A Dynamic Stochastic Analysis of International Patent Application and Renewal Processes

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Abstract

This paper formulates a dynamic stochastic model to examine the joint patent application and renewal behavior under an international patent protection regime. This framework makes it possible to utilize both the cross-sectional (multi-country filing) and the time-series (patent renewal) dimensions of available international patent data to evaluate the private value of patent protection, and allows one to distinguish more aspects of patent value. The private value of European patents in the pharmaceutical and the electronic industries is examined. It is found that pharmaceutical patents are endowed with higher initial returns, and their holders seek for protection in more countries than those of electronic patents. However, pharmaceutical patents depreciate faster than electronic patents, and consequently have lower renewal rates and shorter patent lives.

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1. Introduction

During the past two decades, patent evaluation has attracted considerable academic scrutiny, for both public policy analysis and commercial use. As there are no well-developed markets in which patents are frequently traded so that we can directly observe quotes on their value, researchers have attempted to assess the value (social value as well as private value) using various patent characteristics including simple patent counts (Griliches 1990), forward citations made by other patents (Trajtenberg (1990), Lanjouw and Schankerman (2004), Hall, Jaffe and Trajtenberg (2005)), the length of patent life (most notably Pakes and Schankerman (1984), Pakes (1986), Lanjouw (1998), and Schankerman (1998)), and the family size of the patent (i.e., the number of countries in which the patent holder seeks for patent protection — Putnam (1997), Eaton, Kortum, and Lerner (2003), Deng (2003)).

This paper extends the existing literature by developing a stochastic patent application-renewal model and examining the joint determination of the patent family size and the length of patent lives, and thus is able to incorporate information on both dimensions to estimate the patent value. Most relevant studies in the literature focus on either the family size or the length of the patent life in one country but never examine both in a unified framework.[1] This paper builds such a framework, in which a representative patent applicant has to estimate, *ex-ante,* how potentially valuable his invention will be in each country and decide which countries to seek for patent protection. After the patents being granted, the patent holder then updates his evaluation of the patents in each country, period by period and based on the information he gradually learns, and decide whether or not to keep the patents alive in each country, till the patents finally lapse.

In examining a patent's renewal records, one should realize that the patent renewal is an optimizing process during which the patent holder compares the annual renewal costs to the expected future returns of the patent and then decide how long the patent should be kept alive. Thus the length of a patent's life reveals useful information about its private value to its owner. Similarly, in choosing which countries to seek for patent protection, the prospective applicant will also compare the application costs with the expected future returns in each country and decide

[1] Lanjouw, Pakes and Putnam (1998) use both the patent application and renewal data to weigh the patent value but do not have a structural model to analyze the multi-country application and renewal decisions simutaneously and thus ignore the correlations between the patent family size and the length of patent lives.

which countries to apply. High-valued inventions will be applied for protection in more countries than low-valued inventions, *ceteris paribus*. Therefore, examining the joint distribution of family size and the length of patent's life across different countries will allow us to distinguish more aspects of the patent value, and advance our understanding of how the patent value changes over time as well as across different countries.

Examining the joint application-renewal behaviors may also shed light on some puzzles observed in the data. Typically, inventions with patents in more countries are renewed longer in each country (Putnam (1997)), as both a larger patent family size and a longer life are consistent with a higher value for the underlying invention. However, in studying the patenting behavior under the EPO (European Patent Office) regime, Deng (2003) finds an interesting pattern: the "pharmaceutical and health" patent applicants tend to file applications in more countries than other applicants and the "electronics" patent applicants file in the fewest countries, however the "electronics" patents have the longest patent lives and the "pharmaceutical and health" patents have the shortest. Thus, evaluation based on family size and the length of patent lives will give contradicting inferences on the relative value of these patents. This disparity cannot be easily resolved by either a multi-country patent application model or a renewal model alone, and calls for a joint examination of the patent applications and renewal behavior.

While the joint applicatio-renewal model established in this paper can be applied to the analysis of any multi-country dynamic patenting behavior, the empirical analysis of this paper focuses on examining the EPO patenting behavior.[2] Founded in 1977, the European Patent Office (EPO) provides a unified patent application and examination 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 seeks for 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 patent is granted, the patent holder can then transfer it to the national patent office of the designated countries and enjoy the same patent protection as a national patent holder. The patent designation records in the EPO, when combined with the patent renewal records in all of the EPO member countries as well as data on the application and renewal costs and litigation expenses, make it possible to examine the EPO patent holders' joint application-

[2]I thank Ariel Pakes and Jean Lanjouw for kindly allowing me to use this data set. The original source of the data set is obtained from the European Patent Office, and the data assembly is funded by the OECD.

renewal behavior. Moreover, as Eaton, Kortum and Lerner (2003) note, the European patent 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.

Model estimation is based on a sample of patents from two technology fields: pharmaceutical and electronics, as our primary interest is on the puzzling patenting behaviors in these two fields as described above. Literature has provided different answers in regard to the relative values of these two kinds of patents, and our empirical analysis make contributions by presenting new evidences based on a much larger and more comprehensive patent sample.

A few key findings emerge from model estimation:

First, the values of pharmaceutical patents depreciate faster than electronics patents and have shorter lives. Moreover, the pharmaceutical inventions are endowed with higher initial returns, and consequently their inventors seek for protection in more countries than the electronics. This is consistent with Lanjouw (1998)'s finding that pharmaceutical patents in Germany are endowed with higher values, but in contrast to Schankerman (1998)'s estimate of a lower mean value for pharmaceutical patents in France. As both authors have noted, France has the most stringent pharcaceutical price regulation and the lowest drug prices in Europe, whereas prices in Germany are largely unregulated and substantially higher than many other west European countries. This may explain why Lanjouw (1998) and Schankerman (1998) obtain different value estimates. The analysis in this paper is based on all ten EPO member countries in 1980s, and is thus abstract from any institutional idiosyncracy in individual countries;

Secondly, patent values in different countries are highly correlated with the market size of the country, measured by the real GDP of the country. In particular, pharmaceutical patents exhibit a constant returns to market size, while electronics patents show an increasing returns. This is a direct contribution to the literature as previous studies provides little evidence regarding the scale of economy of the patent value across different countries;

Thirdly, the value distribution of the patent family is found to be much more skewed than that of the national patent as reported in previous literature, with the 1% most valuable patent families accounting for about 50% of the total patent value, compared with 10% to 24% of the total value as estimated by Pakes (1986), Lanjouw (1998) and Schankerman (1998) when analyzing national patent samples. This occurs because the holders of more valuable inventions not only choose to keep their patents alive for longer in one country, but also seek for patent protection in more countries;

Finally, the learning process of the EPO patents are significantly longer than that of the national patents estimated in previous studies: while Pakes (1986) reports that most national patent holders in Germany, France and the U.K. stop exploiting new ways to utilize their patents 5 years after the initial patent applications, our estimates imply that such learning processes are not essentially over until 10 years after the initial applications in some countries.

The outline of this paper is as follows. Section 2 formulates the dynamic stochastic discrete-choice model to analyze the international patent application and renewal behaviors. The EPO patent data set is described in Section 3, along with a summary of some of the characteristics of the pharmaceutical and electronics patent groups. Section 4 analyzes the estimation results of the joint application-renewal model as well as the Monte Carlo simulation results. Section 5 concludes.

2. The Patent Application-Renewal Model

This section first develops the dynamic stochastic discrete-choice model that is used to analyze a representative patent holder's renewal decision rule after patent application being granted, following the framework of Pakes (1986) and Lanjouw (1998). It then solves for the patent applicant's decision rule on which countries to seek for patent protection when he submits the initial application to the EPO, and concludes with the moment conditions and the simulated method of moments (SMM) estimator to be used in model estimation.

The dynamic discrete-choice problem faced by the representative EPO patent applicant is to decide at the beginning of period one whether to file a patent application on invention i, $i = 1, 2, ..., I$, in the multi-national patent protection regime (here the EPO), and if so, whether to designate the patent protection in each of the J member countries, given the fact that the future returns to patent protection are uncertain. Once the patent application is granted, at the beginning of each period thereafter the patent holder has to decide whether to pay a renewal fee in each country to keep the patent in force over the coming period. The inventor aims at maximizing the expected discounted value of the net returns from his action, and is uncertain about the sequence of returns that will be generated in later periods if the patent is to be kept in force. At the beginning of each period he receives new information about patent returns and makes his renewal decision accordingly.

Renewal Decision Rule in a Single Country

We start by analyzing the renewal problem faced by the holder of a patent based on invention i in a single member country j at age t of the patent's life, conditional on the patent having been kept alive in the country till age $t-1$.

The value of the patent at the beginning of age t consists of two parts — the returns $r_{i,j,t}$ to be collected in current period, and the expected value of the option of continuing to renew the patent in the future, net of this period's renewal cost $c_{j,t}$. In case that the total benefit from keeping the patent alive is less than the renewal cost, the value of the patent will become zero forever as its holder will simply choose not to renew the patent and let it permanently lapse. Therefore, the value of patent i in country j can be expressed as:

$$V(t, r_t) = \max\{0, r_t + \beta E_t V(t+1, r_{t+1}) - c_t\}, \qquad t = 1, 2, .., T \tag{2.1}$$

with subscripts i and j omitted. β denotes the discount factor, T the statutory limit to patent life, and E_t 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 governed by three distinct factors:

First, in each year with probability $(1-\theta)$ the patent is subject to obsolescence.[3] As Deng (2004) argues, obsolescence occurs when there is any major technological breakthrough in the same area which makes the current patented invention totally worthless. 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 making the patent totally obsolete, the existence of competing innovations of smaller technological progress will still grad-

[3] 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.

ually erode the monopoly of the patented invention, and this effect is assumed to depreciate the return r_t of the patent at a constant rate δ over time.

Finally, as most patent holders constantly collect new information on the market and experiment with new commercial strategies to exploit the profitability of their inventions over time, we assume that at the beginning of each period the patent holder receives a realized value of a random variable z_t as the outcome of the new commercial experiments. Note that new commercial 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 δr_{t-1} from last year.

Therefore, the assumed evolution of the patent returns is such that, with probability $1-\theta$, the patent obsoletes and the patent value becomes zero forever; and with probability θ,

$$r_t = \max\{\delta r_{t-1}, z_t\} \tag{2.2}$$

where z_t is assumed to be drawn from a two-parameter exponential distribution:

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

with $\gamma \geq 0$ and $\sigma_t = \phi^{t-1}\sigma$ 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 σ_t's are assumed to decay over time to make sure that the probability of drawing returns higher than a given level declines over the patent life.

A patent grants its holder an exclusive right to utilize the patented invention and gather monopoly profits. However, in reality patents are subject to possible challenges and have to be defended by their owners. Lanjouw (1998) recognizes the possibility of patent infringements and analyzes the patente holder's willingness to prosecute the infringers and defend his patent.[4][5] A patent holder has strong incentives to defend his patent on court,[6] because if he chooses not to go to the court or drops the case during the litigation process, then others may infringe

[4] 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 possible patent infringement and litigation into consideration when estimating the private value of patent protection.

[5] 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. For simplicity they are not distinguished in this paper.

[6] 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

with impunity, and returns to patent protection will become zero. Moreover, as Lanjouw (1998) argues, if common knowledge 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. In other words, even if the patent is not involved in an actual litigation case for the current age, the patentee has to be prepared to defend his patent and make sure that the patent is worth defending in case it is infringed.

Taking patent infringements and litigation into consideration will unambiguously 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 (such as Hamburg (2001) or 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:[7]

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

Assuming that an infringement suit will take three years before a ruling[8], and with probability w the patentee wins the case, the patent value in age t becomes

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

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.

[7] 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 those countries the patentees always expect to pay a fixed amount of *minimal* litigation costs, i.e., setting α_0 in equation (2.4) to the fixed minimal costs and α_1 to zero.

[8] As Lanjouw (1998) notes, patent suits in Germany typically are completed within three years. The estimations on the duration of such cases in other European countries, however, are currently not available. In the later sections of this paper, a three-year duration is assumed in all other EPO member countries.

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,[9] and is defined as

$$E_t VL(t+1, r_{t+1}) = \int r_{t+1} G_{t+1}(dr_{t+1}|t) + \beta\theta \iint [r_{t+2} + \beta\theta EV(t+3, r_{t+3})] G_{t+2}(dr_{t+2}|t+1) G_{t+1}(dr_{t+1}|t) \quad (2.6)$$

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).

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. In particular, 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:

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

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,

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

The series of the minimal renewal return $\{r_t^*\}_{t=1}^T$ in this renewal problem can then be solved by integrating equation (2.6) backwards with the terminal condition $V(T+1, r_{T+1}) = 0$.[10]

The Application and Designation Decision Rule

Patent application with the EPO is a two-stage process. The patent applicant has to decide at first whether to file an initial application with EPO, and if so, which EPO member countries

[9] Equation (2.5) assumes that, during the three years of the litigation, once the patent becomes obsolete, the patentee will stop renewing the patent. Lanjouw (1998) made the same assumption, which greatly reduced the computational burden.

[10] A technical appendix specifying the details of derivation and the formulae of the model solution is available from the author upon request.

to designate (by paying the corresponding designation fees) to keep the option of transferring the EPO patent into a national patent in these countries later. The application then goes through an examination process that usually takes three to four years (Deng 2003). Once the patent application is granted the patentee has to decide whether to pay the additional lump-sum expenses (such as the expensive translation costs and other administrative costs if applicable) in each of the designated countries and continue to seek for patent protection in that country. Therefore, the joint application and designation problem faced by the patent applicant is to

$$\max_{R} . \ \{\sum_{j=1}^{J} 1_{j1}(R^*)[h_j\theta^2 r_{j,1} + \beta\theta^2 h_j E_1(r_{j,2} + \beta r_{j,3} + \beta^2 prob_{gr} V(4, r_{j,4})) - C_j - \alpha_{j,0}(1 - w_j)] - C_{EPO}, 0\} \tag{2.9}$$

where C_j is the per-country designation cost, C_{EPO} is the initial application fee due at the EPO, and $h_j = w_j - \alpha_{1,j}(1 - w_j)$ is determined by the litigation cost parameters $\alpha_{j,0}$, $\alpha_{j,1}$ and the winning probability w_j in country j. R represents the patent applicant's decision rule. For instance, $1_{j1}(R) = 1$ means that he chooses to designate country j at the time of the initial filing. It is also assumed that the official examination is an exogenous process and the final granting decision is out of the applicant's control, and that the patent applicants recognize a constant probability of the application being granted $prob_{gr}$.[11]

The above problem is solved backward. At the beginning of the fourth year the patentee has to decide whether to transfer the granted patent to the national patent office in member country j, conditional on the patent application having been approved and that country j was designated three years ago. Therefore, the patent value at age 4 is:

$$V(4, r_{j,4}) = \max\{0, h_j\theta^2 r_{j,4} + \beta\theta^2 h_j E_4 VL(5, r_{j,5}) - C_{j,4} - \beta\theta c_{j,5} - (\beta\theta)^2 c_{j,6} - \alpha_{j,0}(1 - w_j)\} \tag{2.10}$$

[11] An alternative is to view the patent application and examination in whole as a multi-period bargaining process between the applicant and the examiner, and the probability of grant is thus endogenously determined. For instance, the width of the patent claim is a control variable that the applicant can choose: wider claim brings higher expected future returns, but the probability of being granted becomes smaller. In each period the applicant chooses to pay a filing or review fee, makes the claim and bargins with the examiner, or simply abandons his application. However this bargaining process is not the primary focus of the current paper, and instead an exogenously determined constant grant probability is assumed here.

where $C_{j,4}$ is the sum of the lump-sum transfer expenses and the renewal fee due at the national patent office for age 4. $E_4VL(5, r_{j,5})$ is the expected value of the future returns in the following two years. The patentee will pay $C_{j,4}$ and obtain a national patent in country j if and only if $r_{j,4} \geq r^*_{j,4}$, with $r^*_{j,4}$ solving the following function:

$$h_j\theta^2 r_{j,4} + \beta\theta^2 h_j E_4VL(5, r_{j,5}) - C_{j,4} - \beta\theta c_{j,5} - (\beta\theta)^2 c_{j,6} - \alpha_{j,0}(1 - w_j) = 0 \tag{2.11}$$

and the patent value in country j in age one becomes:

$$V(1, r_{j,1}) = \max\{0, h_j\theta^2 r_{j,1} + \beta\theta^2 h_j E_1(r_{j,2} + \beta r_{j,3} + \beta^2 prob_{gr} V(4, r_{j,4})) - C_j - \alpha_{j,0}(1 - w_j)\} \tag{2.12}$$

Similarly, there exists a unique minimal designation return $r^*_{j,1}$ above which the patent applicant is going to designate in country j, conditional on having filed the patent application at EPO.

Finally, with the conditional designation decision rule $1_{j1}(R)$, the inventor will now be able to decide whether he would like to file the initial patent application at EPO. He will choose to file the application if by doing so the sum of the net returns in all designated countries is enough to cover the large application cost C_{EPO}. Otherwise he will not resort to the EPO patent protection regime.

So far we have defined the stochastic Markov process generating the distribution of $\{r_t\}_{t=2}^T$ for a given r_1 and solved for the conditional decision rules throughout the patent life. What is left to be specified in the model is the distributions of the initial returns of the patent r_1. We assume that the initial return of any patent i in country j is lognormally distributed, and

$$r_{ij1} = \exp(\alpha_i + bX_i + \upsilon \log GDP_j + \varepsilon_{ij}) \tag{2.13}$$

That is, the initial return r_{ij1} is determined by a common (across different country j's) factor α_i, a list of patent-specific characteristics X_i, the real GDP of the country j (to approximate the market size of the patented innovation in the designated country),[12] and an idiosyncratic (to each country) factor ε_{ij}. Moreover, both the common and idiosyncratic factors follow lognormal

[12] Notice that υ is an indicator of returns to scale of the economy. It is *ad hoc* assumed to be 1 in the deterministic patent-application study in Putnam (1996). However the estimate in Deng (2003) of υ is about 0.5, indicating a decreasing returns to scale.

distributions:[13]

$$\begin{aligned} \alpha_i &\backsim N(\mu_\alpha, \sigma_\alpha^2) \\ \varepsilon_{ij} &\backsim N(0, \sigma_\varepsilon^2), \quad i.i.d. \text{ across country } j\text{'s} \end{aligned} \tag{2.14}$$

and α_i and X_i are independent of ε_{ij}: $E(\alpha_i \varepsilon_{ij}) = 0$, $E(X_i \varepsilon_{ij}) = 0$.

Finally, to capture the effects of the market sizes on the magnitude of the learning probabilities, the $p.d.f.$ of the independently learned values in any specific country j at age t, z_{ijt}, is defined as

$$q_{jt}(z_{ijt}) = \sigma_{jt}^{-1} \exp\{-(z_{ijt}\sigma_{jt}^{-1} + \gamma)\}, \qquad z_{ijt} \geq -\gamma\sigma_{jt}$$

where $\sigma_{jt} = \phi^{t-1}\sigma_j$ with $0 < \phi \leq 1$, and $\sigma_j = (GDP_j)^{\upsilon}\sigma$. In other words, the realizations of z_{ijt} in any specific country j are assumed to be proportional to the size of the economy, as in defining the distributions of the initial returns in equation (2.13).

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 distributions of the initial returns, it is straightforward to derive the $c.d.f.$ of r_{ijt} (Note that once the patent lapses there are no returns to the patent protection thereafter):

$$1 - F_j(r,t) = \Pr\{r_{ijt} \geq r, r_{ij,t-1} \geq r_{j,t-1}^*, ..., r_{ij,2} \geq r_{j,2}^*, r_{ij,1} \geq r_{j,1}^*\} \tag{2.15}$$

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_{ijt} exceeding the minimal renewal return r_{jt}^*, or $1 - F_j(r_{jt}^*, t)$. The proportion of patents lapsing (the hazard rate) at age t in country j is simply the proportion not paying the renewal fee at age t out of those having paid at age $t-1$:

$$\pi_j(t) = [F_j(r_{jt}^*, t) - F_j(r_{j,t-1}^*, t-1)]/[1 - F_j(r_{j,t-1}^*, t-1)], \qquad t = 5, ..., T \tag{2.16}$$

Similarly, the hazard rate between age 1 (the initial application) and age 4 (when the granted patents are to be transferred to national office j), conditional on the country having been

[13] Schankerman and Pakes (1986) find that the log-normal distribution fits the renewal data better than any other kind of distribution they have tried. Schankerman (1998) also finds the log-normal is the most suitable distribution.

designated when the initial application was submitted, is

$$\pi_j(4) = [F_j(r^*_{j4}, 4) - F_j(r^*_{j1}, 1)]/[1 - F_j(r^*_{j1}, 1)] \tag{2.17}$$

And finally, the proportion of patents not designated in country j at the time of initial application is

$$\pi_j(1) = F_j(r^*_{j1}, 1) = \Pr\{r_{ij,1} < r^*_{j,1}\} \tag{2.18}$$

Equations (2.15) to (2.18) provide the moment conditions required for the estimation. Specifically,

$$E[\pi_N - \pi(\omega)] = 0 \tag{2.19}$$

where $\pi(\omega)$ is an m-variate vector stacking up the hazard probabilities of all country/cohort/age cells as predicted by the model. π_N 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. In particular,

$$\begin{aligned} \widehat{\omega}_N &= \arg\min ||G_N(\omega)|| && (2.20) \\ &= \arg\min ||\pi_N - \widetilde{\pi}_N(\omega)||_{W_N(\omega)} && (2.21) \end{aligned}$$

where $\widetilde{\pi}_N(\omega)$ is a vector of simulation estimates of the aggregate hazard probabilities implied by the parameter ω. $W_N(\omega)$ is a semi-definite weighting matrix. The simulated hazard probabilities are generated by first solving the model to determine the minimal application/renewal returns $r^*_{j,t}$ for each age and country in each cohort, and then using these values to calculate the hazard proportions from the simulation. The simulation size is set to be proportional to the sample size N (in the model estimation later it is set to be three times the number of patents in each cohort).

Identification, uniformity and continuity conditions required to ensure the consistency and asymptotic normality can be found in McFadden (1989) and Pakes and Pollard (1989). Given that all the regularity conditions hold (Lanjouw (1998)) and $W_N(\omega)$ converges in probability to a semi-definite matrix W, the asymptotic distribution of $\widehat{\omega}_N$ is given by

$$\sqrt{N}(\widehat{\omega}_N - \omega_0) \backsim N(0, (\Gamma' W \Gamma)^{-1} \Gamma' W V W \Gamma (\Gamma' W \Gamma)^{-1})$$

where Γ and V are the full-ranked derivative matrix and the asymptotic variance matrix of the moment conditions $\pi_N(\omega) - \widetilde{\pi}_N(\omega)$, respectively.

Hansen (1982) suggests using the sample estimates of the inverse of the asymptotic variances of the moment conditions as the optimal weighting matrix. 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 10 (number of EPO member countries) times 6 (number of cohorts) of them. Thus in the model estimation the following weighting matrix is then adopted:

$$W_N(\omega) = diag(\sqrt{n/N}), \tag{2.22}$$

where n is the number of patents still alive in the specific country-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 Analysis

The patent application and renewal data set, compiled from raw data provided by the European Patent Office (EPO), is used in the model estimation. Although in the data set the earliest observation of EPO patent application is from 1978, we focus on analyzing the pharmaceutical and electronics patent applications which were initiated between 1980 and 1985 (defined as "cohorts" of 1980 through 1985). Years 1978 and 1979 are considered as a transition period during which potential patent applicants may not be aware of the establishment of the new patent-protection regime of the EPO. This ignorance may bias the model estimation and thus the applications filed in these two 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 patents 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 groups of patents. Thus inclding the renewal records of those later patent cohorts may not improve the estimation efficiency. Another advantage of limiting the sample to cohorts 1980 to 1985 is that the member countries of EPO were unchanged during this period. Focusing on a period of stable regime excludes any major institutional changes that the applicants may face, and ensures that the differences between different cohorts in the sample may only arise from the quality of the underlying inventions but nothing institutional.

Table 1 displays the number of patent applications and grant rates of the pharmaceutical and electronics patents[14] used in the model estimation. The electronics patent group is significantly larger than the pharmaceutical group, with a total number of applications about 3 to 4 times larger in all cohorts. During 1980 to 1985, 12,334 pharmaceutical patent applications were filed with the EPO, while 56,743 application were filed by electronics inventors. The patent grant rates, on the other hand, are not very far apart in these two technology groups. For instance, 73% of the pharmaceutical patent applications in cohort 1981 are finally approved, and it is 71% for cohort 1983 and 64% for cohort 1985. In the electronics group, 71% of the patent applications in cohort 1981 are finally granted, and it is 72% for cohort 1983 and 69% for cohorts 1985. When averaged over all cohorts, the grant rate for pharmaceutical patents is 69%, and is 71% for electronics patents. In the model estimation the representative patent applicant is assumed to form an expectation of the grant probability which is set to be identical to the average approval rate of the technology group his application belongs to, as shown on row 9 of Table 1.

Table 1: Number of Patent Applications and Grant Rates of Pharmaceutical and electronics Patents

	Pharmaceutical		electronics	
	Number	Grant Rate	Number	Grant Rate
1980	1,400	74.14%	6,057	71.97%
1981	1,710	73.45%	7,472	71.35%
1982	1,860	71.08%	8,879	71.54%
1983	2,158	70.71%	9,925	71.88%
1984	2,444	64.81%	11,698	70.50%
1985	2,762	63.90%	12,712	68.56%
1980-85	12,334	68.84%	56,743	70.74%
Number of cohort-age-country cells		583		583

Note: Table 1 reports the number of patent applications and grant rates of the pharmaceutical and electronics patent applications, as used in the joint application-renewal model estimation.

[14] Each patent application carries an International Patent Classification (IPC) code assigned by the patent examiners, which is used in categorizing the patents into different technology groups. The detailed grouping criteria are available from the author upon request.

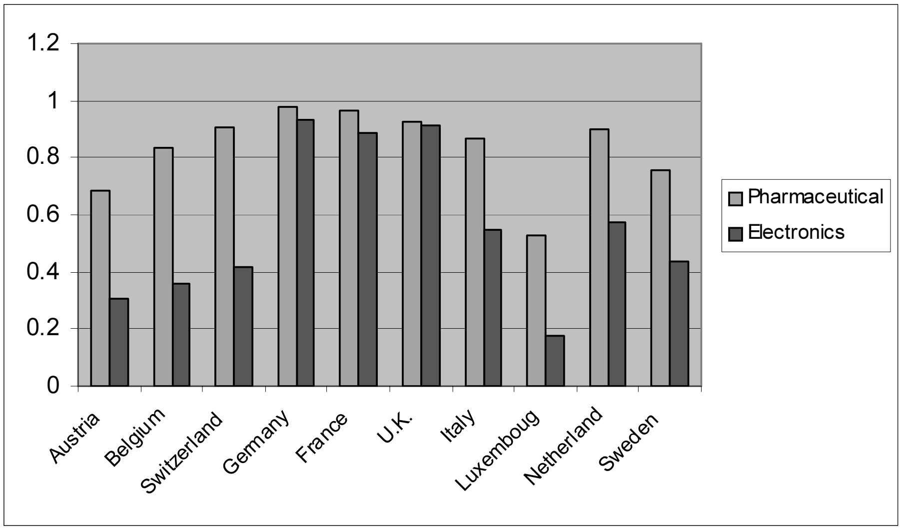
Patent Designation

Figure 1 shows the designation rate in each of the 10 EPO member countries from both technology fields, averaged over cohorts 1980 to 1985. Apparently the pharmaceutical patent applicants designate more countries for patent protection than electronics patent applicants. For instance, 90% of the pharmaceutical patent applicants choose to designate Switzerland, while only 42% of the electronics patent applicants do so. Belgium is designated by 84% of the pharmaceutical patent applicants and only 36% of the electronics patent applicants. However, the designation rates in countries with a larger economy, for example Germany, France, and the United Kingdom, are similar.

Further analysis shows that during 1980 to 1985, the pharmaceutical patent applicants on average choose to desigtnate 8.4 out of the 10 EPO member countries, whereas the electronics patent applicants designate an average of 5.6 countries. If the patent value is measured by the simple counts of their family size, as in Lanjouw and Schankerman (2004), then the average designation rates would suggest that a typical pharmaceutical patent is 50% more valuable than a typical electronics patent. Intuitively this should be correct, since the patent applicant compares the net present value of his invention in each country with the application costs, and chooses to designate countries wherever the net present value exceeds the designation costs. Therefore, the more countries a patent chooses to seek for patent protection, presumably the higher its value.

However, as pointed out by Deng (2003), gauging the private value of patents by simply counting the number of designated countries sometimes can be misleading, because the size of the economy of the countries matter. The revenue a patentee expects to gather from a large economy is presumably higher than that from a small economy because the market size would be larger. In particular, when the application costs in different countries are close, patent applicants would choose to first apply in countries with larger market sizes and then the ones with smaller sizes. Therefore the relative value of the patents may also depend on the relative market sizes of these countries, as in equation (2.13).

Figure 1: Designation Rates in the EPO Member Countries



Patent Renewal

Figure 2 displays the patent renewal rates of the two technology groups in Germany, averaged over different cohorts, and Figure 3 shows the average renewal rates in the U.K. In both figures the renewal curve of pharmaceutical patents lies below that of electronics patents at all ages. For instance, of all the pharmaceutical patents transferred to Germany, only 73% are still alive by the end of age 9, while it is 83% for the electronics patents. 22% of the pharmaceutical patents live up to age 17, the latest age observed in the sample, whereas 29% of the electronics patents live up to this age. In the U.K., 76% of the electronics patents live up to age 9 and 29% live up to age 17, while it is 70% and 25% for the pharmaceutical patents, respectively.

The renewal pattern in other countries is mixed. As Figure 4 shows, in Netherlands the renewal curve of pharmaceutical patents lies slightly above that of electronics patents in early years, with a margin of about 3% till age 12. However the renewal rates of both groups become almost identical after age 14. On the other hand, Figure 5 shows that in Switzerland the renewal rate of pharmaceutical patents is always higher than that of electronics patents, for at least 5%, at every age.

Due to data problem the data set only has a reliable renewal record after 1990 in France, and the renewal pattern there is again mixed: in Figure 6 the renewal curve of pharmaceutical

Figure 2: Average Renewal Rates in Germany

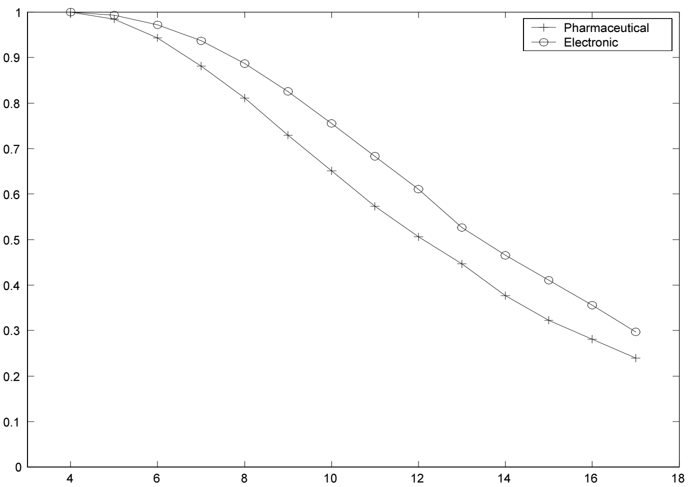


Figure 3: Average Renewal Rates in the U.K

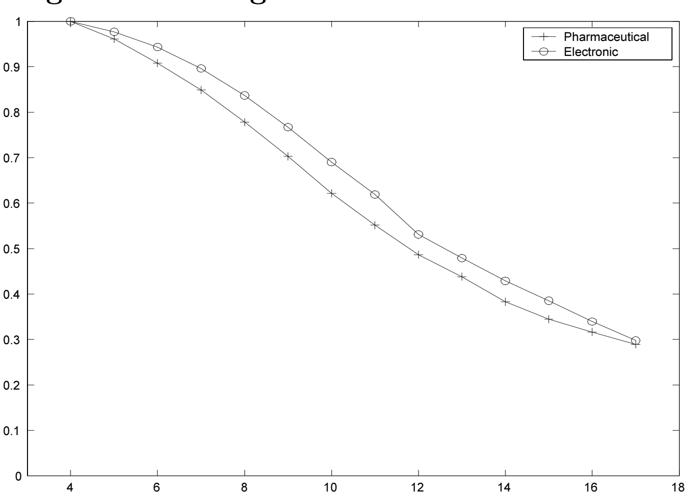


Figure 4: Average Renewal Rates in Netherlands

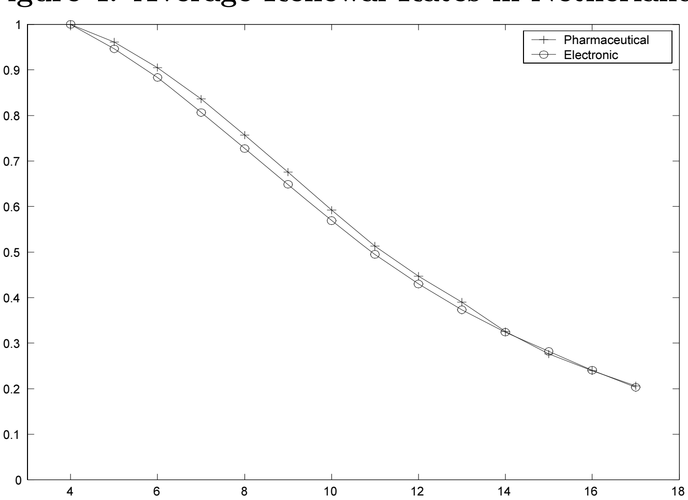


Figure 5: Average Renewal Rates in Switzerland

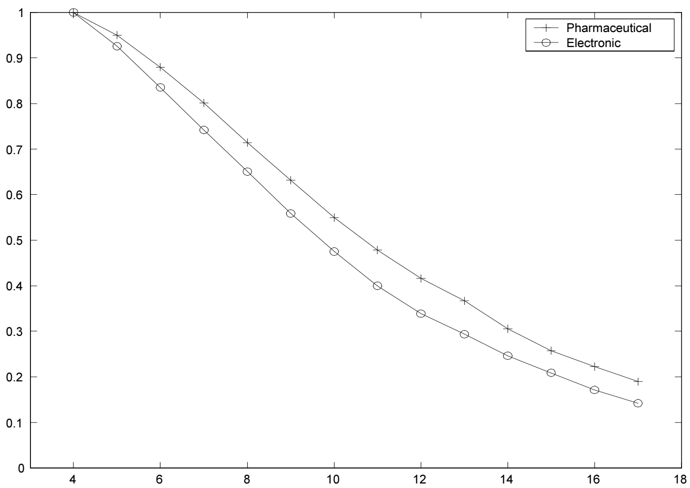


Figure 6: Average Renewal Rates in France

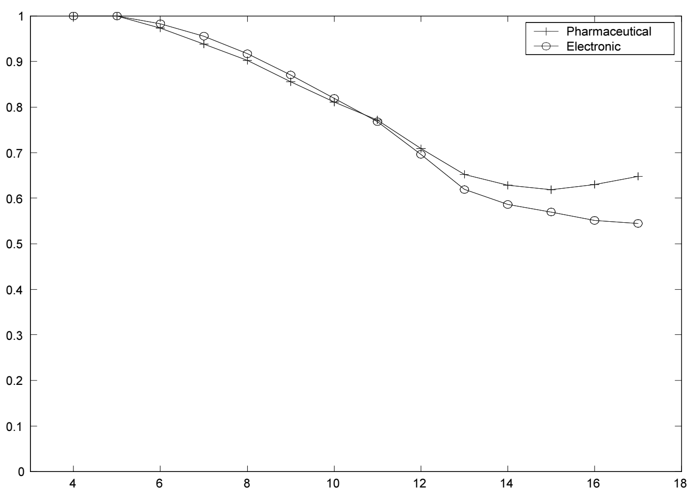
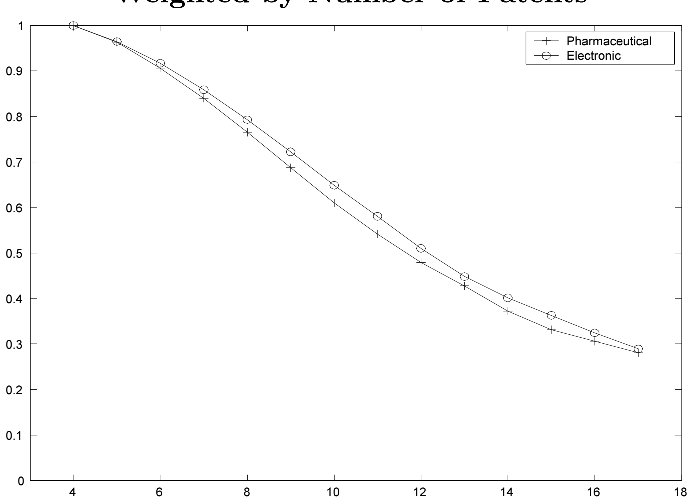


Figure 7: Average Renewal Rates in All Countries, Weighted by Number of Patents



patents lies below that of electronics patents at early ages but goes above the latter after age 12. However it should be noted that the renewal behavior of different cohorts in France varies a lot (Schankerman (1998) also reports that the null hypothesis of no cohort effects is rejected in his renewal study of a French sample), as can be seen by the irregular upward sloping part of the renewal curve of pharmaceutical patents at later ages.[15]

When averaged over different countries using the number of patents in each country as weights, however, the electronics patents clearly have higher renewal rates at all ages and consequently have a longer average life. As Figure 7 displays, 61% of the pharmaceutical patents and 65% of the electronics patents live up to age 10, and at age 15 it is 33% for the pharmaceutical and 37% for the electronics patents. Given these facts, a patent renewal model estimation may suggest a higher average value for the electronics patents than pharmarceutical patents in these EPO member countries, because the owners of the electronics patents are willing to keep them alive for a longer period of time and pay higher renewal costs. This seems inconsistent with their designation decisions, as they choose to designate pharmaceutical inventions in more countries than electronics.

4. Model Estimation

The model is estimated separately for pharmaceutical and electronics patent groups, so all parameters are allowed to vary across technology fields. To reduce the number of parameters to be numerically estimated and alleviate the computational burden, the real discount factor β is set to equal 0.95, consistent with previous literature. For the same reason, the probability

[15] A typical renewal curve should be monotonically downward sloping. However the above figures show the renewal rates *averaged* across different cohorts, and this definition introduces some complications: because the data set ends in 1997, we can only observe the renewal rate at age 17 for cohort 1980, and the renewal rate at age 16 for both cohorts 1980 and 1981, and so on. Therefore, in computing the average renewal rate for late ages, only the renewal rates of the available cohorts are used, i.e., the renewal rate of cohort 1980 at age 17 is shown in Figure 2 to 7 as the average renewal rate at age 17, and the renewal rates of cohorts 1980 and 1981 at age 16 are used to compute the average renewal rate at age 16 as shown, and so on. Therefore, when the renewal behavior in different cohorts varies a lot, such as in France, a hump-shaped renewal curve becomes possible. Fortunately this is not the case in most of the other countries.

of the patentee winning an infringement suit is assumed to be fixed at 0.95 in all countries.[16][17] Lanjouw (1998) and Deng (2004) estimate winning probabilities in Germany, France and the U.K. and obtain estimates of similar magnitude. Finally, all kinds of designation, renewal, and litigation costs are converted to 1997 U.S. dollar values.

Table 2 reports the parameter estimates for both the pharmaceutical and electronics patent groups. The model estimation fits the data reasonably well. The weighted Mean Square Error (MSE), constructed as the sum of squared residuals weighted by the number of patents in each cohort-age-country cell and divided by the total number of cohort-age-country cells, is reported in row C1. Row C2 displays the variances of the actual hazard rates from the sample. The variance of the actual hazard rates can be viewed as the MSE of a "naive" model which predicts that in all cohort-age-country 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 model estimation can serve as a measure of the improvement of model performance over such a "naive" model. As shown in rows C3, compared with the "naive" model, the joint application-renewal model improves the data fitting by about 46% in fitting the designation and renewal pattern of the pharmaceutical patents and about 39% in fitting that of the electronics patents. To separately examine the model's performance in fitting designation and renewal patterns, the total weighted MSE is decomposed into two parts, one in matching the designation rates (row C4) and one in matching the renewal rates (row C5). By comparing them with the variances of the corresponding actual designation and renewal rates in the sample, we conclude that the estimated model performs well in both dimensions: it improves over the "naive" model in fitting the designation rates by 53% and 50% in the pharmaceutical and electronics patent groups respectively, and in fitting the renewal rates by 26% and 15%, respectively.

Obsolescence and Depreciation Dynamics

The estimates of model parameters are all positive and highly significant. The estimates of

[16] Although it sounds appealing to estimate the winning probability in each of the 10 EPO member countries and thus reveal more details of patent litigation system in these countries, such practice would add 10 more parameters to the model estimation (which is already very large and complicated) and greatly increase the computational burden.

[17] A technical appendix describing the details of the numerical estimation procedure is available from the author upon request.

the annual obsolescence rate θ are close in the two patent groups: each year about 5% of patents become obsolete in both industries. This means that over 40% of patents become outdated and die by the end of age 10, simply due to major technological breakthrough in the same field, and by the end of age 15 over 55% die due to the same reason. These estimates of the obsolescence rate are also close to the estimates of 4.9% to 6.4% obtained in estimating the renewal model using EPO patent renewal data in Germany, France and the U.K., as reported by Deng (2004).

The estimates of the deterministic depreciation rate δ, however, are very different between the two patent groups. If there is neither obsolescence observed nor new values learned, the expected value of pharmaceutical patents would depreciate at an annual rate of 13%, much faster than the electronics patents (5%). That is to say, other things being equal, pharmaceutical patents tend to have a shorter life than electronics patents, since at later ages the pharmaceutical patentees are more likely to find that the depreciated patent value is not enough to cover the increasing annual renewal fees, and may choose to let the patent lapse. This is consistent with the observation of a shorter average life for pharmaceutical patents in the preliminary data analysis in Section 3. We will explore possible explanations for different depreciation dynamics in these two technology fields later.

Learning Dynamics

The estimated σ for the pharmaceutical patents, which characterizes the stochastic learning processes, is 10,814, significantly higher than that of the electronics patents (4,519). For patent of a given value, a larger σ implies that the probability of the patent becoming more valuable through learning is higher. Therefore, while deterministically the pharmaceutical patents depreciate faster, stochastically they benefit from a more productive learning process at early ages, which may boost their expected values over time.

The comparison between these two technology fields are further complicated when the decay rate of σ_t, ϕ, is taken into account. Recall that the parameter σ_t of the exponential distribution that characterizes the learning process is defined as $\sigma_t = \sigma\phi^{t-1}$ in equation (2.3). The estimate of the decay rate ϕ is 0.56 for pharmaceutical patents and 0.70 for electronics patents. In other words, although a pharmaceutical patent may have a higher initial learning probability (a higher σ), such probability declines more quickly. And starting from age 6, σ_t of the pharmaceutical group becomes smaller than that of the electronics group. The estimates of the other parameter of the exponential distribution, γ, are similar for these two technology groups.

Table 2: Model Estimation Resluts

	Pharmaceutical		Electronics	
A. Parameter[a]				
θ	0.9498	(0.0224)	0.9523	(0.0361)
δ	0.8651	(0.0304)	0.9457	(0.0212)
σ	10,814	(408.77)	4,519	(219.28)
ϕ	0.5584	(0.0212)	0.6977	(0.0220)
γ	0.4749	(0.0231)	0.4421	(0.0198)
υ	0.9759	(0.0965)	1.3880	(0.1084)
μ_α	10.9755	(0.9227)	9.7903	(0.3558)
σ_α	0.7539	(0.0295)	1.3549	(0.1815)
σ_ε	2.4916	(0.1462)	2.0654	(0.4344)
B. Size of				
B1. Sample	12,334		56,743	
B2. Simulation	37,002		170,229	
B3. Cohort-Age-Country Cells	583		583	
C. Summary Statistics[b]				
C1. MSE($\widetilde{\pi}$)	3.1837×10^{-4}		4.3214×10^{-4}	
C2. V(π)	5.8621×10^{-4}		7.1099×10^{-4}	
C3. MSE($\widetilde{\pi}$)/V(π)	0.5431		0.6078	
C4.MSE($\widetilde{\pi}_{desig}$)/V(π_{desig})	0.4732		0.5028	
C5. MSE($\widetilde{\pi}_{renewal}$)/V($\pi_{renewal}$)	0.7419		0.8485	

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.

It might be more straightforward to simulate the learning processes in these two patent groups and examine the implications of the different parameter estimates. Table 3 illustrates the results of a simulation run of 50,000 draws of pharmaceutical patents and 100,000 draws of electronics patents, based on the parameter estimates as reported in Table 2. Columns 2 to 4 of the table display the percentage of pharmaceutical patents which learn a higher value at each age in Germany, France and the U.K., out of all patents that live up to that age. For instance, at the beginning of age 2, over 10% of the pharmaceutical patent applicants discover a use which generates higher subsequent profits than known before in Germany and in France, and 8% in the U.K. At the beginning of age 3, such percentage drops to 6% in Germany, 5% in France and in the U.K. The proportions of patents learning a higher value continue to decline over the ages. By age 5, only 2% of the pharmaceutical patent holders find more profitable ways to exploit their patented ideas in Germany, and even fewer in France and the U.K. (less than 1%). By age 7, none of the pharmaceutical patent holders from the simulation find an increased patent value in the U.K. The learning process of pharmaceutical patents is essentially over by age 8 in France and by age 10 in Germany. After that, the deterministic depreciation and obsolescence processes begin to dominate the renewal decisions.

Columns 5 to 7 of Table 3 report the simulated learning dynamics of the electronics patents. Similar to the case of pharmaceutical patents, the learning probability in this group also gradually declines over the ages: in Germany from 13% at age 2 to 3% at age 5, and the learning is over by age 11. In France, learning probability drops from 13% at age 2 to 1% at age 5, and to essentially zero at age 9. Such probability is 7% in the U.K. at age 2, 0.13% at age 5, and the learning is over by age 7.

The fact that the dynamics of learning probability is similar in pharmaceutical and electronics patent groups reflects the offsetting effects of different parameters of the learning processes in these two groups. As noted above, the parameter σ_t in the learning process of pharmaceutical patents are initially higher than that of electronics patents, which generates higher probabilities of discovering a higher value for any given level of patent value. However, because the initial returns of pharmaceutical patents is on average higher than those of electronics patents (as shown below in Table 4), the actual probability of finding a return exceeding the present level may not be necessarily higher than that of the electronics patents. The first few rows of Table 3 show that the learning probability of pharmaceutical patents at early ages is higher than that of electronics patents in the U.K., but slightly lower in Germany and France. Moreover, the parameter σ_t of pharmaceutical patents declines faster over time, and by age 6 it becomes significantly lower than that of electronics patents. From then on, the learning probability of pharmaceutical patents is consistently lower than the corresponding probability of electronics patents.

Pakes (1986) reports that in a sample of German and French patents in the 1950s to 1970s, 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. In contrast, model estimation here indicates a significantly longer learning process during the life of EPO patents. This suggests that EPO patents have very different characteristics from the national patents studied in previous literature, most likely, the higher quality of the EPO patents than that of the national patents. As the EPO is a multi-country patent protection regime with higher application costs, only those applicants who decide to seek for protection in more than one country will choose to apply (otherwise they may choose the cheaper national route in the single country they are interested). This selection process leads to a higher quality on average in the EPO sample than in previous studies. Owners of these higher-quality patents would expect higher patent values and are thus more willing to experiment new strategies to exploit the patented ideas. On the other hand, the higher revenues from implementing these patented ideas, especially at early ages, also provide their owners more resources for such explorations.

Table 3: Percentage of Pharmaceutical and electronics Patents Learning a Higher Value

	Pharmaceutical (%)			electronics (%)		
Age	Germany	France	U.K.	Germany	France	U.K.
2	10.27	10.43	8.43	12.81	12.73	6.72
3	5.69	5.42	5.37	7.68	7.39	3.35
4	4.62	4.58	3.25	7.03	7.77	1.57
5	1.61	0.65	0.53	2.94	0.87	0.13
6	0.71	0.17	0.02	1.62	0.33	0.02
7	0.24	0.03	0.00	0.83	0.10	0.00
8	0.04	0.00	0.00	0.38	0.02	0.00
9	0.01	0.00	0.00	0.10	0.00	0.00
10	0.00	0.00	0.00	0.03	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00

Note: Table 3 reports the learning probability from a simulation run of 50,000 draws of pharmaceutical patents and 100,000 draws of electronics patents, based on the parameter estimates reported in Table 2.

Returns to Market Sizes

The estimated value of υ is significantly different from zero, implying that the patent value in a given country is highly correlated with the market size of the country, and increases as the size of the economy increases, i.e., larger market brings more returns to the patent holders. However the estimated degree of returns to market size differ significantly: the expected value of pharmaceutical patents exhibits an approximately constant returns to market size, while electronics patents show increasing returns to market size. For instance, while the market size of Austria is 9.5% of that of Germany, as measured by the ratio of average real GDP in these two countries, the model estimates imply that the expected value of an average pharmaceutical patent in Austria is 10% of that in Germany, whereas the expected value of an average electronics patent in Austria would be only 4% of that in Germany. Previous literature has provided little evidence regarding the degree of returns to market sizes of patent value in different countries.

Previous authors such as Putnam (1997) often make an *ad hoc* assumption of a constant returns to market size. Deng (2003) reports a decreasing returns in estimating a multi-country patent application model, but she does not examine this issue across different technology fields.

The exact reason for such differences in returns to market size remains unclear, but it should be closely related to the different characteristics of these two technology fields: pharmaceutical products are usually based on a single or only a few specific inventions ("discrete" technology as characterized by Levin, Klevorick, Nelson and Winter (1987)), and because the sales of the final products in different countries usually increase at a constant rate as the market size or the population increases, the patent value would exhibit a constant returns to market size. The production of electronics, on the other hand, may rely on various technologies embodied in a large number of inventions ("complex" technology), and a substantial part of the payoffs of the patents are gathered through cross-licensing agreements. In countries with a larger economy and larger electronics industries, a patent will find more uses and more possibilities to negotiate cross-licensing agreements than in countries with a smaller economy. Therefore it is not surprising that the patent value in this group shows an increasing returns to market size, as positive externality or spillover effects may occur when various electronics patents are combined together.[18]

Distribution of Initial Returns and Patent Designation

The estimates of μ_α and σ_α imply that in any specific country, pharmaceutical patents have a higher median initial return and less dispersion than electronics patents, whereas the estimates of σ_ε indicates that these patents also exhibit slightly larger dispersion of their initial returns across different countries. These estimates are consistent with Lanjouw (1998)'s findings of a high pharmaceutical patent value based on a Germany sample, but in contrast to Schankerman

[18] Levin, Klevorick, Nelson and Winter (1987), Merges and Nelson (1990), Kusonoki, Nonaka and Nagata (1998), Kash and Kingston (2000), and Cohen, Nelson and Walsh (2000) all recognize this distinction between "discrete" versus "complex" technology. As Cohen, Nelson and Walsh (2000) explain, "the key difference between a complex and a discrete technology is whether a new, commercializable production or process is comprised of numerous separately patentable elements versus relatively few," and "New drugs or chemicals typically are comprised of a relatively discrete number of patentable elements. In contrast, electronic patents tend to be comprised of a larger number — often hundreds — of patentable elements and, hence, may be characterized as complex." Hall, Jaffe and Trajtenberg (2004) also argues that "drug industry is characterized by discrete product technologies where patents serve their traditional role of exclusion ... whileas computers and communications is a group of complex product industries where any particular product may rely on various technologies embodied in several patents..."

(1998)'s French patent study that the pharmaceuticals are endowed with low median and mean returns and less dispersions than electronics.

As both authors have noted, France has the most stringent pharcaceutical price regulation and the lowest drug prices in Europe, whereas prices in Germany are largely unregulated and substantially higher than many other west European countries. This may explain why Schankerman (1998) obtain a lower estimate for pharmaceutical patents than electronics and Lanjouw (1998) has higher estimates for pharmaceuticals. Our estimates are based on all ten EPO member countries in 1980s, and are thus abstract from any institutional idiosyncracy in individual countries. Moreover, both Schankerman (1998) and Lanjouw (1998) only study the patent renewal behavior, whereas our estimation is based on both the patent renewal and patent designation records. The larger family size of pharmaceutical patents (about 50% larger than electronics) also indicates a higher value and explains why our results are different from Schankerman (1998).

Table 4 displays the distribution of the simulated initial patent returns in each of the 10 EPO member countries in the two simulated patent groups, before the designation decision is made. It reveals that, within the same technology group, the initial returns vary a lot across countries. For instance, the median of the initial returns of simulated pharmaceutical patents is \$59,200 (in 1997 U.S. dollars, same below) in Germany, \$38,285 in France, and only \$440 in Luxembourg, the country with the smallest economy. For the electronics patents, the median of initial returns is \$18,086 in Germany, \$9,794 in France, and only \$17 in Luxembourg. On the other hand, the initial returns of the pharmaceutical patents are on average much higher than those of electronics patents. For example, the median initial return of pharmaceutical patents is 2.3 times larger than that of electronics patents in Germany, 3 times larger in France, and almost 8 times larger in Austria.

The draw of the initial returns from the distribution determines the patent applicants' designation decisions in different countries.[19] As shown in Figure 8, the simulated designation patterns match the data fairly well for both patent groups. Almost all simulated pharmaceutical patents choose to designate Germany, France and Italy at the time of initial filing, but only 88% choose to designate Sweden and 85% choose to designate Austria. The designation

[19] The simulated designation and the renewal patterns as well as the distribution of patent value discussed later are all based on the average fee schedule across different cohorts in each country, and are all generated from the same simulation population as above.

rate for Luxembourg is 49%, the lowest among all EPO member countries. Corresponding to lower initial returns for the simulated electronics patents, their designation rate is also lower in almost all countries: almost 100% in Germany and France, but only 83% in Italy, 56% in Sweden, and 53% in Austria. The average number of designated countries is 8.7 for the simulated pharmaceutical patents and 6.3 for the electronics patents, very close to the average number in the actual sample (8.4 for pharmaceutical and 5.6 for electronics patents as shown in Figure 2).

Table 4: Distribution of the Initial Returns of Simulated Patents

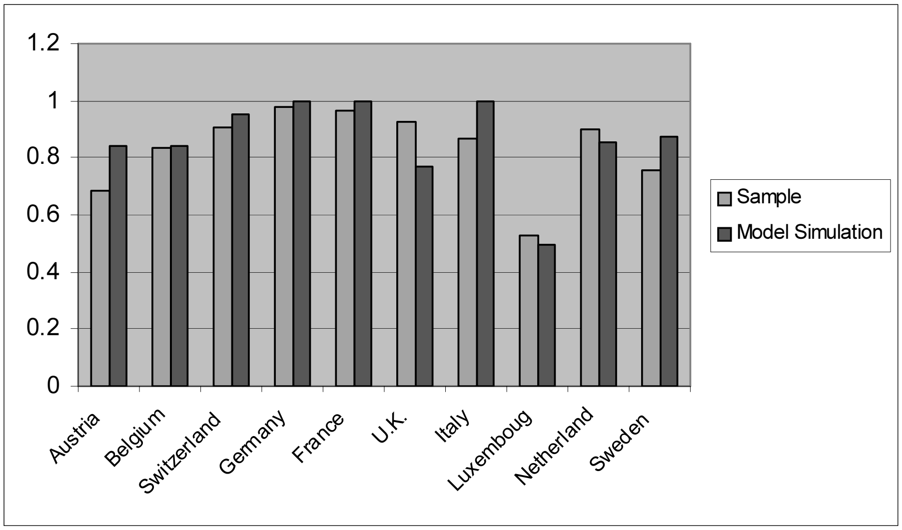
	Real GDP	Pharmaceutical					
	Ratio	50%		75%		90%	
		Value	Cum. %	Value	Cum. %	Value	Cum. %
Austria	0.0947	6,025	0.47%	34,305	2.74%	166,450	9.44%
Belgium	0.1133	6,851	0.49%	40,428	2.87%	195,900	10.01%
Switzerland	0.1310	8,174	0.48%	46,564	2.74%	221,420	9.37%
Germany	1.0000	59,200	0.46%	346,360	2.72%	1,608,900	9.30%
France	0.6419	38,285	0.47%	224,700	2.77%	1,098,100	9.65%
U.K.	0.4579	27,739	0.50%	158,200	2.88%	765,730	9.97%
Italy	0.4508	27,567	0.47%	158,460	2.73%	748,960	9.39%
Luxembourg	0.0066	440	0.51%	2,524	2.98%	12,657	10.37%
Netherlands	0.1682	10,664	0.43%	60,470	2.46%	293,930	8.48%
Sweden	0.1013	6,141.9	0.47%	35,745	2.71%	176,790	9.51%
Standard Deviation	——	18,708	——	109,440	——	513,960	——

	Electronics					
	50%		75%		90%	
	Value	Cum. %	Value	Cum. %	Value	Cum. %
Austria	687	0.68%	3,624.0	3.67%	16,284	11.89%
Belgium	859	0.73%	4,657.6	3.93%	20,872	12.74%
Switzerland	1,070	0.69%	5,631.5	3.63%	25,050	11.71%
Germany	18,086	0.67%	95,252	3.65%	413,060	11.67%
France	9,794	0.72%	52,364	3.89%	236,880	12.68%
U.K.	6,048	0.70%	31,858	3.74%	146,800	12.25%
Italy	6,002	0.69%	31,794	3.74%	142,180	12.08%
Luxembourg	17	0.68%	90	3.69%	411	11.97%
Netherlands	1,526	0.69%	8,053	3.69%	35,718	11.88%
Sweden	738	0.69%	3,954	3.74%	17,964	12.22%
Standard Deviation	5,773	——	30,473	——	133,360	——

Note: Table 4 reports the distribution of the initial patent returns (prior to the designation decision being made) in each of the 10 EPO member countries, based on a simulation run of 50,000 draws of pharmaceutical patents and 100,000 draws of electronics patents. Columns 3, 5, 7, 9, 11 and 13 display the initial returns of the patents, and columns 4, 6, 8, 10, 12 and 14 display the cumulative proportions of the initial returns in the total initial returns of the simulated patent group in each country. All monetary values are in units of 1997 U.S. dollars.

Figure 8: Simulated and Actual Designation Rates

Pharmaceutical Patents



Electronics Patents

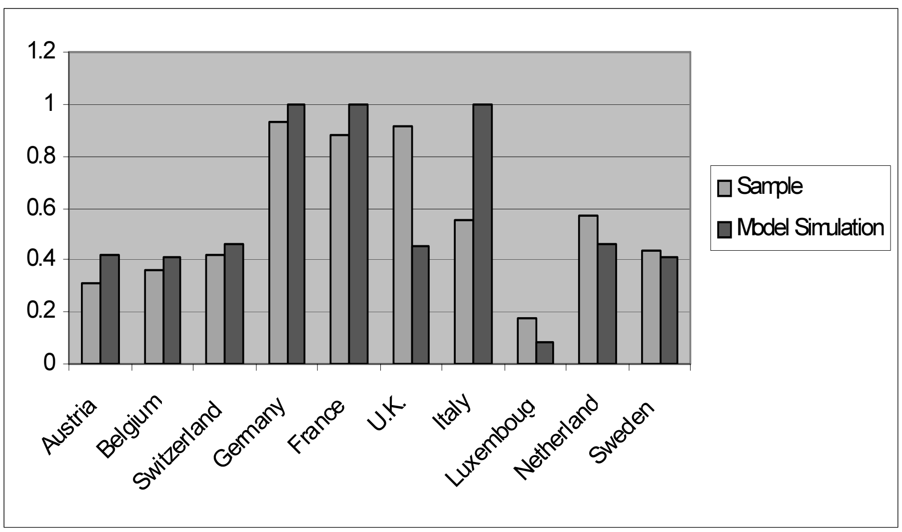


Table 4 also reveals that the distribution of the initial patent returns is highly skewed. For instance, in Germany, the sum of initial returns of the bottom 50% of pharmaceutical patents applications contributes less than 0.5% of the total initial returns of the whole pharmaceutical group, and over 90% of the total initial returns is attributed to the top 10% patents. The bottom 50% of electronics patent applications contributes only 0.7% of the total initial returns of the whole group in Germany, while the top 10% contributes 88% of the total initial returns. The distribution of the initial returns in other countries has a similar pattern.

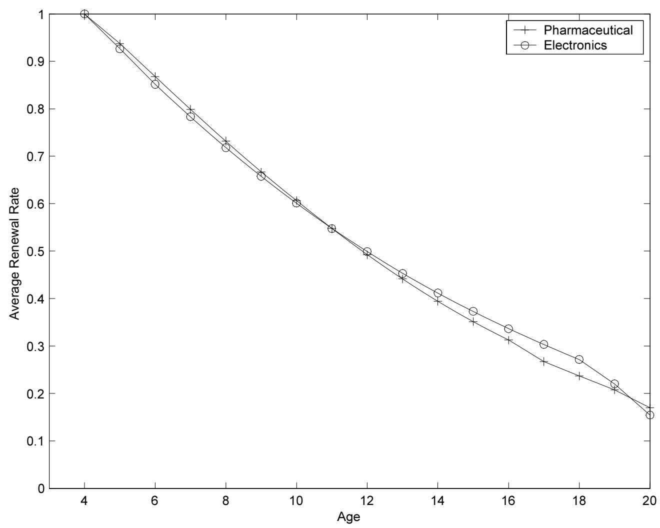
Patent Renewal Decisions

Figure 9 compares the renewal rate averaged across different countries in both groups at each age, weighted by the number of patents transferred to each country. Endowed with higher initial returns and learning probabilities, the pharmaceutical patents have a higher renewal rate than electronics patents at early ages. However, a higher depreciation rate (13%) and more rapidly decaying learning probabilities depreciate the expected value of pharmaceutical patents more quickly, and as a result thrir renewal rate becomes lower at later ages. As show in Figure 9, the average renewal rate of pharmaceutical patents is about 1 to 2 percentage points higher than that of electronics patents at each age until age 10, however after age 11 electronics patents have a higher renewal rate. For instance, 28% of the simulated electronics patents live up to age 18, while only 23% of the simulated pharmaceutical patents are still alive by then.

The depreciation dynamics plays a vitally important role in the evolution of patent value over time and consequently in the patentees' renewal decision making. Different depreciation rates of these two groups may come from the different characteristics of technological competitions in these two fields. Pharmaceutical patents are often based on "discrete" technologies which are more likely to be exclusively utilized in the production of the final products such as drugs. Drugs treating the same diseases are substitutes: when a new drug is introduced, it quickly becomes a competitor to the existing ones and erodes their market shares. As a result the value of the old pharmaceutical patents significantly depreciate once a new patent is born in the same area. In contrast, new technologies in the electronics industries are often the results of some successive technological innovation process ("complex" technologies as explained above), and the patent owners often profit from the patented ideas through cross-licensing agreements. As Levin, Klevorick, Nelson and Winter (1987) point out, a firm's bargaining power in negotiating cross-licensing agreements depends on the relative size of its patent portfolio. Thus, the electronics patent owners would have a strong incentive to maintain the size of their patent portfolio, as under asymmetric information this would strengthen their bargaining power. As the quality of patents in the portfolio is heterogeneous, there are some low-quality or "lemon" patents not worth being renewed at some point. However at the equilibrium the owner of the patent portfolio may still choose to "over renew" these "lemon" patents, as doing so will increase the size of his patent portfolio and subsequently increase his bargaining power. Thus the average renewal rate of electronics patents would tend to be higher, *ceteris paribus*.[20]

Interestingly, at very late ages (age 19 and 20), the simulated average renewal rates in both groups converge. This may reflect the existance of some "elite patents" in both groups, whose values are so high that their owners may choose to renew for a full 20 years despite the huge renewal costs. Figure 9 indicates that these "elite patents" account for about 17% of total patents in both groups.

Figure 9: Average Renewal Rates of the Simulated Patents



[20] In addition to possible "over renewal", an electronics firm may also have an incentive to "over patenting" (seeking patent protection for some "lemon" inventions otherwise will not be worth patenting), as doing so will also increase the size of his patent portfolio and strengthen his bargaining power. This is consistent with the empircal observation of numerous patents held by electronics firms and laboratories, and possibly also explain why an average electronics patent has lower value than pharmaceuticals in our estimates — because their values are "diluted." Of course, whether the patent applications of these "lemon" inventions will be approved is another question. The examination and granting process is assumed to be independent of the patent quality in this paper. However, even if the granting process is modeled as an endogenous process in which the applicant bargains with the patent examiner, at the equilibrium we may still find "over patenting," as the electronics firms will have incentives to devote more resources in bargaining with patent examiners for "lemon" inventions than, say, pharmaceutical firms.

How Valuable are the EPO Patents?

Finally we explore how much net value an EPO patent applicant expects to receive throughout the patent's whole life, conditional on the patent applications will be granted. Here the net value of a patent (indeed the value of a patent family based on the same invention) is defined as the discounted sum of patent returns at all ages (from initial application till patent lapses) in all EPO member countries that the patentee may designate, net of all kinds of administrative expenses including designation and translation expenses as well as the annual renewal fees when applicable, but not litigation costs.

Table 5 reports the percentiles and Lorenz curve coefficients from the simulated value distribution. Columns 2 and 3 of the table show that the distribution of the net value of pharmaceutical patents is highly skewed. For instance, 25% of the pharmaceutical patents have a value of $27,400 or less, while they contribute about 0.02% of the total value of all simulated pharmaceutical patents. The bottom 50% of pharmaceutical patents accounts for only 0.40% of the total value of the whole group, and the lower 90% contributes about 16% of the total value. On the other hand, the top 1% most valuable patents, with a minimal value of $142 million, accounts for 46% of the total value. Similarly, the distribution of the net value of electronics patents, as reported in columns 4 and 5, is also highly skewed. For instance, the lower 90% of the electronics patents contributes less than 15% of the total value of the electronics group, whereas the top 1% contributes 51% of the total value. On the other hand, electronics patents have significantly lower value than pharmaceutical patents, especially at the high end of the value distribution. For instance, the 85% percentile of the value of pharmaceutical patents is $8.4 million, nearly 4 times of that of electronics patents, which is $2.2 million.

It is worth noting that the distribution of the simulated patent value in Table 5 is much more skewed than the ones estimated in previous studies. For instance, in Pakes (1986), the top 1% most valuable patents accounts for 16% of the total value in France, 12% in the U.K., and 10% in Germany. Lanjouw (1998) estimates that in Germany the top 1% accounts for 8% to 10% of the total values in different technology fields, and Schankerman (1998) reports that in France the top 1% accounts for 12% of the total value in pharmaceutical and 24% in electronics patent groups. In contrast, Table 5 indicates that the top 1% accounts for about half of the total value in both pharmaceutical and electronics patent groups in our sample.

Table 5: Distribution of the Net Value of Simulated Patents

	Pharmaceutical		electronics	
Percentile	Value ($million)	LC	Value ($million)	LC
25%	0.0274	0.02	0.0111	0.04
50%	0.4078	0.40	0.1155	0.46
75%	3.5906	4.42	0.8792	3.95
85%	8.4145	10.28	2.1831	9.17
90%	14.6810	16.14	3.9041	14.57
95%	31.6340	27.45	8.8216	25.39
98%	77.1490	42.73	21.6860	40.49
99%	142.3800	53.71	39.6020	51.15

Note: Columns 2 and 4 report the percentiles of the distribution of the total realized patent values in all 10 EPO member countries from the simulation. Columns 3 and 5 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.

There is a clear conceptual distinction between the above estimates and those reported in the previous national studies. Table 5 displays the distribution of the sum of patent values in all ten EPO member countries, i.e., the net value of a patent family, whereas all the studies above focus on the patent value in one single country. Therefore, the larger skewness in our estimation reflects the fact that within each group *holders of more valuable inventions not only choose to keep their patents alive for longer in one country, but also seek for patent protections in more countries.* The latter introduces a second source of skewness and consequently the distribution of total patent value becomes more skewed than the ones from the previous studies.

5. Concluding Remarks

This paper formulates a dynamic stochastic model to examine the joint patent application and renewal behaviors under an international patent-protection regime. The model takes a first step in utilizing both the cross-sectional (multi-country filing) and the time-series (patent renewal) dimensions of international patent data to evaluate the private value of patents in a unified structural framework, allowing us to examine the correlations between the patent family sizes and the length of patent lives, and advancing our understanding of how the patent value changes over time as well as across different countries.

The model is estimated using the designation and renewal records of the pharmaceutical and electronics patent applications filed with the European Patent Office during 1980 to 1985.

Estimation results suggest that pharmaceutical patent applicantions on average are endowed with higher initial returns, and the patent applicants seek for protection in more countries than the electronics patent applicants. However, pharmaceutical patents depreciate faster than electronics patents, and consequently they have lower renewal rates and shorter patent lives. We also find that the patent values in different countries are highly correlated with the market size of the country, and the patents in the two technology fields exhibit different scale of economy. In addition, compared with the national patents studied in previous literature, inventions filed with the EPO have a more skewed value distribution and a longer learning process of their own values.

A direct application of the our estimation results would be to construct of a simple “weighting index” that measures the relative value of different patents using the patent family sizes and the length of patent lives, which is more accurate than simple patent counts as a measure of innovative output in analyzing the R&D efficiency. On the other hand, although combining the patent application and renewal data reveals more aspects of patent value, the patent renewal data are not available until later stage of a patent’s life. For evaluation of patents at earlier ages, it is therefore useful to exploit other characteristics of patent data available at or near the patent’s “birth”, such as the number of patent claims or patent citations. A study of the linkage between these characteristics and the estimated patent values from this study would also provide further insights into the value of patents. These will be topics for future research.

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