial returns from holding the patent, i is the discount rate, and T^* is the optimal lifespan of the patent. The lognormal distribution on R_0 induces a distribution of these values. The parameters μ, σ and δ can be used to generate the quantiles of the distribution of V and their standard errors by simulating the value distribution.[13]

Table 4 presents the distribution of the value of patent rights for the 1970 cohort of patents in each technology field. The value of patent rights includes all net returns accruing from the date of application until the optimal expiration date. The distribution is generated for the model with oil shocks to the decay rate since that model is favored by the data, but the main conclusions also hold for the model without oil shocks.

The most prominent feature of the distributions is the sharp skewness in each technology field. Most patents have very little private value. The median value of patent rights (in 1980 U.S. dollars) is only \$1631 in pharmaceuticals, \$1594 in chemicals, \$2930 in mechanical, and \$3159 in electronics (excluding Japan). The value of patents rights rises sharply with the quantile, especially in the mechanical and electronics technology groups. There are some highly valuable patents in the tails of the distributions, as shown by the upper quantiles, and these patents account for a large fraction of the total value of patent rights for the 1970 cohort in each technology group. The top one percent of patents accounts for about 15 percent of the total value of patent rights in pharmaceuticals and chemicals, and about 25 percent in mechanical and electronics (excluding Japan). The top five percent of patents accounts for about 40 percent of total value in pharmaceuticals and chemicals, and more than 50 percent in the mechanical and electronics groups.[14] The quantiles of the distribution are estimated quite precisely in pharmaceuticals and chemicals. The precision is worse for the mechanical and electronics technology fields, especially in the upper five percent of the tail. Nonetheless, the estimates indicate clear differences across technology fields in the mean value of patent rights. The mean value is estimated to be

$4313 in pharmaceuticals, $4969 in chemicals, $15,120 for mechanical patents, and $19,837 in electronics (excluding Japan). The estimates in Table 4 confirm that the technology fields break down into two distinct categories. Both in terms of the mean value and the degree of skewness in the distributions, there is clear evidence that pharmaceutical and chemical patents fall into one category and mechanical and electronics patents into another.[15]

A comparison of the last two columns in Table 4 also shows that including electronics patents of Japanese origin raises the mean value of patent rights for that technology field by a factor of three and greatly reduces the precision of the estimates. A more detailed look at differences across countries of origin is provided in Section 4.

3.3 Equivalent Subsidy to R&D

The estimates of mean value can be used to obtain the total value of patent rights for a given cohort of patents in each technology field. A comparison between the total value of patent rights and the R&D expenditures used to produce those patents provides an estimate of the subsidy rate to R&D conferred by the patent system (hereafter, the equivalent subsidy rate). This section presents estimates of the equivalent subsidy rate for each technology field for the 1970 cohort of patents.

Suppose for argument that all inventive output is patented, inventions have no private value unless they are patented, and that the level of R&D is adjusted until it earns a normal rate of return at the margin. For the marginal patent, the ratio of the value of patent rights (discounted at the cost of capital) to R&D would equal unity - i.e., a 100 percent subsidy rate since patent protection is the only source of returns to invention. In fact the equivalent subsidy rate will be less than unity, because some inventions are not patented and those that are retain private value even without patent protection. As such, the equivalent subsidy rate is a summary index of the "importance" of patent protection. Of course, the equivalent subsidy rate computed for an entire cohort of patents will be an upper bound to the marginal subsidy conferred by patent protection, if there are diminishing returns to R&D.

The total value of patent rights is obtained by multiplying the estimates of mean value from Table 4 by the number of patent applications. To construct the measure of R&D, one requires a concordance between the industrial classification of available R&D data and the technology classification of patents, and a procedure to apportion the R&D performed by each country of origin to the patents it holds in France (see Appendix 2 for details). The 1970 data on R&D are used since the lag between R&D and patent applications is very short (Pakes and Schankerman 1984; Hall, Griliches and Hausman 1986). Computations are done for company-funded and total R&D performed by business enterprises.

Table 5 summarises the results. The estimated subsidy rate to total R&D is 15.6 percent, and 24.2 percent for company-funded R&D (averaged over technology fields).[16,17] Hence patent protection generates perhaps as much as a quarter of the private returns to inventive activity. Of course, this means at least 75 percent of the private returns to invention are obtained from sources other than patents. This finding is consistent with qualitative survey evidence that firms rely on many methods to appropriate the rents from invention (for example, see Levin et.al. 1987). The size of the (average) equivalent subsidy rate is also consistent with quantitative survey evidence of specific inventions. Mansfield et.al. (1981) report that patent protection raises imitation costs by about 11 percent (median estimate). In a competitive R&D market without patent protection, these costs would be dissipated through additional imitation. With patent protection, these costs presumably accrue to the patentee and hence represent the value of the patent right. Therefore, the average subsidy rate obtained from the patent renewal model should be similar to the increase in the costs of imitation, and it is (15 versus 11 percent).

The importance of patent protection as a source of returns to R&D varies widely across technology fields. The equivalent subsidy rate varies from 4.0 percent in pharmaceuticals to 21.4 percent in electronics (using total R&D). These variations are due to differences in the mean value of patent rights (since there is little variation in the ratios of the number of patents to R&D - see rows 3 and 4). On this measure, the patent system appears most effective in the mechanical and electronics technology groups, and least effective in pharmaceuticals and chemicals.

This ranking is sharply at odds with the conventional wisdom that patent protection is important for pharmaceuticals and chemicals but not for the mechanical and electronics sectors. All available survey evidence points to this conclusion (for example Taylor and Silberston 1973; Mansfield et.al. 1981; Levin et.al. 1987). How can one reconcile the rankings based on survey evidence with those derived from the patent renewal model? The main sector requiring explanation is pharmaceuticals, since survey evidence indicates that patents raise imitation costs for drugs by 30-40 percent (Mansfield et.al. 1981; Levin et.al. 1987). The equivalent subsidy rates for mechanical and electronics patents (13.9 and 21.4 percent) are actually not that different from estimates of the increase in imitation costs due to patents in these sectors (7-15 percent).

The main explanation for pharmaceuticals lies in the institutional context. There has been strict price regulation of patented pharmaceutical products in France since 1945. Every patentee (regardless of country of origin) must obtain governmental authorisation to market any pharmaceutical invention. For ethical drugs the authorisation involves agreement on an administered price which applies to all reimbursed purchases in the private and public sectors.[18] For "parapharmaceuticals" the regulation is less formal – the authorities fix "recommended prices" for manufacturers which are normally respected. This governmental price regulation would certainly be expected to reduce the private value of patent rights for pharmaceutical patents. This reduction in mean value occurs for two reasons. The whole distribution of the value of patent rights will be shifted to the left since price regulation applies to all pharmaceutical patents. Price regulation should also reduce the skewness of the distribution of appropriable returns, since huge rents on important products would presumably be disallowed. This further reduces the mean value of patent rights. In the extreme case where price regulation allows for only a normal return to R&D costs, patent protection would be worthless and the equivalent subsidy rate would fall to zero. Effective price regulation may be an important determinant of the low equivalent subsidy rate for pharmaceuticals.

There is a second explanation also due to price regulation. The procedure to compute the R&D costs for pharmaceutical patents held in France may overstate the true costs, and hence understate the true subsidy rate. R&D for each country of origin is allocated to its patents held in France in proportion to the ratio of its exports (to France) to total sales. This corresponds to the profit maximising allocation of common R&D costs for a monopolist (patentee) selling in a number of markets with the same price elasticity. However, price regulation in France raises the effective price elasticity facing the patentee and lowers the profit maximising allocation of R&D to the French market. While some form of pharmaceutical price regulation for pharmaceuticals exists in a number of countries, it is effectively absent in the largest market, the United States.

It is not possible to assess the quantitative importance of these two factors without more information on the demand structure and regulatory price determination. But they underscore the important point that the effectiveness of patent protection depends on the broader institutional setting, including other forms of regulation impinging on an industry.

3.4 Patent Counts and Mean Value

It is common practice to use the number of patents as an indicator of patented (more broadly, inventive) output. The validity of this practice depends on whether the mean value of patents varies over time, and whether those changes are correlated with movements in patent counts. The value of patents themselves cannot be measured directly, but there is good reason to expect that the value of patent rights would be correlated with it. This section summarises movements in the mean value of patent rights over time for each technology field, and characterises the relationship between the quantity and "quality" of patents.

Figures 7-10 present indices of the number of patent applications, mean value and total value of patent rights for each technology field (normalised in 1969).[19] There are two distinct subperiods 1969-1976 and 1977-1981. During the first period the number of patent applications declines about fifteen percent in each technology field, except pharmaceuticals where it rises by about the same amount. The mean value of patent rights shows a modest decline, except for the cohorts immediately after the major oil shock (1973 and 1974) where it falls sharply in each technology field.

The number of patent applications in France fell sharply during the second period, by about ninety percent in pharmaceuticals and fifty percent in the other technology fields. These declines had little to do with a fall in real inventive output, however, reflecting instead the introduction of the European Patent Convention in 1978. The European patent conferred protection for an invention in multiple designated member countries, the application fee depending on the number of countries specified by the patentee. The effect was to reduce the cost of multiple applications for the same patent. The data set used in this paper contains French national patents but excludes European patents with France as a designated state. Hence, any self-selection into European patents would register as a decline in the number of patent applications in France. The evidence in the figures indicates that a process of self-selection is at work. The sharp break in the path of patent applications occurs in 1977, just when the European Patent Convention became effective. The drop is especially severe in pharmaceuticals and chemicals, but even in the mechanical and electronic technology groups there is evidence of an accelerated decline at that time.[20]

It has been argued in the literature on intellectual property that patents taken out in multiple countries are more likely to be higher value patents (Soete and Wyatt 1983; Basberg 1983). Since the European patent economises on multiple applications, the introduction of this option should have lowered the mean value of national patents applied for in France. In fact the opposite occurred. There is a sharp increase in the mean value of patent rights in each technology field which occurs quite abruptly in 1977, though in pharmaceuticals and chemicals there is some more gradual increase beginning in 1975. This striking negative covariance between movements in patent counts and mean value, and their timing, strongly suggest that the process of self-selection into European Patents is not random with respect to the value of patents. The evidence supports the hypothesis that the relatively low valued patents were taken out as European Patents.

Section 4. Empirical Results by Technology Field and Country of Origin

4.1 Estimates of the Patent Renewal Model

The nonparametric tests reported in Section 1 indicated that there are variations in the value distributions both across technology fields and countries of origin. This section presents results from a parametric specification of the patent renewal model that incorporates differences across countries of origin as well as technology fields. There are two reasons to conduct this analysis. The first is to check whether allowing for differences across countries of origin changes the basic empirical characterisation of technology groups presented in Section 3. The second is to measure the differences across countries of origin in the mean value of patent rights and to explore the determinants of those differences.

The specification used in this section allows for a completely unrestricted sequence $\{\mu_c\}_{c=1}^{N}$ for each country of origin, but imposes the same value of σ and δ. This is equivalent to allowing for a proportional rescaling of initial revenues of all patents (for a given cohort) in different countries of origin. The specification permits the time path of mean values over cohorts to differ for each country of origin but imposes a common coefficient of variation.

Table 6 presents the empirical results (for brevity, the estimate of μ for the 1970 cohort is reported) for the model with oil shocks, but the conclusions also hold for the baseline model. The estimates of μ do vary across countries of origin. The restriction that there are no differences, $\mu_c^{ij} = \mu_c^j$ for all i, is decisively rejected for each technology group. The computed F(52,585) statistics are all larger than twenty (see test T1), compared to a criticial value at the 0.05 level of 1.4. Nonetheless, the estimates of the other parameters (σ, δ, δ_{74} and δ_{80}) are very close to the constrained estimates presented in Section 3.1. The point that should be emphasised is that the empirical characterisation of different technology fields in terms of mean value, dispersion, skewness, and decay rates does not depend on whether one allows for variations across countries of origin. Since the parameters σ and δ do not vary within a given technology group, the ranking of countries of origin in terms of mean value is given by the ranking in terms of μ. For each country of origin the estimates of μ in Table 6 imply the same ranking of technology groups in terms of the mean value as the one obtained from the constrained specification in Section 3.1 – in descending order, electronics, mechanical, chemicals and pharmaceuticals.

Test T2 examines the hypothesis that the differences across countries of origin in the mean value of patent rights are stable over time. This hypothesis implies the parameter restriction $\mu_c^{ij} - \mu_c^{kj} = \alpha_{ik}$.[21] The computed F(48,585) statistic is less than two in the chemicals, mechanical and electronics technology groups and about five in pharmaceuticals, compared to a critical value at the 0.05 level of about 1.4. Hence the time paths of mean value do differ across countries of origin, but the evidence is strong only for pharmaceuticals.

The parameter estimates in Table 6 are used to produce (by simulation) the entire time paths of mean values for each technology field and country of origin. To summarise this information, Table 7 presents index numbers for the mean value of patent rights for the 1970–72 and 1979–81 cohorts (normalised by the United States). The table reveals a systematic ranking of countries of origin in terms of mean value. The typical ranking in descending order is Japan, France, the United States, Germany and the United Kingdom. The dominance of patents of Japanese origin in the mechanical and electronics technology fields is particularly striking. It is interesting to note that the ranking in terms of mean value is the same as the ranking of patent renewal curves (see Figures 3-6).

These variations in mean value, however, do not necessarily reflect differences in the underlying quality of patented inventions produced by the various countries of origin. There is some selection process that determines which patents are applied for in France, so the mean value of the observed sample of patents from each country of origin can differ from the unconditional mean. Presumably foreign applicants are more self-selective than domestic ones. The table shows, however, that (apart from Japan) the mean value of French patents is generally higher than for foreign applicants. This suggests that at least part of the strength of Japanese patents is real, not simply an artifact of selection. Without modelling the selection rule, it is not possible to quantify this effect.

4.2 Exploring Variations in Mean Value

This section presents some evidence on the determinants of the variations over time and across countries of origin in the mean value of patent rights. It was shown that the fraction of patents granted declines sharply over the sample period and differs systematically among countries of origin (within a given technology group). Since the sample used for the empirical work is designed to exclude "involuntary attrition", variations in the grant rate should affect the mean value of patents that are eventually granted. The first hypothesis is that variations over time in the grant rate reflect changes in the stringency of the patent screening process and that stringent screening weeds out the low value patents.[22] This hypothesis implies a negative correlation across cohorts between mean value and grant rate, for a given technology group and country of origin.[23] The second hypothesis concerns the comparison across countries of origin, given the cohort and technology group. It is reasonable to assume that the patent screening criteria do not depend on which country is applying for the patent. Hence, differences across countries of origin in the grant rate will reflect differences in the distribution of the value of patent rights and should be positively correlated with mean value. The third hypothesis is that there is a negative correlation across cohorts between the number of patent applications and mean value, holding grant rates constant. Such correlation could be the result of self-selection of lower value patents into the European patent after 1978, but it could also arise from an underlying tradeoff between quantity and quality of patents in the search process generating inventive output.[24] These three hypotheses are tested here in the context of reduced form relationships and no structural interpretation should be given to the parameters.

The following specification is used

$$\ln \bar{V}_{ijc} = \alpha_o + \alpha_1(\theta_{ijc}-\theta_{.jc}) + \alpha_2(\theta_{.jc}-\theta_{.j.}) + \alpha_3 \ln A_{ijc} + \epsilon_{ijc} \tag{8}$$

where V, θ and A denote mean value, grant rate and the number of patent applications, respectively. The subscripts i, j and c denote the country of origin, technology field and cohort, respectively, and a dot denotes an average. The disturbance ϵ_{ijc} is assumed to be independently and identically distributed. The hypotheses imply $\alpha_1 > 0$, $\alpha_2 < 0$, and $\alpha_3 < 0$. The estimates of the mean value are taken from the model with oil shocks (Table 6). Equation (8) is estimated by ordinary least squares for each technology field separately and pooled (including intercepts for each technology field).

Table 8 presents the results. All three hypotheses are strongly supported by the evidence in each technology field, and together they account for between a third and half of the variation in mean value. The estimate of

α_1 confirms that, given the cohort, countries of origin with higher grant rates have larger mean value and the effect is large. The estimate of α_2 indicates that, given the country of origin, higher grant rates for a cohort are associated with lower mean value, with a semi-elasticity of about (minus) unity. The estimate of α_3 confirms that there is an inverse relation between mean value and the number of patent applications, with an elasticity of about -0.15. The parameters are estimated quite precisely, and their similarity across technology fields is striking. The null hypothesis of homogeneity across technology fields is not rejected - the $F(9,240)$ statistic is 1.57, compared to a critical value at the 0.05 level of 1.92.

This evidence indicates that the patent screening process is not random (in relation to value of patent rights), and suggests that data on grant rates may be a useful supplementary indicator of the mean value of patents. It is important in this context, however, to distinguish between variations over time and differences across countries of origin in the grant rate.

Concluding Remarks

This study provides econometric evidence on the private value of patent rights for different technology fields and countries of origin. The findings are derived from parametric estimation of a model of patent renewal, applied to data on patents held in France during the period 1969-1987. The main empirical findings can be summarised as follows. The distribution of the private value of patent rights is sharply skewed in all technology fields, confirming previous research using aggregate data (Schankerman and Pakes 1986). Most of the value of patent rights is accounted for by highly valuable patents in the tail of the distribution. There are sharp differences across technology groups, however, which fall rather neatly into two categories. The value distributions for pharmaceuticals and chemicals are characterised by a low mean, less dispersion and skewness, and slow rates of depreciation. Patents in the mechanical and electronic fields exhibit larger mean value, greater dispersion and skewness, and faster depreciation. The property rights generated by the patent system confer sizeable economic rents on patentees. On the average these rents are equivalent to subsidy rate to R&D of about 15 percent. Hence patent protection is a significant source of returns to inventive effort, but it does not appear to be the major one. This confirms survey evidence that firms rely on a variety of mechanisms other than patents to protect inventions. The importance of patent protection varies sharply across technology fields, equivalent to a subsidy to R&D of 5-10 percent in pharmaceuticals and chemicals but 15-20 percent for mechanical and electronics patents. The surprising unimportance of patent protection in pharmaceuticals is ascribed to effective price regulation of ethical drugs in France and hence may not generalise to other countries.

There were substantial movements over time in the mean value of patent rights and the number of patent applications in each technology field. An abrupt decline occurred in patent counts and a closely timed rise in the mean value of patent rights during the late 1970s. These changes were due mainly to systematic self-selection of low valued patent applications into European Patents, but more effective screening by the French Patent Office also contributed to the increase in mean value. The two oil price shocks in 1974 and 1980 had large negative impacts on the private value of patent rights, on the same order of magnitude as the decline in the value of firms registered in the stock market.

There are systematic differences across countries of origin in the mean value of patent rights. Japan and France have the largest mean value in each technology field, followed by the United States, Germany and the United Kingdom. Patents originating in Japan are substantially more valuable than for other countries and the difference is most striking for electronics patents. It was not possible with the available data to determine how much of these variations in mean value is due to differences in the quality of the inventions and to self-selection in the application process. Variations in the mean value of patent rights are correlated with patent grant rates across countries of origin and over time. This finding suggests that the patent screening process is not random and that patent grant rates may be a useful supplementary indicator of the value of patents.

In terms of future research in this area, the most important task is to conduct empirical studies of disaggregated patent renewal data for other countries. The key question is whether the rankings of technology fields and countries of origin found in this paper are confirmed in other national markets. If so, such evidence would demonstrate the usefulness of patent renewal data and establish empirical regularities relevant to economic policy. If not, the task will be to identify the economic factors (including institutional considerations) that account for variations across national markets.

ENDNOTES

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[1] The renewal fee schedule was changed almost annually - in 1968, 1970, 1972, 1974-1975, 1977-1981 and 1981-1987. Nominal fees are converted to real terms using the GDP deflator for France. The schedules of renewal fees (in real terms) are quite similar across cohorts. Analysis of variance reveals that the between-cohort dimension accounts for only about 20 percent of the total variance, the remaining 80 percent being between-age (within-cohort) variance.

[2] Some additional nonparametric tests are summarised here (details of test statistics are omitted for brevity). First, if patents of Japaness origin are excluded, the hypothesis that the value distributions are the same across the remaining four countries of origin is rejected in all technology fields <u>except</u> electronics. This indicates that Japan is an outlier in the electronics field (see also the parametric estimates of mean value in Section 4). Second, the tests in Table 2 were conducted using a finer disaggregation of technology fields, viz., the fifteen groups comprising the four broad technology fields used in this paper. Not surprisingly, the hypothesis that the value distributions are the same across these fifteen technology fields is rejected for each of the five countries

of origin. The hypothesis that the distributions are the same across countries of origin is rejected in 12 of the 15 technology fields (11 of 15 if Japan is excluded). Hence, some of the observed differences across countries of origin may be due to the fact that countries specialise in different technology fields but the available disaggregation in the data is not fine enough to capture it. These nonparametric findings are generally consistent with those of Pakes and Simpson (1989) using Scandinavian data.

[3] Strictly speaking, under the stated conditions a higher mean value would not ensure that the grant proportion would be larger. It would be guaranteed if the distribution of the value of patent rights for that country of origin stochastically dominates.

[4] The condition that the sequence $(R_{ac}-C_{ac})$ is non-increasing in age is sufficient but not necessary for the renewal rule in (2) to hold. It needs only to hold in the neighbourhood of the optimal cancellation age. Specifically, there must exist a T for which $R_{ac}-C_{ac} > 0$ for $a<T$ and $R_{ac}-C_{ac} < 0$ for $a>T$, where T is the last age at which the patentee pays the renewal fee. The net revenues $R_{ac}-C_{ac}$ may be increasing in some interval before T.

[5] I experimented with the Pareto, Weibull, and lognormal distributions. The comparison is based on two different measures of statistical fit suggested by Amemiya (1981): 1. the sum of squared differences between P_{ac} and $\hat{P}_{ac}$, where $\hat{P}_{ac}$ is the estimate of P_{ac} implied by the parameters of the model, and 2. the weighted sum of squared differences between P_{ac} and $\hat{P}_{ac}$, using as weights the binomial sampling variance of P_{ac} around its true value, $P_{ac}(1-P_{ac})/A_c$ where A_c is the number of patents in cohort *a*. The comparison is made for each technology group separately (pooling across countries of origin), using a specification

that allows for the mean value of patent rights to differ across cohorts (maintaining the same coefficient of variation) and for a constant decay rate. The lognormal fits better than the Weibull in all four technology groups according to both fit criteria. In most cases the lognormal also fits better than the Pareto. In those cases where the Pareto is marginally superior, the parameter estimates for the Pareto are not economically sensible (they imply that the renewal rate rises with renewal fees and that the depreciation rate is negative).

[6] For the lognormal distribution, the median, mean and coefficient of variation of initial revenues are given by $\exp(\mu^2)$, $\exp(\mu+\frac{1}{2}\sigma^2)$ and $(\exp(\sigma^2)-1)^{\frac{1}{2}}$. See Johnson and Kotz (1971).

[7] Two remarks are in order. First, the patents studied here provide legal protection only for sales made in France (whether domestic production or imports). This applies to all countries of origin, including France. In this context, the assumption that the decay rate is the same for all countries of origin within a given technology group does not seem severe. Second, I also experiment with specifications that allow the effect of the oil price shocks on the decay rate to persist for several years. See note 12.

[8] Because the model in (6) is nonlinear in P_{ac}, allowance for the sampling error requires linear approximation to yield a tractable form. The true dependent variable is $y^*_{ac} = \Phi^{-1}(1-P^*_{ac})$. The observed renewal proportion is $P_{ac} = P^*_{ac} + v_{ac}$ where v_{ac} is a binomial sampling error with zero mean and variance $P_{ac}(1-P_{ac})/A_c$. Substituting into y^*_{ac} and taking a linear approximation to the nonlinear function Φ^{-1}, $y_{ac} = y^*_{ac} - \omega v_{ac}$ where $\omega = \partial\Phi^{-1}/\partial v$ is evaluated at some fixed point and

hence treated as an unknown constant over a and c. This introduces the error term $u_{ac} = \omega v_{ac}$ into the estimated equation.

[9] The composite error $\zeta_{ac} = \epsilon_{ac} + u_{ac}$ has variance $\sigma_c^2 + \omega^2 P_{ac}(1-P_{ac})/A_c$. The model is estimated in three stages. Consistent estimates of the composite error, $\hat{\zeta}_{ac}$, are obtained using ordinary nonlinear least squares. Then $\hat{\zeta}^2_{ac}$ is regressed against a constant and $P_{ac}(1-P_{ac})/A_c$ using ordinary least squares and the fitted value is retrieved, $\hat{F}_{ac}$. The model is then re-estimated using $\hat{F}^{*}$ to perform generalised nonlinear least squares.

[10] The data set does not contain the number of patent applications rejected each year for a given cohort, so it is not possible to remove patent rejections from the raw data. Hence some of the observed attrition of patents reflects involuntary dropouts due to the granting procedure, but these nonrenewals are not explained by the model of patent renewal and should be purged. Schankerman (1990) presents evidence that the effect of patent rejections is minimal after age three, so estimation of the patent renewal model is conducted on the sample of patents that survive to age three. Renewal rates are normalised by the fraction of patents that renew at age three for the associated cohort (that is, P_{ac}/P_{3c}). This procedure should also take care of the learning effects in the patent renewal decision, documented by Pakes (1986). Pakes shows that patentees learn about the sequence of returns at early ages and hence do not behave according to the simple renewal rule in equation (2), but these learning effects are completed within three to four years.

[11] The point estimates of the parameters are not consistent with the stochastic dominance of the distribution of the initial returns for any technology group. For the lognormal, the α-quantile of revenues,

R_α, is given by $\exp(\mu+U_\alpha \sigma)$ where U_α is the α-quantile of the standard normal distribution. The ratio for two different groups k and ℓ is $R^k_\alpha/R^\ell_\alpha = \exp(\mu_k-\mu_\ell+U_\alpha(\sigma_k-\sigma_\ell))$. For stochastic dominance of group k and ℓ, this ratio must exceed unity for all $\alpha \in (0,1)$. It is easily verified that the necessary and sufficient conditions for this to hold are $\mu_k > \mu_\ell$ and $\sigma_k = \sigma_\ell$.

[12] The specification reported in the text forces the oil price shock to affect only the current decay rate, so the downward revaluation of the value of patents occurs fully during the year of the shock. In order to check whether the large estimated effect is due to this restrictive assumption, I estimated a version of the model that permits the effect of the oil shocks to persist for three years – i.e., incorporating separate decay rates for each year during 1974-1976 and 1980-1982. A comparison is made between the cumulative depreciation during those three year periods implied by this extended model with that implied by the estimates reported in the text. The parameters in the more flexible version imply an even larger (long run) reduction in the flow of returns to patents (in some cases by as much as 50 percent larger), so the conclusion stated in the text is conservative. Second, a model with a completely free sequence of decay rates for different years was also estimated. It provides evidence of jumps in the decay rate after the two oil price shocks, but the individual estimates are very imprecise.

[13] While the distribution of R_0 is lognormal, the distribution of V is not since lognormality is only preserved under multiplication of random variables. The procedure to generate quantiles is based on drawing 50,000 random numbers from a lognormal distribution parameterised by μ and σ. For each draw, the estimate of δ and

observed renewal fees are used to compute the optimal expiration date according to the renewal rule (equation (4) in Section 3.1), and the associated net value of patent rights for that draw is generated. In this way the entire distribution of the value of patent rights is simulated. Simulations based on perturbations of μ, σ and δ are used to compute numerical derivatives of the quantiles with respect to parameters and standard errors for the quantiles are constructed by the delta method. The generalisation for the model with year-specific decay rates δ_{74} and δ_{80} is straightforward.

[14] The fraction of total value in the top percentile of patents is given by $0.1\ V_{.99}/\tilde{V}$ where $V_{.99}$ denotes the value for the top percentile and $\tilde{V}$ is the mean value for all patents in the cohort. This is a conservative estimate since it assigns the lower bound value $V_{.99}$ to all patents in the top percentile. For the top five percent of patents, the figure is computed using values for the 0.95, 0.975 (not reported in the table) and 0.99 quantiles as follows: $(0.025\ V_{.95} + 0.015\ V_{.975} + 0.01\ V_{.99}$. The specific estimates in percentage terms for the top one (five) percent of patents are 12 (34) in pharmaceuticals, 14 (38) in chemicals, 21 (50) for mechanical, and 24 (55) for electronics excluding Japan. Inclusion of Japan in electronics raises the figure by about five percentage points. The estimates based on the model without oil shocks are almost identical.

[15] As noted in Section 1, the grant rate is much larger for pharmaceuticals and chemicals than for the other technology fields, for each country of origin. The conventional wisdom is that inventions in these technologies are more "patentable" because of the nature of patent law. An alternative explanation is that patent examiners screen patents according to some fixed cutoff (defined in

terms of "inventive step") which is correlated with patent values, and that the distributions of patent values in pharmaceuticals and chemicals stochastically dominate those in the other fields. However, the estimates of mean values in Table 4 are not consistent with this second explanation (see also footnote 11). Hence the evidence suggests, albeit indirectly, that differences in grant rates do reflect a systematic bias in patent law that favors "patentability" of inventions in pharmaceuticals and chemicals.

[16] The subsidy rates reported in the text are based on the mean values from the fixed effects model with oil shocks (Table 4). If the model without oil shocks is used, the subsidy rate for company-funded R&D (total R&D) varies from 3.4 (3.3) percent in pharmaceuticals to 24.8 (15.0) percent in electronics. The main conclusions in the text are unchanged.

[17] Using aggregate patent renewal data for France, Schankerman and Pakes (1986) estimate a subsidy rate on company-funded R&D for the 1970 cohort of 6.8 percent. They measure the value of patent rights for patents that survive until age five and include returns accruing from age five of the patent. In the present study the parameters of the model are estimated using patents that survive until age three, but the mean value of patent rights is simulated using these parameters to characterise the entire population of patents and to include all returns from the date of application. To make them comparable, the subsidy rate reported here must be multiplied by $[(1-\delta)/(1+i)]$ P_5, where P_5 is the proportion of patents that survive until age five. Using $\delta = 0.1$, $i = 0.1$ and $P_5 = 0.7$ (sample mean), the average subsidy rate for company-funded R&D reported in the text translates to 6.2 percent.

[18] The specific guidelines for setting prices have changed over time. Prior to 1972, prices were set to compensate the patentee for the basic raw materials and capital investment, plus some allowance for a "profit margin". Since 1972 prices are set more informally, with no explicit allowance either for production or R&D costs, but economising on health costs is an officially stated objective. I would like to thank Ms Virgine Perotin of the Centre d'Etude des Revenu et des Couts (CERC) in Paris for helpful discussions of pharmaceutical regulation in France.

[19] The mean values for each cohort are based on the parameter estimates from the fixed effects model with oil shocks. The time paths of mean and total value are similar for the model without oil shocks, except that the declines in mean value for cohorts 1973–1975 are less sharp. The electronics sector includes patents originating in Japan, but this does not affect the time path.

[20] To measure how much of the overall decline in patent applications is due to the European patent, I computed (using other data sources) for each technology group the total number of patent applications applicable to France in 1982, including both national patents and European patents with France as a designated country. The results show that all of the decline in Figures 7–10 is due to self-selection into European patents, except in pharmaceuticals where about a quarter of the decline can be explained in this way. See Schankerman (1990) for details.

[21] The logarithm of the mean level of initial returns for country of origin i in technology group j for cohort c, r_{oc}^{ij}, is $\mu_c^{ij} + \frac{1}{2}\sigma^2$. The time paths for countries i and k are the same if and only if $r_{oc}^{ij} - r_{oc}^{kj}$ is independent of c. This is the condition given in the text.

[22] It is not necessary that patent examiners themselves screen systematically according to patent values. Even if they randomly reject some fraction of applications, self-selection by potential patentees on the basis of expected profitability of patenting (including the probability of rejection) would generate the same result.

[23] One alternative hypothesis is that variations in the grant proportion are due to differences across cohorts in the underlying distribution of the value of patent applications, in which case the expected correlation would be positive. It should also be recalled that grant fractions are defined here as the percentage of applications of a given cohort that are eventually granted (not those granted in a particular year), so that granting lags do not directly affect these grant fractions or their relationship to mean value.

[24] The first evidence of an inverse relationship between patent counts and mean value (neglecting grant fractions) was reported in Schankerman and Pakes (1986). For more discussion of the interpretation of this finding, see Pakes and Simpson (1989).

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Table 1. Grant Rates in France, by Country of Origin and Technology Field for 1970-72 and 1979-81 Cohorts (%)

	Technology Field			
Country	Pharmaceuticals	Chemicals	Mechanical	Electronics
Germany	90.0 66.0	92.2 71.6	93.8 43.5	91.1 70.9
France	89.5 89.3	94.6 83.7	92.7 57.7	91.9 73.2
United Kingdom	86.7 76.2	89.5 65.5	93.1 36.3	87.3 48.8
Japan	94.1 91.6	96.7 86.1	97.2 61.2	96.4 70.1
U.S.	89.5 82.4	92.5 70.1	93.8 41.6	92.2 60.0
Number of Applications	1249 250	5911 3153	14,112 8,835	9245 5668

Notes. The top figure in each cell refers to the average for the 1970-1972 cohorts, the lower figure for the 1979-1981 cohorts. To minimise truncation bias for later cohorts, the number of grants in the last available year must be less than five percent of cumulated grants from that cohort (this required deleting cohorts after 1982).

Table 2. Nonparametric Tests on Renewal Rates for Technology Fields and Countries of Origin

	Panel A			Panel B	
	Test for Equality Among Technology Fields			Test for Equality Among Countries of Origin	
	d	χ^2_d/d		d	χ^2_d/d
Germany	32	14.1	Pharmaceuticals	31	18.1
France	32	28.4	Chemicals	41	39.0
U.K.	32	10.8	Mechanical	41	22.6
Japan	32	19.8	Electronics	41	50.3
U.S.	32	9.6			

Notes. The number of restrictions for the Chi-square test is denoted by d. For details of the test, see Pakes and Simpson (1989).

Table 3. Parameter Estimates for the Patent Renewal Model, by Technology Field[a]

Parameter	Panel A Pharmaceuticals			Panel B Chemicals			Panel C Mechanical			Panel D Electronics		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
μ^b	6.41	7.10	7.36	6.55	7.11	7.39	6.78	7.82	8.11	7.22	8.75	9.24
	(.21)	(.37)	(.41)	(.22)	(.36)	(.40)	(.28)	(.58)	(.63)	(.46)	(1.13)	(1.26)
σ	1.04	1.37	1.37	1.17	1.52	1.51	1.37	1.98	1.96	1.51	2.39	2.36
	(.09)	(.16)	(.16)	(.10)	(.17)	(.17)	(.14)	(.30)	(.29)	(.21)	(.57)	(.56)
δ	.004	.058	.031	.017	.068	.043	.045	.132	.097	.074	.192	.153
	(.02)	(.029)	(.027)	(.018)	(.029)	(.028)	(.024)	(.045)	(.042)	(.037)	(.079)	(.075)
δ_{74}			.39			.43			.51			.65
			(.09)			(.09)			(.10)			(.14)
δ_{80}			.24			.21			.31			.39
			(.06)			(.06)			(.07)			(.12)
R^2	.90	.90	.90	.90	.91	.91	.89	.90	.90	.84	.85	.85
mse	1.14	1.09	1.05	1.10	1.07	1.03	1.09	1.06	1.03	1.07	1.05	1.02
df	635	622	620	650	637	635	650	637	635	650	637	635
$T1^c$		5.48			4.69			4.61			3.54	
%Δmse		.115			.096			.094			.072	
$T2^d$			12.92			12.55			12.63			9.05
%Δmse			.042			.040			.040			.029

Notes overleaf.

Notes

a All estimates are from the lognormal patent renewal model, allowing for binomial sampling error and constant variance renewal error. Estimated standard errors are in parentheses. Column (1) is the no-effects model. Column (2) allows for fixed cohort effects in μ. Column (3) includes both fixed cohort effects in μ and year effects in δ for 1974 and 1980.

b The reported μ is for the 1970 cohort, except in the no-effects model.

c T1 refers to the test of the no effects model: $\mu_c = \mu$ for all c. The test statistic distributes as F(13,df).

d T2 refers to the test of the hypothesis $\delta = \delta_{74} = \delta_{80}$ in the specification with fixed effects for μ. The test statistic distributes as F(2,df).

Table 4. Distribution of the Value of Patent Rights for the 1970 Cohort, by Technology Group: Oil Shock Model

Quantile	Pharm	Chem	Mech	Elect	Elect (excluding Japan)
0.25	515	447	638	1,450	627
	(128)	(103)	(312)	(1,256)	(279)
0.50	1,631	1,594	2,930	7,933	3,159
	(539)	(591)	(1,666)	(9,228)	(1,708)
0.75	5,427	5,807	13,769	46,964	16,322
	(2,437)	(2,859)	(9,935)	(53,265)	(11,055)
0.90	11,787	13,735	40,840	170,958	53,122
	(6,061)	(7,039)	(35,547)	(315,079)	(58,822)
0.95	19,920	24,363	83,857	402,292	113,403
	(11,211)	(13,814)	(81,228)	(826,778)	(105,162)
0.99	52,139	69,906	321,966	2,016,797	481,429
	(34,565)	(46,983)	(375,386)	(4,984,719)	(538,827)
Mean	4,313	4,969	15,120	68,502	19,837
	(1,995)	(2,591)	(13,692)	(134,208)	(18,020)

Notes.

Figures refer to the private value of patent rights (in 1980 U.S. dollars), measured from date of patent application. They are simulated using parameter estimates for the lognormal patent renewal model with fixed cohort effects and constant decay rate in Table 3. The discount rate is set at 0.10. Estimated standard errors in parentheses are computed by the delta method.

Table 5. Patent Applications, Value and R&D for the 1970 Cohort, by Technology Field

	Pharm	Chem	Mech	Elec (excluding Japan)
1. Applications, A	1199	6188	14,290	8863
2. Mean Value[a], $\overline{V}$ (\$1980)	4313	4969	15,120	19,837
3. A $\overline{V}/R\&D_C$	0.041	0.072	0.299	0.354
4. A $\overline{V}/R\&D_T$	0.040	0.067	0.161	0.214
5. Wtd Ave.[c] A $\overline{V}/R\&D_C$ = 0.242				
6. Wtd Ave. A $\overline{V}/R\&D_T$ = 0.156				

Notes.

a Mean value estimates are taken from Table 4.

b The procedure to construct estimates of R&D by technology field is described in Appendix 2. $R\&D_C$ and $R\&D_T$ refer to company-funded and total R&D, respectively.

c The weighted averages are constructed using R&D figures.

Table 6. Parameter Estimates for the Patent Renewal Model with Country of Origin Differences; Oil Shock Version

Parameter	Pharmaceuticals	Chemicals	Mechanical	Electronics
μ_{1970}				
Germany	7.09	7.19	8.05	8.52
	(0.24)	(0.23)	(0.35)	(0.44)
France	7.84	7.71	8.45	9.27
	(0.29)	(0.26)	(0.39)	(0.51)
United Kingdom	7.09	6.95	7.89	8.34
	(0.24)	(0.22)	(0.34)	(0.43)
Japan	7.36	7.81	9.17	10.44
	(0.25)	(0.27)	(0.44)	(0.62)
United States	7.10	7.20	8.23	8.89
	(0.24)	(0.23)	(0.37)	(0.48)
σ	1.36	1.51	2.10	2.34
	(0.10)	(0.10)	(0.17)	(0.22)
δ	0.027	0.041	0.111	0.144
	(0.016)	(0.016)	(0.024)	(0.029)
δ_{74}	0.400	0.429	0.542	0.650
	(0.054)	(0.051)	(0.056)	(0.055)
δ_{80}	0.224	0.211	0.327	0.376
	(0.036)	(0.034)	(0.042)	(0.047)
R^2	0.96	0.97	0.97	0.98
mse	0.03	0.03	0.02	0.02
df	568	583	583	583
T1	23.31	23.86	35.98	65.24
T2	5.11	1.72	2.12	1.95

Notes.

All estimates are from the lognormal patent renewal model, allowing for binomial sampling error and constant variance renewal error. The model allows for a full set of cohort/country of origin interactions for μ and year effects in δ for 1974 and 1980. Estimated standard errors are in parentheses.

Table 7. Mean Values of Patent Rights, by Country of Origin
(normalized by United States)

1970-72 Cohort

	Pharmaceuticals	Chemicals	Mechanical	Electronics
Germany	0.95	1.05	0.82	0.67
France	2.05	1.66	1.30	1.51
United Kingdom	1.00	0.78	0.72	0.57
Japan	1.47	1.97	2.81	4.70
U.S.	1.00	1.00	1.00	1.00

1979-81 Cohort

	Pharmaceuticals	Chemicals	Mechanical	Electronics
Germany	0.76	1.16	1.10	0.87
France	1.29	1.48	0.92	1.08
United Kingdom	0.64	0.99	0.70	0.77
Japan	1.46	2.59	3.54	6.15
U.S.	1.00	1.00	1.00	1.00

Notes.

These index numbers are computed from simulated mean values based on the parameter estimates presented in Table 6. Mean values are averaged for the 1970-72 and 1979-81 cohorts to remove transitory variations.

Table 8. Parameter Estimates for the Mean Value Equation

Parameter	Pharmaceuticals	Chemicals	Mechanical	Electronics	Pooled
Intercept	8.20 (0.05)	8.47 (0.04)	9.90 (0.06)	10.88 (0.09)	8.21 (0.06)
D_C	–	–	–	–	0.27 (0.08)
D_M	–	–	–	–	1.68 (0.08)
D_E	–	–	–	–	2.65 (0.08)
α_1	3.19 (0.74)	4.22 (0.65)	4.29 (0.70)	6.91 (1.17)	4.80 (0.43)
α_2	-0.85 (1.41)	-1.01 (0.55)	-0.66 (0.31)	-1.12 (0.84)	-0.87 (0.26)
α_3	-0.04 (0.05)	-0.11 (0.06)	-0.24 (0.07)	-0.25 (0.12)	-0.14 (0.04)
R^2	0.24	0.44	0.46	0.37	0.85
df	61	61	61	61	253

Notes.

Estimates are for the mean value equation (8) in the text, where D_C, D_M and D_E are technology group dummies for chemicals, mechanical and electronics, respectively. Estimated standard errors are in parentheses.

Figure 1
Renewal Rates : Non-Japanese Origin

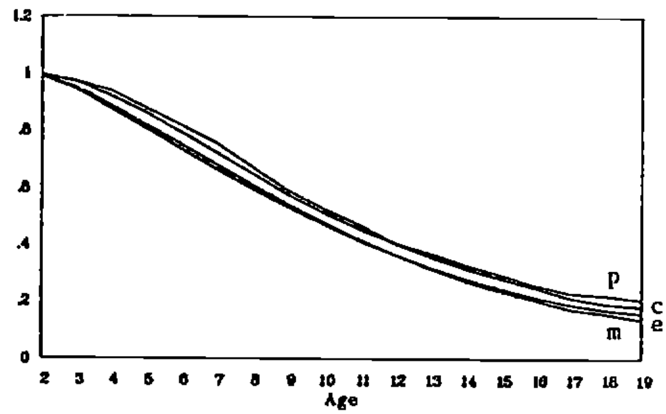

Figure 2
Renewal Rates : Japanese Origin