Renewal Study of European Patents: A Three-country Comparison

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Abstract

This paper utilizes the renewal records of the EPO (European Patent Office) patents and estimates the patent value distributions in Germany, France, and the U.K. We extend the patent renewal study for the same three countries in Pakes (1986) by examining how the possible patent infringments affect patent holders' renewal decision makings as well as patent evaluations. In addition, the utilization of EPO-route patent renewal records in our study corrects the possible data inconsistancy problem in Pakes (1986). Estimation results indicate a highly skewed distribution of patent values in all three countries, as found by Pakes (1986). However, the quality and the private value of the EPO patents in our sample are substantially higher – the estimated median values are three to ten times higher than those of the national patents in Pakes (1986). More interestingly, the EPO patente holders are found to be much more willing to invest resources on finding new commercialization strategies in order to exploit their patented idea than the national patent holders in Pakes (1986).

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1. Introduction

The search for accurate methods to evaluate patent rights has a long history in both academia and industry. Pakes and Schankerman (1984) and Pakes (1986) propose to evaluate patents based on the patent holders' renewal decisions. As the two papers argue, the patent renewal process can be viewed as an optimizing process: in each period the patent holders compare the renewal fees with the expected future returns from the patents, and decide whether to pay the renewal fees and keep the patents alive, or not to pay and let the patents lapse. Therefore the length of patent lives is a natural indicator of the private value of the patents. Pakes (1986) then develops a stochastic patent renewal model and estimates the distributions of patent value in post-war Germany, France, and the U.K.

However, patent renewal fees are far from the only kind of costs that the patent holders expect to pay. More importantly, patents are constantly subject to possible infringements and revocation suits throughout their whole lives. Lanjouw and Schankerman (2001) examine a sample of 5,452 U.S. patents and find that more valuable patents are considerably more likely to be involved in litigation. This underscores the necessity of taking the possible patent infringement and litigation into consideration when estimating the private value of patent protection, as the willingness to protect the patent rights also reveals important information about the value of those rights to their holders.

This paper extends Pakes (1986) by examining how the possible patent infringements affect patent holders' renewal decision making as well as the evaluation of patents. As Lanjouw (1998) points out, when patents are subject to possible infringements, the patent holders will take the future litigation costs into consideration when deciding whether to renew the patents. Therefore the minimal expected future returns that warrant renewing the patents should be higher than without having to worry about possible infringements. Consequently, when using the patent renewal records to evaluate the patents, the renewal model in Pakes (1986) tends to underestimate the patent values.

We adopt the framework established by Lanjouw (1998) and estimate the distribution of patent values in the same three European countries as examined in Pakes (1986): Germany, France, and the U.K. A noteworthy feature of our study is the utilization of the renewal records of the EPO (European Patent Office)[1] patents in those three countries. A huge advantage of

[1] Founded in 1977, the European Patent Office (EPO) provides a unified patent application and examination

using this data set lies in the similarity of patent quality across different countries. In our sample, all granted patents have passed through the same application and examination procedures at the European Patent Office. This guarantees the quality of the analyzed patents in different countries is similar. In contrast, the patent sample used by Pakes (1986) was collected separately from individual national patent offices in Germany, France and the U.K. Thus his estimation results for those three countries are not directly comparable, since patents in different countries had gone through different examination processes and were subject to different granting criteria, and therefore the quality of granted patents might be substantially different across countries.

Another problem with the sample in Pakes (1986) is that, his German sample consisted of only the granted patents, whereas his French and the U.K. samples included all patent applications, i.e., both the granted and the declined patent applications in these two countries. Thus the estimated distributions of patent values in these three countries are not directly comparable in his study. For instance, Pakes (1986) reports a much higher average value on the German patent sample than on the French sample. However, one cannot really tell whether such differences in value estimates indicate some important institutional characteristics in these two countries, or simply comes from the fact that the German sample only contains the granted patents while the French sample contains both the granted and declined patent applications.

This kind of discrepancy is no longer a problem in our sample, since only the granted EPO patents are used in the estimations, and all of them are granted according to the same selection criteria. As a matter of fact, preliminary analysis indicates a very high degree of overlap in the patent identifications in different countries: more than 90 percent of the patents in our sample renewed in all three countries. This guarantees that our estimation results of the patent value distributions are directly comparable across different countries. Therefore the differences in estimation results must reflect institutional differences in those countries, as the estimations are net of possible biases resulting from different selection criteria in the sample. Moreover, as noted by Eaton, Kortum and Lerner (2003), during the past two decades the EPO patenting

procedure for the member countries. Instead of filing a patent application and going through the tedious examination and granting process in each and every country in which the inventor intends to seek patent protection, an EPO patent applicant only needs to file a single application and, upon paying a per-country designation fee, chooses which countries to designate for future patent protection. Once the application is approved, the patentee can then transfer the EPO patent to the national patent office of the designated countries and enjoy the same patent protection as a national patentee.

route has almost entirely replaced direct applications to national patent offices — in most of 1990s "patents that do not originate with the EPO constitute fewer than 10 percent of patent applications arriving at the national patent offices." Thus our analysis has direct bearings on one of the most important patent protection regime in the world.

Some interesting findings emerge from the model estimation. Like Pakes (1986), we find that the distributions of patent values are highly skewed in all three countries. However, the quality and the private value of the EPO patents in our sample are significantly higher than those of the national patents in Pakes (1986) and other studies of national patents, most notably Lanjouw (1998). For instance, the median value of the simulated EPO patents in Germany is about three times as large as that of German patents reported by Pakes (1986), after being adjusted for inflation. And the differences are even larger in France and the U.K. More interestingly, we find that EPO patent holders are more willing to invest resources on finding new commercialization strategies in order to exploit their patented idea than the national patent holders in Pakes (1986): while Pakes (1986) reports that most patent holders stop exploiting new ways to utilize their patents five years after the initial patent applications, our estimates imply that such learning processes are not essentially over until 10 years after the initial applications.

The outline of this paper is as follows. Section 2 lays out a dynamic stochastic patent renewal model as developed by Pakes (1986) and Lanjouw (1998), taking possible patent infringements into account when analyzing patent holder's renewal decision making. The EPO patent data set is described in Section 3, along with some statistics of the patent protection regimes in Germany, France, and the U.K. Section 4 estimates the patent renewal model. The Monte Carlo simulation results are also reported in this section. Section 5 concludes.

2. The Patent Renewal Model

Model Specifications and Model Solution

Let us focus on the patent renewal problem faced by the patent holder i in country j when his patent is at age t, i.e., the patent has been granted and renewed up to age $t-1$.

If the patent holder decides to pay the renewal fee for age t, the net value of patent will be the sum of two parts — the returns $r_{i,j,t}$ to be collected in current age t, and the expected value of the option of continuing to renew the patent in the future — minus the renewal cost $c_{j,t}$. If the total benefit from keeping the patent alive is less than the renewal cost, the patent holder will simply choose not to renew the patent and let it permanently lapse, in which case the value of the patent becomes zero forever. Therefore, the value of patent i in country j can be expressed as:

$$V_j(t, r_{i,j,t}) = \max\{0, r_{i,j,t} + \beta E_t V_j(t+1, r_{i,j,t+1}) - c_{j,t}\}, \qquad t = 1, 2, .., T \tag{2.1}$$

or, by neglecting the subscripts i and j,

$$V(t, r_t) = \max\{0, r_t + \beta E_t V(t+1, r_{t+1}) - c_t\}, \qquad t = 1, 2, .., T \tag{1'}$$

where β is the discount rate, T is the statutory limit to patent life, and E_t is the expectation operator conditional on the information available up to age t. $V(T+1, .) = 0$ because the patent expires after age T.

The evolution of the returns of the patent is assumed to follow a stochastic Markov process. Following Pakes (1986) and Lanjouw (1998), I assume that there are three distinct factors governing this process:

First, in each year with probability $(1-\theta)$ the patent is subject to obsolescence.[2] Obsolescence occurs when there is any major technological breakthrough from competitors which makes the current patented technology totally worthless, at least commercially. If this happens the patent holder will naturally choose not to pay the renewal fee from now on and let the patent lapse.

Secondly, even if there is no major technological breakthrough which totally obsoletes the patent, the existence of competing innovations of smaller technological progress will still gradually erode the profitability of the patented technology, and I assume that this will depreciate the return r_t at a constant rate δ over time.

Finally, to capture the fact that most patent holders constantly collect new information on market and experiment with new commercial strategies to exploit the profits from patent protection over time, I assume that in each year the patent holder draws a random variable z as the patent return generated by the new commercial strategies. Note that new commercial

[2] In Pakes (1986) the probability of obsolescence is assumed to vary with the current return of the patent r_t, and therefore is varying over the patent's life. However, Lanjouw (1998) finds from the data that the obsolescence does not have a noticeable trend over age and seems to be constant. Therefore a constant obsolescence probability $(1-\theta)$ is assumed throughout this paper.

strategies may not necessarily result in a more profitable use of the patent, and if this is the case the current year's patent return will simply be the depreciated return from last year.

In summary, the patent return in age t is given by

$$\begin{aligned} r_t &= \max\{\delta r_{t-1}, z_t\} && \text{with probability } \theta \\ &= 0 && \text{with probability } 1-\theta \end{aligned} \tag{2.2}$$

and z_t is assumed to follow a two-parameter exponential distribution:

$$q_t(z_t) = \lambda_t^{-1} \exp\{-(z_t\lambda_t^{-1} + \gamma)\}, \qquad z_t \geq -\gamma\lambda_t \tag{2.3}$$

where $\gamma \geq 0$ and $\lambda_t = \phi^{t-1}\lambda$ with $0 < \phi \leq 1$.

As noted by Lanjouw (1998), patent holders tend to experiment with the marketing strategies which they believe to be most lucrative first, and accordingly here smaller λ_t's are assumed over time to make sure that the probability of uncovering a use which leads to returns greater than a given number declines over the patent life.

A patent grants its holder an exclusive right to utilize the patented technology and gather monopoly profits. However, patents are subject to possible challenges and have to be defended by their owners. As a result the patentee will not be able to receive all of the potential returns with certainty. Lanjouw (1998) recognizes the possibility of patent infringements and analyzes the patentee's willingness to prosecute the infringers and defend his patent.[3] A patentee has strong incentives to defend his patent, because if he chooses not to go to the court or drops the case during the litigation process (which normally takes three years),[4][5] then others may infringe with impunity, and returns to patent protection will become zero. Moreover, if common knowledge

[3] In practice there are two kinds of litigation in terms of patent challenges: the infringement suits initiated by the patent holders against the infringers, and revocation suits initiated by patent challengers against patent holders. However they are not distinguished in this paper.

[4] An alternative to prosecuting the infringers is seeking for settlements outside the court. However, as Lanjouw and Lerner (1998) point out, the patent holders have more to gain from winning the suit than the infringers have to lose. The infringers are unable to adequately compensate the patent holders simply because monopoly prices cannot be sustained in the final goods market with two firms. Moreover, winning a case by the patent holders may generate reputational benefits in threatening the possible infringers in the future. Therefore, patent holders often turn to courts to resolve disputes.

[5] As Lanjouw (1998) notes, patent suits in Germany typically are completed within three years. The estimations on the duration of such cases in France and the U.K., however, are currently not available. In the empirical estimation, a three-year duration is assumed for both countries.

is assumed, then the patentee will only renew the patent when he is willing to prosecute the infringers, since if he is not then all the potential competitors will certainly infringe.

Taking patent infringements and litigation into consideration will change the patentees' renewal decision, not only because the expected benefits to the patentees of renewing becomes smaller, but also for the fact that pursuing prosecution incurs litigation expenses, although such expenses may be at least partially compensated if the patentee finally wins the case. Recent survey studies (see for example, Hamburg (2001), Meller (2001)) indicate that in European countries like Germany and Austria litigation expenses are calculated based on the "value-of-the-case" (VOC): the patent courts apply rough estimates when trying to find out what the VOC should be, and the litigation expenses increases approximately linearly in VOC[6]:

$$\begin{aligned} \text{Litigation costs } (LC) &= \alpha_0 + \alpha_1 * VOC \\ &= \alpha_0 + \alpha_1[r_t + \beta E_t V(t+1, r_{t+1})] \end{aligned} \tag{2.4}$$

Assume that an infringement suit will take three years before a ruling, and with probability w the patentee wins the case. The value of the patent in age t can then be expressed as

$$\begin{aligned} V(t, r_t) = \max.\{&0, [w - \alpha_1(1-w)]\theta^2 r_t + \beta\theta^2[w - \alpha_1(1-w)]E_t VL(t+1, r_{t+1}) \\ &-c_t - \beta\theta c_{t+1} - (\beta\theta)^2 c_{t+2} - \alpha_0(1-w)\} \end{aligned} \tag{2.5}$$

where $E_t VL(t+1, r_{t+1})$ is the expected value of the future returns given that the patentee is in the second year of litigation process, and is defined as

$$\begin{aligned} E_t VL(t+1, r_{t+1}) = &\int r_{t+1} G_{t+1}(dr_{t+1}|t) + \beta \iint [r_{t+2} + \beta EV(t+3, r_{t+3})] \\ &G_{t+2}(dr_{t+2}|t+1) G_{t+1}(dr_{t+1}|t) \end{aligned} \tag{2.6}$$

where $G_{t+1}(s|t) = prob(r_{t+1} \leq s|t)$ defines the $c.d.f.$ of the Markov process $(r_{t+1}|t)$ described in equations (2.2) and (2.3).

[6] On the other hand, in other countries like France there is not a clear relationship between the litigation costs and the court-estimated value of infringement cases. In the model estimation it is then assumed that in these countries the patentees always expect to pay a fixed amount of *minimal* litigation costs, i.e., α_1 in equation (4) equals zero.

Pakes (1986) provides the regularity conditions for the existence of a unique solution to the patent renewal problem and discusses the general form of the solution. Specifically, there exists a threshold minimal return r_t^* for each age of the patent depending on the renewal fee schedule $\{c_t\}_{t=1}^T$, and the representative patentee pays the renewal fee c_t if and only if the current return r_t equals or exceeds the threshold minimal return r_t^*: $r_t \geq r_t^*$. Moreover, r_t^* is non-decreasing in t, and is implicitly defined by:

$$r_t^* + \beta E_t V(t+1, r_{t+1}) - c_t = 0 \tag{2.7}$$

for each age t from equation (2.1), or, in the present model, after taking into account of the possible infringement and the subsequent litigation,

$$\begin{aligned} &[w - \alpha_1(1-w)]\theta^2 r_t^* + \beta\theta^2[w - \alpha_1(1-w)]E_t VL(t+1, r_{t+1}) - c_t \\ &\qquad -\beta\theta c_{t+1} - (\beta\theta)^2 c_{t+2} - \alpha_0(1-w) = 0 \end{aligned} \tag{2.8}$$

The series of the minimal renewal return $\{r_t^*\}_{t=1}^T$ in this renewal problem could be solved through integrating equation (2.6) backwards with the terminal condition $V(T+1, r_{T+1}) = 0$.[7] Finally, following Pakes (1986), the initial value of the patent i when transferred to country j is assumed to follow a country-specific lognormal distribution[8]:

$$\log(r_{i,4}) = \alpha_i \backsim N(\mu_\alpha, \sigma_\alpha^2) \tag{2.9}$$

Time subscript in equation (2.9) is 4 because the examination processes at the EPO take three to four years on average, therefore most patents are around age 4 when transferred to national patent offices.

Moment Conditions and Estimation Algorithm

Given the conditional distribution of r_{t+1}, $G_{t+1}(s|t) = prob(r_{t+1} \leq s|t)$ and the initial distributions of the patent returns, it is straightforward to derive the cumulative density function of the patent value $r_{i,t}$. (Note that once the patent lapses there are no returns to the patent protection thereafter):

[7] A technical appendix containing the details of derivation and the formulae of the model solution as well as numerical estimation strategy is available upon request.

[8] Schankerman and Pakes (1986) find that the log-normal distribution fits the renewal data better than any other kind of distribution they have tried.

$$1 - F(r,t) = \Pr\{r_{i,t} \geq r, r_{i,t-1} \geq r^*_{t-1}, ..., r_{i,2} \geq r^*_2, r_{i,1} \geq r^*_1\} \tag{2.10}$$

Therefore, in any cohort of patents, the proportion of patent holders who pay the renewal fees at age t is simply the proportion with current return $r_{i,t}$ exceeding the minimal renewal return r^*_t, or $1 - F(r^*_t, t)$. The proportion of patents lapsing (the hazard rate) at age t is therefore simply the proportion not paying the renewal fee at age t out of those having paid the renewal fee at age $t-1$:

$$\pi(t) = [F(r^*_t, t) - F(r^*_{t-1}, t-1)]/[1 - F(r^*_{t-1}, t-1)] \tag{2.11}$$

Equations (2.10) to (2.11) provide the moment conditions required for the estimation. Specifically, I have

$$E[\pi_N(\omega)] = \pi(\omega) \tag{2.12}$$

where $\pi(\omega)$ is a vector stacking up all cohorts' $\pi(t)$, $t = 4, .., T$ (or T_L since for some cohorts the renewal data is truncated so that final ages are not observed in the data). $\pi_N(\omega)$ is the vector of hazard rates from the sample, where the subscript N denotes the sample size. ω is a vector consisting of all the parameters.

The model is estimated using a simulated method of moment (SMM) estimator, $\widehat{\omega}_N$, of the true parameter vector ω_0. Specifically, $\widehat{\omega}_N$ is chosen so as to minimize

$$||G_N(\omega)|| = ||\pi_N(\omega) - \widetilde{\pi}_N(\omega)||_{W_N(\omega)} \tag{2.13}$$

where $\widetilde{\pi}_N(\omega)$ is a vector of simulation estimates of the aggregate hazard rates implied by the parameter ω. $W_N(\omega)$ is a weighting matrix. Normally one would use the sample estimates of the inverse of the asymptotic variances of the moment conditions, or the simulated estimates of it, to obtain the most efficient SMM estimates. However, calculating such a weighting matrix is computationally unfeasible due to the large dimension of the moment conditions, since there are 18 (number of ages) times 6 (number of cohorts) of them. The weighting matrix used in the estimation is thus

$$W_N(\omega) = diag(\sqrt{n/N}), \tag{2.14}$$

where n is the number of patents still alive in the specific cohort-age cell. In other words, the simulated moment conditions are weighted by the sample size in calculating the objective function $||G_N(\omega)||$.

3. Data Description

The patent renewal data set compiled from information provided by the European Patent Office (EPO) are used in the model estimation. The EPO received the first patent application on June 1, 1978. However, I will focus on analyzing the patent cohorts of 1980 through 1985 (defined as "cohorts" of 1980 through 1985), since years 1978 and 1979 are arguably a transition period during which potential patent applicants may not have been aware of the establishment of the new patent-protection regime. This may bias the model estimation and thus the applications filed in these one and half years are excluded from the sample of interest. On the other hand, the patents cohorts after 1985 are also excluded from the sample. This is because the maximal age of those patent observed in the data set is 11 years, as the available patent renewal records end in 1996. Since the lapse of patents is a gradual process, the renewal patterns during early ages of patent lives are quite similar across different countries. Thus analyzing the renewal records of those later patent cohorts may not contribute much to the efficiency of the model estimation.

Table 1 summarizes the characteristics of the sample. Model estimation uses renewal data on all of the patents in cohorts 1980 to 1985 that are transferred to Germany, France or the U.K., a total of 120,768 patents. The statutory limit of patent life is 20 years in all three countries during

Table 1: Characteristics of the Data in the Renewal Model Estimations

	Germany	France	U.K.
Application dates at the EPO	1980-85	1980-85	1980-85
Years of renewal	1984-1996	1984-1996	1984-1996
Number of cohort-age cells	63	42	63
Number of granted patents (out of 120, 768 patents)	113,053	108,587	110,651

Note: Table 1 describes the characteristics of the data used in estimating the patent renewal model in Germany, France and the U.K. The renewal records before 1990 are incomplete for France, and therefore are excluded from the estimation sample.

the sample period. Hence the sample contains patent renewal information in most years of their lives (for cohort 1980, 16 years, and for cohort 1985, 11 years). Consequently, there are 63 cohort-age cells in each of the German and U.K. sample (the sum of number of observed renewal ages since age 5 in all cohorts), as shown in row 3. However, the patent renewal records in France before 1990 are incomplete and are excluded from the estimation sample. As a result, there are only 42 cohort-age cells in the French sample. Row 4 of the table reports the number of patents transferred to each of the three countries. There is a high proportion of overlap among patents transferred to different countries, *i.e.*, most of the EPO patent holders in the sample chose to seek patent protection in all of these three countries.

Figure 1 provides the average hazard rate at each age in each of Germany, France and U.K., weighted over cohorts by the number of patents in each cohort. The hazard rate in age t is defined as the proportion of patents dropped at age t out of the patents alive up to age $t-1$. Figure 2 displays the associated patent renewal rate at each age, i.e., the patents alive at each age as a percentage of all the patents granted, averaged over different cohorts in each country. It is clear from Figure 1 that the renewal patterns in these three countries are distinctively different: for instance, compared with the U.K., the hazard rate in Germany is substantially lower at earlier ages and higher at later ages. The hazard rate in France is consistently lower in all ages than that in Germany and the U.K. Correspondingly, the patent renewal rate in Germany is larger than that in the U.K. at earlier ages in Figure 2, and the renewal rate in France is consistently the highest at all ages.

Figure 1: Average Hazard Rates in Germany, France and the United Kingdom

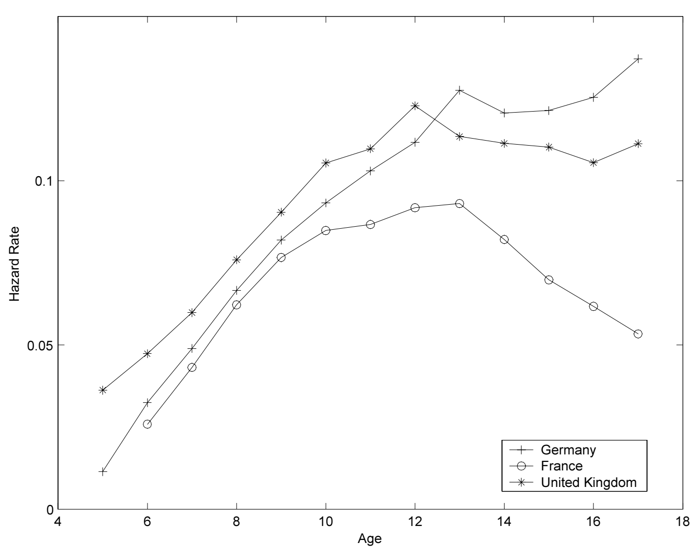


Figure 2: Average Renewal Rates in Germany, France and the United Kingdom

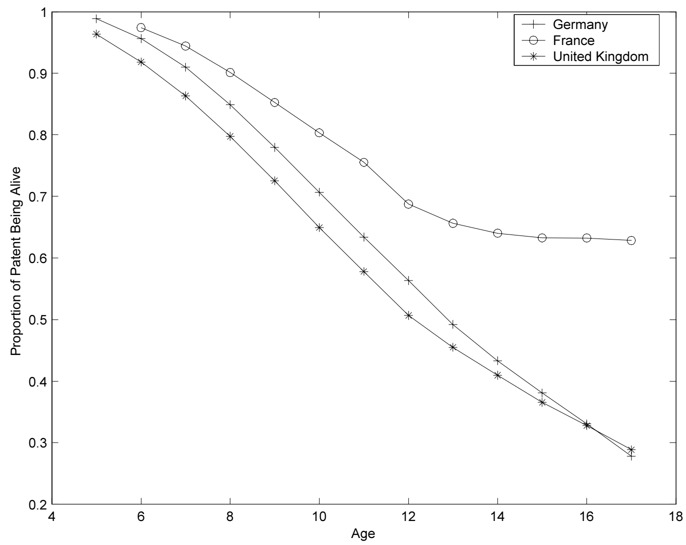
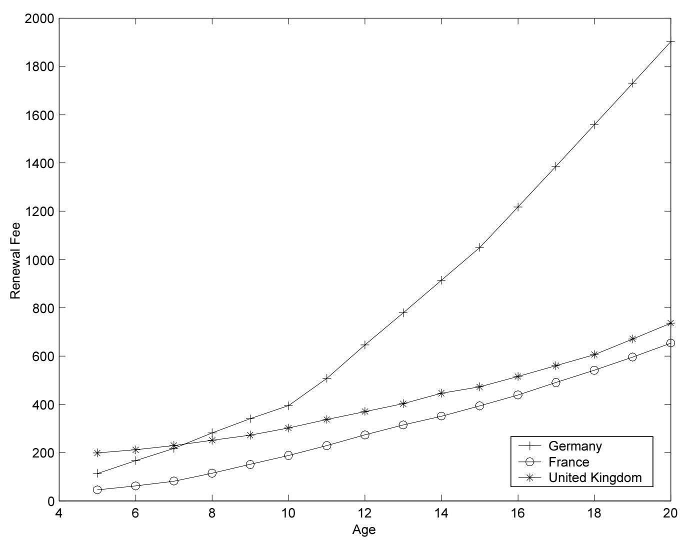


Figure 3: Average Renewal Fee Schedules in Germany, France and the United Kingdom



As noted earlier, there is high proportion of overlap among the patents in different countries, therefore the quality of patents should be similar across countries. Consequently, the heterogeneity of the intrinsic quality of these patents can only have limited effects on the different renewal patterns observed. There should be other explanations for the observed variations in the renewal pattern across different countries.

One possible explanation could be the different renewal costs across countries. Figure 3 plots the average renewal fee schedule in each of the three countries.[9] The renewal costs in France are the lowest at all ages among these three countries, which helps explain the high proportions of patent renewal in France. Compared with the U.K., the renewal fees in Germany are lower at earlier ages, but increase at a much faster pace at subsequent ages. This should, *ceteris paribus*, generate lower hazard rates at earlier ages and higher ones at the later ages in Germany than in the U.K., and we see this in Figure 1.

Difference in the strength of patent protection across countries may also contribute to the difference in the renewal patterns. For one thing, a patentee may form different expectations of the probability of winning a infringement suit in different countries, and this is closely related to institutional details such as different judicial systems in each country. Litigation cost is another factor that should be taken into account. A survey performed by Bouju (1987) demonstrates that the litigation costs of patent infringement cases vary substantially in European countries. In France, the litigation costs associated with the patentees in infringement cases[10] before the court of first instance[11] would be about $33,515 in 1997 U.S. dollars. However, in U.K., such costs would be $164,768, nearly four times larger than in France. The litigation costs in Germany are the lowest among the three countries. The average costs for a case valued $68,400 would be

[9] The renewal fee schedules were obtained originally in nominal domestic currency, converted to real domestic currency using the country's own GDP price deflator, and then converted to 1997 U.S. dollar values using the official exchange rate in 1997. All monetary values are therefore in 1997 U.S. dollars.

[10] The figures on litigation costs obtained from Bouju (1987) are only the minimal costs in patent infringement cases concerning the plaintiff, i.e., the patentee or his successor, assignee or any other party entitled to sue for infringement, hereinafter called "the patentee". The nominal amounts include 1) "the fees to be paid to attorneys and other agents authorized to deal with the court"; and 2) "the legal costs, if any, to be paid to courts". However, They do not take into account: 3) "the fees paid to attorneys and consultants for studying the case and checking the validity of the patent and the reality of the infringement before the suit is initiated", or 4) "the costs to be paid by the patentee if he loses the suit, especially the damages awarded to the defendant"; or 5) "the costs incurred by the defendant during the suit to build up the defence, not the damages to be paid by the defendant if he is declared infringer and loses the suit".

[11] The court of first instance refers to the Tribunal of First Instance (TGI) in France, High Court in United Kingdom, or District Court in Germany. Consequently, the litigation costs discussed here only include the costs incurred during proceedings in the court of original jurisdiction. They do not include the costs of going through the court of appeal or the supreme court.

$6,525, for a case valued $222,300 would be $14,095, and even for a case of value of $684,020 would be $30,074, significantly lower than similar costs in France.

4. Model Estimation and Simulation

Table 2 reports the parameter estimates of the renewal model for each of Germany, France and the U.K. To alleviate the dimensionality problem in the numerical optimizations, all the estimations are performed conditional on setting the real discount factor β equal to 0.95. Lanjouw (1998) made the same assumption, and Deng (2003) reports a β estimate of similar magnitude.

The parameter estimates in three countries are all positive and highly significant. The Mean Square Error (MSE), constructed as the sum of squared residuals divided by the number of cohort-age cells, is reported on row C1 of the table. By comparing the MSE to the variances in the actual hazard rates across different cohort-age cells as reported in row C2, it can be seen that the model-implied hazard rates seem to fit the German data quite well.[12] However, in the French sample the renewal behavior in earlier ages was not observed. As a result there are not enough variations in the renewal pattern, which may explain why the model's performance is less satisfactory.

The estimated probabilities of a patentee winning an infringement suit in all three countries are fairly high, ranging from 90% in Germany to 98% in France and the U.K. However, it should be noted that these estimates cannot be directly interpreted as the winning probabilities *once* an infringement suit actually occurs in these countries. As noted in Section 2, these probability estimates are based on the assumption of common knowledge. If this assumption is relaxed, then the patentee will recognize that infringements may not necessarily occur even if he chooses not to defend his patent. In such cases, the estimated w could be essentially interpreted as a composite probability, consisting of the winning probability once an infringement occurs plus the probability of the patent not being infringed. Therefore the winning probability once an infringement suit actually occurs would be lower than the estimated w in Table 2.

The estimates of the decay parameters δ and θ do not vary much among the three countries. Annual depreciation in returns is fairly low in France (7.5%) and Germany (7.7%), and the

[12] The reported variance in the actual hazard rates can be viewed as the MSE of a "naive" model which predicts that in all cohort-age cells the hazard rates would be constant and is identical to the average hazard rate. Therefore, the differences between the variance of the actual hazard rates and the MSE implied by the current model estimation can serve as a measure of the improvement of the model performance over such a "naive" model.

highest in the U.K. (10.3%). On the other hand, about 2.6% to 5.4% of the patents become obsolete each year in all three countries. This alone means that over 73% of patents die simply due to obsolescence by the end of age 13 in France, and 53% in Germany. In an estimation of a similar model using industry-level data in Germany from 1953 to 1988, Lanjouw (1998) reports even higher annual obsolescence probabilities, ranging from 7% to 12%. Pakes (1986) has a different specification of obsolescence process, therefore his estimates are not directly comparable.

Table 2: Patent Renewal Model Estimation Results

	Country					
	Germany		France		U.K.	
A. Parameter[a]						
θ	0.9490	(0.1395)	0.9741	(0.0212)	0.9462	(0.0413)
δ	0.9233	(0.0854)	0.9245	(0.2014)	0.8967	(0.0534)
λ	9,980.0	(374.0)	4,929.8	(754.3)	6,999.1	(397.5)
ϕ	0.5994	(0.0524)	0.6200	(0.1352)	0.5969	(0.0504)
γ	0.1496	(0.0519)	0.4135	(0.0902)	0.1992	(0.0715)
w	0.8991	(0.1318)	0.9704	(0.2116)	0.9777	(0.0578)
μ_α	8.8368	(0.4695)	7.9434	(0.7324)	8.0908	(0.8103)
σ_α	1.4550	(0.4173)	1.9589	(0.4265)	1.8984	(0.6273)
B. Size of						
B1. Sample	113,053		108,587		110,651	
B2. Simulation	226,106		217,174		221,302	
B3. Cohort-Age Cells	63		42		63	
C. Summary Statistics[b]						
C1.MSE($\widetilde{\pi}$)	4.56×10^{-4}		3.88×10^{-4}		5.31×10^{-4}	
C2. V(π)	1.5×10^{-3}		4.40×10^{-4}		9.97×10^{-4}	
C3. MSE($\widetilde{\pi}$)/V(π)	0.3040		0.8818		0.5326	

a. Estimated standard errors are reported in parentheses.

b. MSE is calculated as the sum of squared residuals weighted by the number of patents in each cohort-age-country cell. V(π) is the sample variance from the data.

Parameter λ, ϕ and γ together define the exponentially distributed stochastic learning process z_t. In particular, other things being equal, a high λ implies that the probability of the patent becomes more valuable is high. A low ϕ means that the potential learning opportunities recede quickly over time, and a high γ decreases the probability of the newly learned returns being greater than a given value.

The dynamics of learning processes implied by these estimates are displayed in Table 3, which reports the results of a simulation run of 100,000 draws based on the average fee schedule across different cohorts in each country, as well as the parameter estimates reported in Table 2. Column 2 of the table displays the learning probabilities in Germany. At the beginning of age 5, about 10% of the patent holders discover a use which generates higher subsequent profits than known before. At the beginning of age 6, however, much less learning occurred, only about 4.5% discover more profitable ways to utilize the patented idea. It should be noted that the reduction in learning comes not only from a smaller λ_t of the learning process, but also from the fact that the increase in patent value at age 5 due to learning makes it more difficult to draw a new z_6 exceeding the existing value. The learning probability continues to decline over the ages, and in age 10 the probability of learning has dropped to a mere 0.05%, indicating that the learning process is almost over by then, and the obsolescence process starts to dominate the renewal decisions. The situation in France and the U.K. is similar to that in Germany. In France, starting with a learning probability of 14% in age 5, this probability steadily decreases with time and by age 11 only 0.15% of the simulated patents successfully increase their value through learning. In the U.K., 17% of the patentees find more profitable ways to exploit their patented idea in age 5, 14% in age 6, 7% in age 7, and only 0.01% by age 11. Therefore, in all three countries, most of the learning activities occur in the early ages, and by age 10 or 11 the learning probability already becomes negligible.

Table 3: Percentage of Patents Learning a Higher Value

	Country		
	Germany	France	U.K.
Pr. $(z_5 > \delta r_4)$	10.24	14.01	17.19
Pr. $(z_6 > \delta r_5)$	4.51	8.56	13.58
Pr. $(z_7 > \delta r_6)$	1.86	4.63	6.64
Pr. $(z_8 > \delta r_7)$	0.71	2.35	3.15
Pr. $(z_9 > \delta r_8)$	0.20	0.99	1.17
Pr. $(z_{10} > \delta r_9)$	0.05	0.38	0.40
Pr. $(z_{11} > \delta r_{10})$	0.01	0.15	0.01

Note: Table 3 reports the learning probabilities from a simulation run of 100,000 draws of patents in Germany, France and U.K., based on the average fee schedule across different cohorts in each country, as well as the parameter estimates reported in Table 2.

With a sample of German and French patents in the 1950s to 1970s, Pakes (1986) estimates that the learning process is essentially over by the age of 5. Lanjouw (1998) shows that the learning stops by age 6 or 7 in all technology groups in her sample of German patents in 1953 to

1988. By contrast, my estimates imply a longer learning process during the life of EPO patents. As indicated by Table 3, even at age 7, about 2% EPO patentees in Germany, 5% in France and 7% in the U.K. still discover new ways to increase the profits from utilizing the patents, and the learning probability does not become zero until age 10 or 11 in these countries. This suggests that the sample of EPO patents analyzed in this study have very different characteristics from patents studied in previous literature. The quality and the private value of the EPO patents are significantly higher than those of the national patents studied in Pakes (1986) and Lanjouw (1998), and the higher expected value makes it worthwhile for the patentee to invest more resources on finding new commercialization strategies in order to exploit the patented idea.

The above finding may be explained by a close look at the EPO application fee schedule. Compared with the application fees at the national patent offices, the relatively higher EPO application cost prohibits the patents with lower private values from initiating EPO applications from the start. As a result, the EPO patents are on average more valuable and would be justifiably considered "elite patents". Pakes (1986) provides an estimation of net values of the simulated patents in Germany, France and the U.K. (see columns 3, 5 and 7 in Table 5 below). In his simulated French sample, 25% of the patents have a net value of $119 (in 1997 U.S. dollars, same below) or less, 50% have a net value of $844 or less, and 75% have a net value of $5,896 or less. In other words, even at the top 25% percentile of this French sample, the net value of the patent is still not enough to cover the initial EPO application and examination cost of 8,660 DM in 1985 (or $6,794 in 1997 U.S. dollars). His simulated U.K. and German patents have higher values than the French ones on average, with a 50% percentile of $2,397 and $9,880, respectively. Nevertheless, one may expect that the initial EPO application and examination cost excludes a considerable proportion of Pakes' simulated sample from entering the EPO sample.

Another interesting finding is that Table 3 indicates a higher percentage of the U.K. and French patents successfully learning new values than German patents on every patent age. This may indicate some systematic differences in the commercialization and marketing processes in these countries. For instance, if the patent holders know what the value of their patents will be in the future when they transfer their granted patents to the national patent offices in these countries, then less learnings are expected. However, if there is considerable uncertainty in their minds, then they are more likely to experiment new strategies to exploit the patent values. The higher uncertainty around the patent value right after the patent transfers in the U.K.

and France, as revealed by the higher estimates on σ_α in these two countries, supports this explanation.

Pakes (1986) reports that on early ages German patents are more likely to learn higher values than French patents. However, as his French sample includes both the granted and declined patent applications, it is hard to tell whether the differences in learnings are due to some systematic differences in the commercialization or marketing environment in these two countries, or simply reflect the fact that in his sample French patents are of less quality and consequently their holders are less willing to devote resources to exploit their potential values. In contrast, the estimated differences in learning in this study must be attributable to the institutional differences in these countries, since the identities of patent samples across different countries are very similar, therefore we are essentially controlling the patent quality and the other characteristics of the patents and the patent holders.

Table 4: Distribution of Realized Patent Values in Germany, France and the United Kingdom

	Country					
	Germany		France		U.K.	
Percentile	Value	LC	Value	LC	Value	LC
25%	9,592	1.25	3,202	0.24	3,331	0.36
50%	27,657	6.04	12,376	2.04	11,682	2.45
75%	80,883	19.53	51,710	8.97	46,188	9.95
85%	141,123	31.38	107,612	16.73	94,628	18.12
90%	205,265	40.78	176,898	23.84	153,401	25.51
95%	355,512	55.54	362,609	36.80	310,911	38.79
98%	651,442	71.14	816,066	53.21	677,268	55.36
99%	967,509	79.86	1,370,912	63.97	1,129,647	66.07
maximum	2,283,163	——	87,450,357	——	70,028,060	——
mean	90,221	——	96,768	——	81,351	——

Note: Columns 2, 4 and 6 report the percentiles of the distribution of realized patent values from a simulation of 100,000 draws in each country. columns 3, 5 and 7 report the Lorenz curve coefficients of the simulated distribution. Monetary values are in units of 1997 U.S. dollars, and Lorenz curve coefficients (LC) are in percentage points.

Table 4 reports the percentiles and Lorenz curve coefficients from the distribution of realized patent values from the simulation. The realized patent value is defined as the discounted sum of patent returns after the patent is granted, net of all kinds of administrative expenses including the annual renewal fees in the subsequent years, but excluding any litigation costs. Column 2 of the table shows that the distribution of the realized patent value in Germany is quite skewed. For instance, 25% of German patents have a realized value of $9,592 or less, while they contribute about 1.25% of the total value of all simulated German patents. The lower 50% of the distribution contributes about 6% of the total value of the simulated German patents, and the lower 90% of simulated patents only accounts for 41% of the total value. On the other hand, the top 1% most valuable patents, with a minimal value of $967,509, accounts for about 20% of the total value. The value distribution in France, as reported in column 4, is even more skewed. The lower 90% of simulated patent only accounts for 24% of the total value of all simulated French patents, and the top 1% accounts for about 36% of the total value, with a minimal value of $1,370,912. The distribution in the U.K., as shown in columns 6 and 7, is less skewed than in France, but significantly more skewed than in Germany.

Table 5 compares the simulated values obtained by this study with those obtained by Pakes (1986). Columns 2, 4 and 6 are taken from Table 4 above, and columns 3, 5 and 7 are taken from Table V of Pakes (1986). It should be noted that the monetary values in Pakes (1986) are expressed in units of 1980 U.S. dollars. For convenience of comparison I convert them into 1997 U.S. dollar values by multiplying them with the ratio of GDP price deflators. As expected, the patents simulated in this study are more valuable than those in Pakes (1986). In particular, the median value of the simulated EPO patents in Germany, $27,657, is about three times as large as that of German patents obtained by Pakes ($9,880). A comparison of the values of columns 2 and 3 on all percentile levels shows similar results. This indicates a significant difference in the average quality of the two patent groups.

This difference comes from several sources. First, as discussed above, the EPO route of applying for patent protection is more cost-effective to patents intending to file in multiple countries and of higher quality. Secondly, Pakes (1986) studies patents of cohorts 1950 to 1972, whereas this study focuses on cohorts 1980 to 1985. Therefore, the EPO patent sample is on average 15 to 20 years younger. The difference in patent value may reflect a general trend of increasing patent value over time. Growth in the scale of the economy, as well as improvement in the business environment over this period, for instance, may enable the patentees to better exploit the patented idea and obtain higher profits even with unchanged patent quality. Moreover, advance in science and technology in general increases the average quality of inventions over time.

Table 5: Comparison of Simulated Patent Values

	Country					
	Germany		France		U.K.	
Percentile	EPO	Pakes	EPO	Pakes	EPO	Pakes
25%	9,592	3,160	3,202	119	3,331	562
50%	27,657	9,880	12,376	844	11,682	2,397
75%	80,883	30,932	51,710	5,896	46,188	12,558
85%	141,123	51,238	107,612	16,262	94,628	24,265
90%	205,265	69,905	176,898	27,529	153,401	35,087
95%	355,512	103,890	362,609	49,945	310,911	54,891
98%	651,442	149,860	816,066	80,924	677,268	81,021
99%	967,509	187,010	1,370,912	105,100	1,129,647	102,820
maximum	2,283,163	662,390	87,450,357	410,540	70,028,060	590,965
mean	90,221	25,549	96,768	8,897	81,351	11,625

Note: Table 5 compares the simulated values obtained by this study with those obtained by Pakes (1986). Columns 2, 4 and 6 are taken from Table 4 above, and columns 3, 5 and 7 are taken from Table V of Pakes (1986). All monetary values are in units of 1997 U.S. dollars.

Columns 4 through 7 reveal that the differences between the average value of the EPO patents and that of the national patents are even larger in France and the U.K. While this could be interpreted as a reflection of higher average quality and value in the EPO patent group, it should be kept in mind that the French and U.K. patent sample in Pakes (1986) includes both the applications finally granted and those declined, while his German patent sample as well as the EPO patents analyzed in this section are only the granted ones. Therefore, the difference between the average value of the EPO patents and those of the French and the U.K. patents in Pakes (1986) also reflects the difference between the quality of the granted patent group and that of the declined group.

5. Concluding Remarks

This paper extends Pakes (1986) by examining how the possible patent infringements affect patent holders' renewal decision making as well as the evaluation of patents. We utilize the renewal records of the EPO (European Patent Office) patents in the same three European countries as examined in Pakes (1986): Germany, France, and the U.K. This guarantees the consistency of patent qualities and other characteristics of the patents and patent holders across different countries, and therefore any substantial differences in estimation results must be attributable to the institutional differences in those countries.

Estimation results indicate that the distributions of patent values are highly skewed in all three countries, as found by Pakes (1986). However, the quality and the private value of the EPO patents in our sample are significantly higher than those of the national patents in Pakes (1986) and other studies of national patents, most notably Lanjouw (1998). For instance, the median value of the simulated EPO patents in Germany is about three times as large as that of German patents reported by Pakes (1986), after adjusting for inflation. And the differences are even more substantial in France and the U.K. More interestingly, we find that EPO patent holders are more willing to invest resources on finding new commercialization strategies in order to exploit their patented idea than the national patent holders in Pakes (1986): while Pakes (1986) reports that most patent holders stop exploiting new ways to utilize their patents five years after the initial patent applications, our estimates imply that such learning processes are not essentially over until 10 years after the initial applications.

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