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# The License of Right, Compulsory Licensing and the Value of Exclusivity

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**Abstract**

This paper uses the License of Right (LOR) provision implemented in Section 23 of the German Patent Act to answer the following questions: What is the distribution of the private value of the right to exclude others provided by a patent? What are the welfare implications of having a License of Right system? Section 23 of the German Patent Act grants a patentee a 50% reduction on the annual renewal fees if he voluntarily allows anyone to use the invention only in return for reasonable compensation. We build a parametric discrete choice model of patent renewal and LOR declaration to exploit data on granted German patent applications from 1983-1988. Our estimates show that the distribution of the value of the right to exclude others is very skewed and its relative importance rises with patent age. For most patent owners the exclusion right is very valuable. Nevertheless, for a small fraction of patents a commitment to license non-exclusively may even increase the returns from patent protection. The welfare implications of the License of Right system in Germany are twofold. It increases the private value of patent rights but lowers the patent office's revenues. Furthermore, we are able to distinguish between two motives for declaring LOR, the cost-saving and the commitment motive. The fraction of declarations made out of the cost-saving motive is relatively low for young patents but increasing with patent age. In a counterfactual experiment we simulate the impact of making LOR declarations compulsory. We show that a compulsory licensing system could deprive the patent owners of a very substantial part of the incentives currently provided by the patent system.

**Keywords:** value of exclusivity, patent valuation, license of right, compulsory licensing, patent renewal model

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# 1 Introduction

By definition a patent is an exclusion right over an invention granted by society for a limited period of time. In exchange, the patent applicant is obliged to disclose all technical information on the claimed invention to society. If the patent protects exactly one product and knowledge is not cumulative, the following economic trade-off ensues: On the one hand, the protection against competition from others should increase the incentives of the inventor to invest in innovative activities and the obligation to disclose his invention should promote the dissemination of knowledge (dynamic efficiency). On the other hand, the right to exclude others may create temporary monopoly power and impose a welfare loss on society (static inefficiency).

However, recent theoretical as well as empirical economic literature has recognized that at least two of the assumptions on which the traditional economic trade-off described above is based on may often fail in reality. Most of the innovation activities are inherently cumulative (Scotchmer 1991) and products are often covered by multiple patent rights (Heller and Eisenberg 1998). In this case two additional opposed welfare effects arise.[1] On the one hand, patents may even increase competition by helping to establish a market for knowledge. They can be traded as an input good as well as facilitating entry of new competitors hence improving static efficiency. On the other hand, in the new setting the exclusivity right gets a new leverage. If an inventor is excluded from the use of patents his invention builds on, or if the access to all complementary patents needed for commercialization is denied, he will not be able to appropriate any returns. To reduce the fragmentation threat firms may even increase their "defensive" patenting activities (Ziedonis 2004) creating an even denser net of patent rights. This behavior can considerably hamper dynamic efficiency. Already existing knowledge will remain underused and inventors can be discouraged to invest in the combination of new ideas and inventions. Thus, the question arises how to reduce the economic distortions created by the exclusive right conferred by a patent while maintaining the positive incentive effects to inventors.

One possible approach to tackle the problem is to increase access to patented inventions by reducing the exclusivity rights of patentees. Alongside private solutions–such as standards, clearing houses, and patent pools where patent owners transfer their rights into a bundle which can be licensed by others–several institutional initiatives have been discussed.[2] Two prominent examples are Compulsory Licensing (CL) and Licenses of Right (LOR). Both systems are based on the idea of transforming the patent right from an absolute permission rule with a right to exclude others (Merges 1996) into a liability rule, where the patent

[1] See Hall and Harhoff (2012) for an extensive discussion.
[2] See Schovsbo (2009) for an overview.

owner has only a right to reasonable remuneration, i.e., licensing revenues. The CL system requires the patent owner by law to make licenses available to any party requesting a license. Although it clearly reduces the degree of exclusivity CL may considerably reduce the profits from patent protection and diminish the incentives to engage in innovative activities. In contrast, LOR is a system where the patent may, at the request of its owner, be transformed into a liability rule. However, it is rather unlikely that patentees would voluntarily give up their right to exclude others, unless the legislator provides appropriate incentives. To be able to analyze both systems economically and derive possible welfare statements it is necessary to know the distribution of the returns from patent protection. But even more important is to know which part of the value can be attributed to the right to exclude others and which part can be sustained with only a right to reasonable remuneration.

Hence, the aim of this paper will be twofold. First, we will present a framework for estimating the distribution of the value of exclusivity using German patent data. Second, we will use the estimation results to evaluate the welfare effects of the LOR system as implemented in Germany. We will further calculate the patent owners' losses in private value associated with the introduction of a CL system.

The License of Right or "Willingness to License" was introduced on October 01, 1936 into the German patent system. It is stated in Sec. 23 of the German Patent Act that "[i]f the applicant for a patent or the person recorded as patentee [...] declares to the Patent Office in writing that he is prepared to allow anyone to use the invention in return for reasonable compensation, the annual [maintenance] fees falling due after receipt of the declaration shall be reduced to one half [...]."[3]

In Germany, License of Right is declared for almost 6% of all granted patent applications. However, the usage rates differ highly across technology areas as well as across applicant types. In the area of electrical engineering LOR is declared for over 11% of all patents whereas in the area of chemistry and biotechnology the usage rate is 1.3%. More than 12% of patents filed by large corporations and only less than 2% of patents filed by small corporations are endorsed LOR when they expire.

Assuming rational behavior, the patent applicant will only declare LOR if his expected returns from patent protection without the right to exclude net of the reduced renewal fees will exceed the expected returns from full patent protection net of the regular renewal fees. The difference between the returns from full patent protection and the returns from patent protection without the right to exclude others is what we define as the value of exclusivity. We will use the decision to declare LOR taken by the patent owner to identify the distribution

[3]If the parties are unable to agree on a compensation scheme it can be assessed by the Patent Division at the written request of one of the parties. This makes the provision enforceable for the patent owner as well as the potential licensee.

of the value of exclusivity for German patents.

To perform the estimations we will develop a model of patent renewal and LOR declaration. This model extends the traditional patent renewal models first developed in Pakes and Schankerman (1984), Pakes (1986), and Schankerman and Pakes (1986). The traditional patent renewal models are discrete choice models which incorporate a patentee's optimal decision when to let his patent expire in order to estimate the distribution of the private value of patent protection. Given that for each additional year of patent protection the patentee has to pay renewal fees, he will only maintain patent protection as long as these yearly fees do not exceed his expected returns from having a patent. We extend this framework and allow for a third option, the declaration of LOR. Similar to the German provision, if the patentee chooses the third option, the maintenance fees will be reduced, and he will lose the right to exclude others. Thus, the decision to declare or not to declare LOR ought to contain information about the private value of exclusivity. The model is subsequently estimated using a simulated general method of moments estimator (SGMM).

Subsequently, we employ the estimated parameters to evaluate the effects of two hypothetical policy changes. First, we consider the abolishment of the LOR option from the German patent system. From this experiment we learn about the effects of LOR on the private value of patent protection and on the German patent office's revenues. Patent maintenance fees are usually one of the main sources of patent office finance. In our second experiment we introduce a compulsory licensing requirement for all patents from the application day on. This allows us to estimate the costs imposed on the patent holders by a CL system.

The outline of the paper is as follows. In the next section we develop the patent renewal model incorporating the decision to declare LOR. Section 3 presents the estimation strategy and the stochastic specification. The data are described in Section 4. In Section 5 and Section 6 we discuss the estimation results and its implications. Section 7 concludes.

## 2 The Model

**Patent system** An agent can acquire a patent with full protection, which allows him to exclude others from the patented invention. Keeping patent protection–we will call it strategy (K)–is not free of charge and the agent must pay renewal fees $c_t = f_t$ at the beginning of each period $t \in 1, ..., T$. $T$ is the maximum number of years a patent is allowed to be renewed. If he decides not to pay the fees the patent will expire (X) forever. As is common in most patent systems, the fees are rising with a patent's maturity $f_t \leq f_{t+1}$. Alternatively, the patentee can switch to the License of Right regime which we will call strategy (L). Contrary to the full protection regime, it prohibits excluding others from the invention but maintains the right to reasonable remuneration through licensing. In turn, the patent owner is only required to pay half of the statutory renewal fees $c_t = \frac{1}{2} f_t$. We further assume that once LOR has been declared, the patentee can never return to full patent protection. He can either renew within the LOR regime (L) or let the patent expire (X).

We also assume that each patent belongs to exactly one agent. Furthermore, all agents are rational in the sense that in the beginning of each period they will choose the regime that will maximize their expected profits given the available information.

**Evolution of returns** We assume that a patent generates returns $z_t$ in each year $t$ which depend on the type of patent protection. Returns are 0 if the patent expires, $z_t = 0$. The per period returns in case of full patent protection, $z_t = r_t$, differ from those of a patent endorsed LOR by a multiplicative factor $g_t^l$ such that $z_t = y_t = g_t^l r_t$. The factor $g_t^l$ represents the fraction of the returns which can be realized by a patent without the right to exclude others. This means in turn that $(1-g_t^l)r_t$ corresponds to the returns that can be derived from exclusivity. We allow $g_t^l$ to exceed 1. It might well be that the commitment to non-exclusive licensing may even increase the patentee's revenues.[4]

The yearly returns are not constant and evolve over time in the following way:

- In the beginning of a patent's life an initial return from full patent protection, $r_1$, is assigned to each patent. Let $r_1$ be drawn i.i.d. from a continuous distribution $F_{IR}$ on a positive domain.

- The returns from full patent protection in the following years $r_t$, $t \in 2, ..., T$, change over a patent's life cycle. We assume that they evolve from the previous period such that $r_t = g_t^k r_{t-1}$, where $g_t^k \in \left[0, B^k\right]$ is the growth rate of returns in case of full patent protection.[5] A growth rate $g_t^k < 1$ represents a depreciation, whereas $g_t^k > 1$ represents an increase of the revenues from full patent protection. The growth rates are drawn i.i.d. from continuous distributions with the cumulative density functions $F_{g^k}(u^k|t) = Pr\left[g_t^k \leq u^k\right]$, $t \in 2, ..., T$. We assume that the probability to have a high growth rate $g_t^k$ and to discover a way to increase the returns compared to the previous year decreases with the patent's maturity in the sense of first-order stochastic dominance $(F_{g^k}(u^k \mid t) \leq F_{g^k}(u^k \mid t+1))$.[6]

- The shares of returns which can be realized in a LOR regime $g_t^l \in \left[0, B^l\right]$, $t \in 1, ..., T$, are drawn i.i.d. from yet other distributions with the cumulative density functions

[4] See Rudyk (2012) for a discussion.

[5] This stochastic specification fulfills the Markov property. This means that the returns in the future periods are independent of past periods' returns.

[6] Usually, the application and usage of an invention is determined early in a patent's life. The probability to discover new uses in later periods should hence decrease over time.

$F_{g^l}(u^l|t) = Pr\left[g_t^l \leq u^l\right]$, $t \in 1, ..., T$. Furthermore, we assume that the probability to have a high LOR growth rate is also decreasing with the patent's age throughout all periods in the sense of first-order stochastic dominance $F_{g^l}(u^l \mid t) \leq F_{g^l}(u^l \mid t+1)$.[7]

- We assume that the patentee has perfect information about the distributions of all future growth rates in all regimes but that the per period returns $z_t$, i.e, the growth rates $g_t^k$ and $g_t^l$, are revealed to him only in the beginning of each period $t$.

**Maximization problem** The agent has to choose the strategy with the highest expected value in the beginning of each period, since this is when the renewal fees are due. His value functions in each regime will consist of returns and costs from the current period as well as the option value of his choices in future periods. We define $\widetilde{V_K}(t, r_t, y_t)$ as the value function of the patentee's optimal strategy in year $t$ if the patent has been renewed with full patent protection (K) in all previous periods. In this case the patent owner can choose between all three strategies, (K), (L), and (X). Similarly, $\widetilde{V_L}(t, y_t)$ is the value function of the patentee's optimal strategy in year $t$ if LOR, i.e., strategy (L), has been declared in one of the previous periods and strategy (K) in all periods preceding the declaration. In this case he can only choose between strategy (L) and (X) for the following year.

Consider now a patent in the beginning of year $t$, $t < T$, which has been renewed with full patent protection in all previous periods. The patentee has three choices. He can either keep full patent protection (K), declare LOR (L), or let his patent expire (X). If he decides not to pay the renewal fees in this period and lets his patent expire (X) his returns from this strategy, $\widetilde{V}^X(t)$, will be 0:[8]

$$\widetilde{V}^X(t) = 0$$

If the agent decides instead to renew the patent with full patent protection (K) his value function will consist of the returns in the current period $r_t$, net of the renewal fees $f_t$, plus the discounted option value of having the full strategy choice–strategies (X), (K), and (L)–in the subsequent period. The option value will be a function of the current returns $r_t$. With $\beta$ as the discount factor between the periods we get the following value function for strategy (K):

$$\widetilde{V}^K(t, r_t) = r_t - f_t + \beta E\left[\widetilde{V_K}(t+1, r_{t+1}, y_{t+1}) \mid r_t\right] \tag{1}$$

[7] This is just a simplifying assumption. Nevertheless, in the estimations below we will allow for the possibility that the probability to have a higher LOR growth rate may increase with a patent's age. We will test the assumption using German patent data.

[8] $\widetilde{V}^i(.)$, $i = K, L, X$ denotes the value function in case the patentee would choose strategy $i$. It does not mean that this is his optimal strategy in the corresponding year.

with

$$E\left[\widetilde{V_K}(t+1, r_{t+1}, y_{t+1}) \mid r_t\right] = \int\int \widetilde{V_K}(t+1, u^k r_t, u^l u^k r_t) dF_{g^k}(u^k \mid t) dF_{g^l}(u^l \mid t)$$

and

$$\widetilde{V_K}(t+1, r_{t+1}, y_{t+1}) = max\left\{\widetilde{V}^K(t+1, r_{t+1}), \widetilde{V}^L(t+1, y_{t+1}), \widetilde{V}^X(t+1)\right\}$$

If instead he decides to declare LOR (L), his current returns from patent protection will equal $y_t = g_t^l r_t$. The renewal fees for all following years will be reduced by half. He will also lose the right to return to the full protection regime (K). The patentee will only be able to renew his right to reasonable remuneration (L) or to let the patent expire (X). We assume that once the declaration has been made the LOR growth rate $g_t^l$, which is the share of profits without the right to exclude, remains constant in the following periods. This means that if LOR has been declared in year $a$ and the patent is allowed to expire in year $b$, it must be that $g_t^l = g_a^l$ for all periods $t \in \{a, a+1, ..., b\}$. The LOR growth rate varies only as long as LOR has not yet been declared. The justification for this assumption is that a declaration may go along with the conclusion of licensing agreements. This means that the potential for non-exclusive licensing will be determined at this stage for all future periods. The option value, $E\left[\widetilde{V_L}(t+1, y_{t+1}) \mid r_t, g_t^l\right]$, will now depend on the current returns $r_t$ from full patent protection as well as the LOR growth rate $g_t^l$ from the period of declaration. Thus, the value function for a patentee who chooses to declare LOR (L) is:

$$\begin{aligned} \widetilde{V}^L(t, y_t) &= y_t - \tfrac{1}{2} f_t + \beta E\left[\widetilde{V_L}(t+1, y_{t+1}) \mid r_t, g_t^l\right] \\ &= g_t^l r_t - \tfrac{1}{2} f_t + \beta E\left[\widetilde{V_L}(t+1, g_t^l r_{t+1}) \mid r_t\right] \end{aligned} \tag{2}$$

with

$$E\left[\widetilde{V_L}(t+1, g_t^l r_{t+1}) \mid r_t\right] = \int \widetilde{V_L}(t+1, g_t^l u^k r_t) dF_{g^k}(u^k \mid t)$$

and

$$\widetilde{V_L}(t+1, y_{t+1}) = max\left\{\widetilde{V}^L(t+1, y_{t+1}), \widetilde{V}^X(t+1)\right\}$$

Now that we have stated the value functions we will describe the solution to the maximization problem. Since the maximum number of years a patent can be renewed is finite, $T < \infty$, the option value in the last period is always 0 independent of the protection regime. Thus, the model can be solved by backward recursion determining an agent's optimal decision in each period.

The agent's optimal decision in each year $t$ is fully determined by the size of the per period returns $r_t$ and the LOR growth rate $g_t^l$ (and thus $y_t$). Dependent on whether these returns will exceed certain threshold values or not, the patentee will either choose to keep full patent protection (K), to declare LOR (L), or to let it expire (X):

- $\{\hat{r}_t\}_{t=1}^T$ : patent returns that make the agent indifferent between keeping a patent with full patent protection (K) in year $t$ and letting it expire (X). It is defined by $\widetilde{V}^K(t, \hat{r}_t) = 0$.[9]
- $\left\{\hat{g}_t^{l-}(r_t)\right\}_{t=1}^T$ : growth rates that make the agent indifferent between declaring LOR (L) and letting a patent expire (X) in year $t$. It depends on the level of returns $r_t$ from full patent protection and is defined by $\widetilde{V}^L\left(t, \hat{g}_t^{l-} r_t\right) = 0$.
- $\left\{\hat{g}_t^{l+}(r_t)\right\}_{t=1}^T$: growth rates that make the agent indifferent between declaring LOR (L) and keeping full patent protection (K). It depends on the level of per period returns $r_t$ from full patent protection and is defined by $\widetilde{V}^K(t, r_t) = \widetilde{V}^L\left(t, \hat{g}_t^{l+} r_t\right)$.

The following lemma guarantees that these threshold values exist and are unique.

**Lemma 1.** *The value functions $\widetilde{V}^K(t, r_t)$ and $\widetilde{V}^L(t, y_t)$, with $t = 1, ..., T$, are*
*(i) increasing and (ii) continuous in the current returns $r_t$ and $y_t$,*
*(iii) and non-increasing in $t$.*

*Proof.* See Appendix A.1. □

All three vectors of cut-off functions define the strategy space for a patent owner in each year. Consider a patent that has been renewed with full protection up to period $t$. The patentee can now choose between all three strategies: (K), (L), and (X). As one can see in Figure 1 the cut-off functions $\hat{r}_t$, $\hat{g}_t^{l+}(r_t)$, and $\hat{g}_t^{l-}(r_t)$ divide the $(r_t, g_t^l)$-space in exactly three regions. Letting the patent expire (X) will be the optimal strategy if and only if the current per period returns $r_t$ as well as the LOR growth rate $g_t^l$ will both be lower than their corresponding threshold values $\hat{r}_t$ and $\hat{g}_t^{l-}(r_t)$ (the region in the lower left corner in Figure 1). In this case renewal in any regime, (L) or (X), would not justify the costs of renewal. If in turn the current per period returns from full patent protection are high enough, $r_t \geq \hat{r}_t$, renewal will be optimal in any case. The agent will renew with full patent protection (K) as long as the LOR growth rate is not too high, $g_t^l < \hat{g}_t^{l+}(r_t)$. These patents are located in the lower right part of the figure. A declaration of the willingness to license (L) will be the optimal strategy if the LOR growth rate is high enough, such that $g_t^l \geq \hat{g}_t^{l+}(r_t)$. We call

[9] Remember that $\widetilde{V}^X(t) = 0$ throughout all periods.

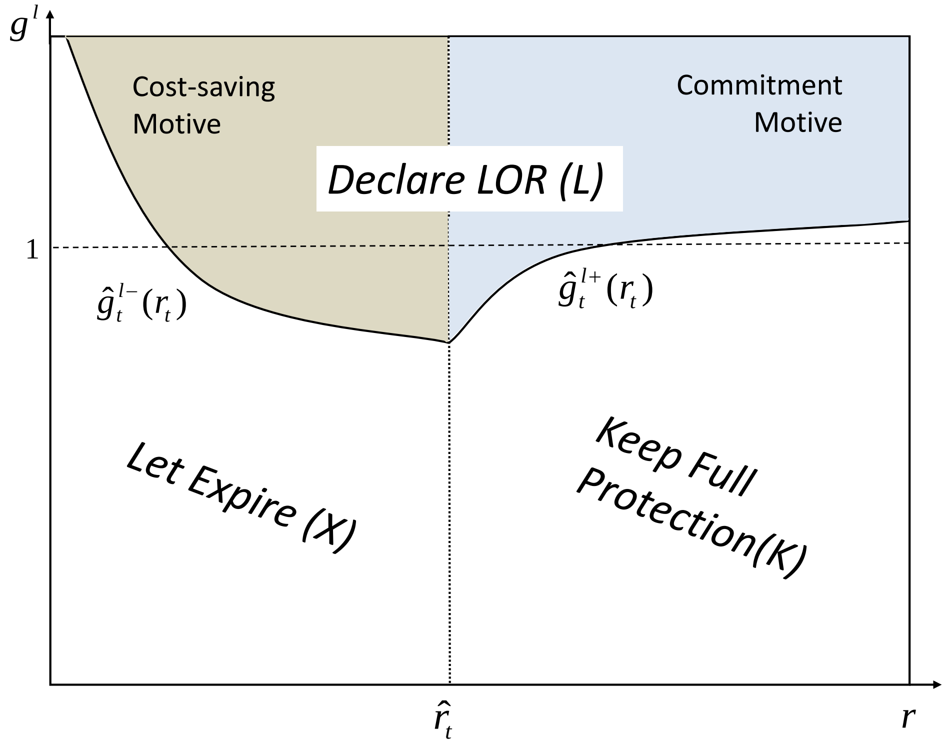


Figure 1: Strategy Space of a Patent with Full Protection

this the commitment motive for LOR declaration. By committing to license non-exclusively and simultaneously reducing all future renewal fees the patentee can improve his expected profits. In this case he will declare LOR instead of keeping full patent protection. These patents are located in the upper right part of the figure. Patentees can also declare LOR out of the cost-saving motive. These are all patents which are situated in the upper left part of the figure. If the current per period returns are too low, $r_t < \hat{r}_t$, such that renewal with full patent protection will never be optimal, the patentee may still declare LOR. As long as he can sustain a sufficient part of the returns without the exclusion right, i.e., $g_t^l \geq \hat{g}_t^{l-}(r_t)$, the reduction in future renewal fees can turn the LOR declaration into a profitable strategy.

Consider now a patent that has been renewed up to period $t$ and for which LOR was declared in year $a$, $a < t$. The patentee has only two options, he can either renew the patent endorsed LOR (L) or let it expire (X). In this case $\hat{y}_t = g_a^l r_t$ are the minimum revenues that a patent endorsed LOR has to generate in this period for the patentee to keep patent protection.[10] We can rewrite $\hat{y}_t$ as a function in the $(r_t, g_t^l)$-space. Thus, given per period returns $r_t$, all patents already endorsed LOR with growth rates $g_a^l \leq \hat{g}_t^{l-}(r_t)$ will not be renewed (see Figure 2).

[10] $\hat{y}_t$ is defined in $\widetilde{V}^L(t, \hat{y}_t) = 0$.

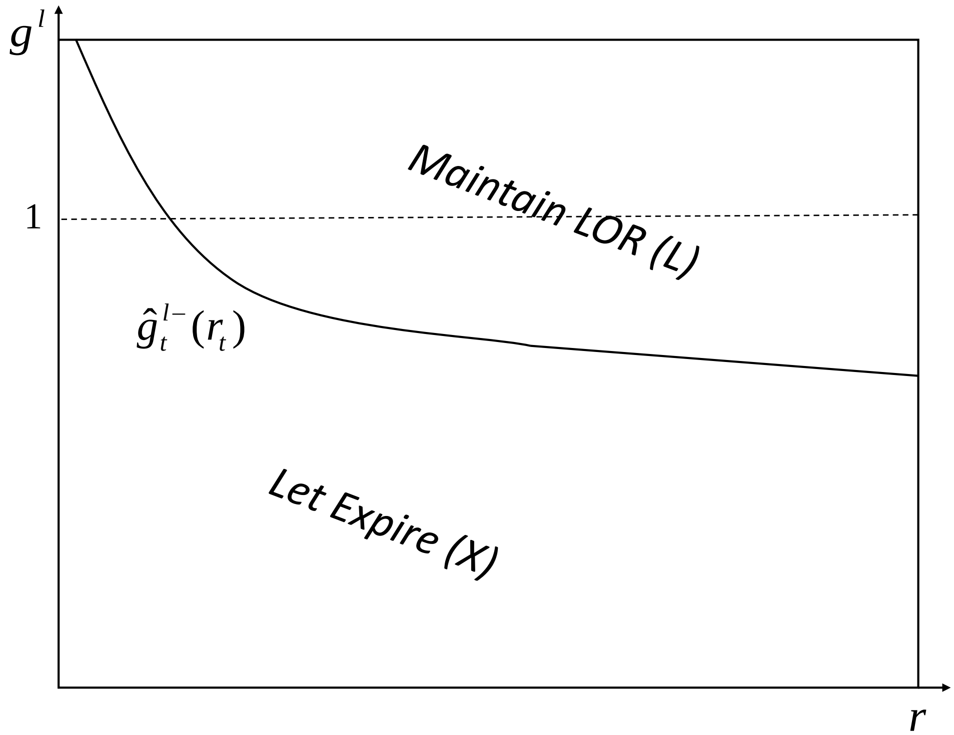


Figure 2: Strategy Space of a Patent Endorsed LOR

## 2.1 Comparative Statics

This section analyzes how the returns from patent protection $r_t$–we call it selection effect–and the age of a patent $t$–we call it horizon effect–determine the agent's strategy space.

**Selection effect** The selection effect tells us how the probability to observe a declaration of LOR varies with changes in returns from full patent protection $r_t$.

**Proposition 1.** *If it holds that*[11]

$$1 + \beta \frac{\partial \left\{ E\left[ \widetilde{V_K}(t+1, g^k_{t+1} r_t, g^l_{t+1} g^k_{t+1} r_t) \right] - E\left[ \widetilde{V_L}(t+1, \hat{g}^{l+}_t(r_t) g^k_{t+1} r_t) \right] \right\}}{\partial r} > \hat{g}^{l+}_t(r_t)$$

*then*

*(i)* $\hat{g}^{l-}_t(r_t)$ *will be decreasing in* $r_t$ *and*

*(ii)*$\hat{g}^{l+}_t(r_t)$ *will be increasing in* $r_t$.

*Proof.* See Appendix A.1. □

[11] We have checked this assumption for the stochastic specifications which we use for the structural estimations. Simulations have shown that this condition is always satisfied at reasonable parameter values.

Assume that an agent has renewed his patent up to period $t$. There are two cases to be considered. If $r_t < \hat{r}_t$ the patentee has to decide whether to declare LOR (L) or to let it expire (X). He will only declare LOR if the current returns from a patent endorsed LOR, $y_t = g_t^l r_t$, and the option value, $E\left[\widetilde{V_L}(t+1, \hat{g}_t^{l+} g_{t+1}^k r_t)\right]$, are high enough to cover the renewal fees $\frac{f_t}{2}$. We know from Lemma 1 that the option value is non-decreasing in per period returns $r_t$. Thus, the higher $r_t$, the lower can be the share of returns realized during the LOR regime, $g_t^l$, such that the agent is still willing to renew the patent. This is why the threshold value functions $\hat{g}_t^{l-}(r_t)$ decrease in $r_t$ in the respective region (see Figure 3). If the returns from full patent protection are high enough, $r_t \geq \hat{r}_t$, the agent will choose between strategy (K) and strategy (L). Now, the higher the per period returns $r_t$, the less important will be the reduction in renewal fees relative to the potential reduction in expected (future) returns due to the loss of exclusivity. Therefore, a high growth rate $g_t^l$ is needed for the patentee to choose LOR for valuable patents. This is represented by an increasing function $\hat{g}_t^{l+}(r_t)$ in Figure 3. To sum up, if the returns in case of full patent protection with the right to exclude others are relatively low, the probability of observing a declaration $Pr(g_t^l \geq \hat{g}_t^{l-}(r_t) \mid r_t < \hat{r}_t)$ in year $t$ will be increasing with $r_t$. If instead the patent is able to generate relatively high returns in case of full patent protection, the probability of declaration $Pr(g_t^l \geq \hat{g}_t^{l+}(r_t) \mid r_t \geq \hat{r}_t)$ will be decreasing in $r_t$.

**Horizon effect** In our model, by assumption not only the renewal fees but also the probability distributions vary with $t$. Consequently, the patent age should have an impact on both the decision to declare LOR (L), the decision to keep full patent protection (K), or to let the patent expire (X). This is reflected in the following propositions.

**Proposition 2.** *The cut-off values $\hat{r}_t$ are non-decreasing in $t$.*

*Proof.* See Appendix A.1. □

The threshold value $\hat{r}_t$ is only relevant for patents that kept full protection in all previous periods. It divides these patents into two categories. Those that would certainly have been dropped (patents with $r_t < \hat{r}_t$) and those that would certainly have been renewed with full protection (patents with $r_t \geq \hat{r}_t$), if the LOR system had not existed. Given that the renewal fees are increasing and the option value decreasing with $t$, the minimum returns, $\hat{r}_t$, needed to belong to the second category, will also increase with $t$ (see Figure 3).

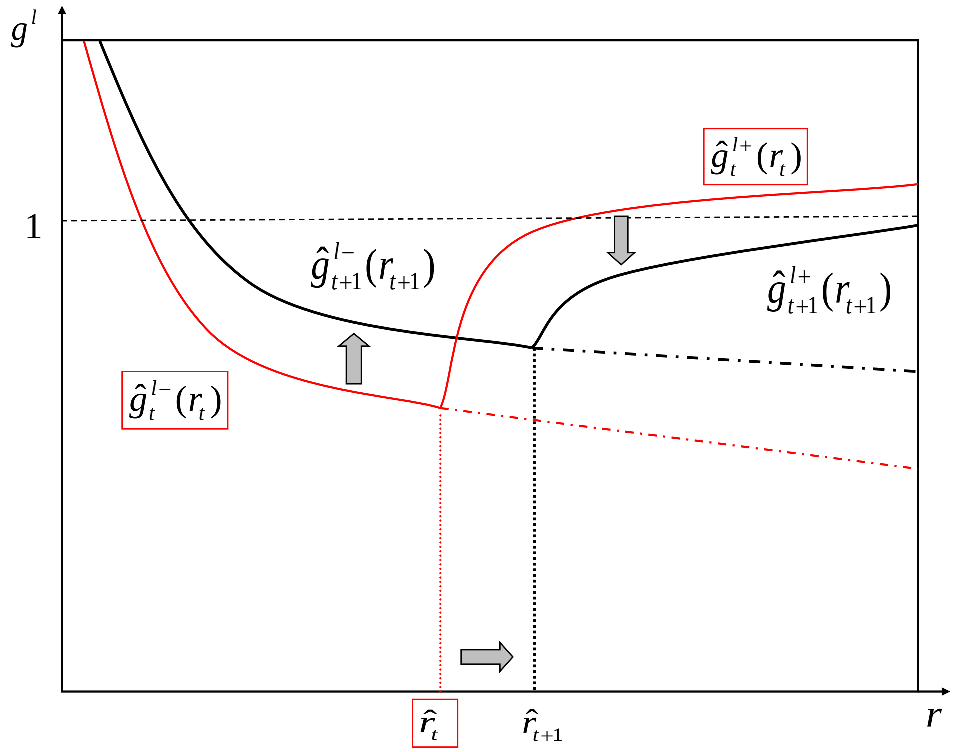


Figure 3: Selection and Horizon Effect

**Proposition 3.** *Given* $r_t$,

*(i)* $\hat{g}_t^{l-}(r_t)$ *is non-decreasing in* $t$ *and*

*(ii) the effect of* $t$ *on* $\hat{g}_t^{l+}(r_t)$ *is ambiguous.*

*Proof.* See Appendix A.1. □

Let us consider patents with relatively low returns from full patent protection ($r_t < \hat{r}_t$). For younger patents the renewal fees are lower and the option value higher than for older patents. Thus, the minimum LOR growth rate needed for the agent to renew a younger patent should be equal or even lower than the one needed for an older patent. This shifts the cut-off value function $\hat{g}_t^{l-}(r)$ upwards for older patents (see Figure 3).

For patents with higher per period returns ($r_t \geq \hat{r}_t$) the horizon effect is ambiguous and depends on the exact specification of the distributions of the growth rates. There are several countervailing effects. On the one hand, $\hat{g}_t^{l+}(r)$ should decrease as patents get older, since the maintenance fees are rising with a patent's maturity, and so is the cost difference between both regimes. Furthermore, the older the patent, the smaller will be the loss in option value (the patentee is giving up option (K)) in case of a declaration. On the other hand, $F_{g^l}(u^l \mid t)$

is decreasing in $t$, reducing the chance for older patents to draw a high LOR growth rate $g_t^l$. Thus, $\hat{g}_t^{l+}(r)$ may nevertheless increase with $t$.[12]

To sum up, patent age influences not only the probability of expiration but also the probability to observe a LOR declaration. For patents with relatively low returns from full patent protection, the probability of observing a declaration $Pr(g_t^l \geq \hat{g}_t^{l-}(r_t) \mid r_t < \hat{r}_t)$ will decrease with $t$. If instead the returns are high, the probability $Pr(g_t^l \geq \hat{g}_t^{l+}(r_t) \mid r_t \geq \hat{r}_t)$ may either increase or decrease with $t$. The probability of expiration in year $t$ is defined as $Pr(g_t^l < \hat{g}_t^{l-}(r_t) \wedge r_t < \hat{r}_t)$ for patents not endorsed LOR and $P(g_t^l < \hat{g}_t^{l-}(r_t))$ for patents already endorsed LOR. We know from Proposition 2 and Proposition 3 that $\hat{r}_t$ and $\hat{g}_t^{l-}$ are both increasing with age $t$. Therefore, these probabilities must increase with a patent's maturity.

# 3 Estimation

## 3.1 Estimation Strategy

In the first step of the structural estimation we assign a stochastic specification to our structural model which will depend on a vector of parameters $\omega$. In general, the stochastic specification we assign to our model will determine the process how the growth rates evolve over time as well as the distribution of initial returns. Although in theory a solution to the problem described above can be found analytically, it is hardly possible in practice due to the high complexity of the model. Thus, we are using a weighted simulated minimum distance estimator (SGMM) $\hat{\omega}_N$ developed by McFadden (1989) and Pakes and Polland (1989) and already applied by Lanjouw (1998) and Serrano (2011). To estimate the vector of the true parameters $\omega_0$ we will use legal events data on German patent applications. According to Lanjouw (1998) it is advantageous to fit hazard probabilities instead of mortality rates or other statistical moments.[13] The estimator is the argument that minimizes the norm of the distance between the vector of true and simulated hazard proportions:

$$A(\omega)\,\|h_N - \eta_N(\omega)\| \tag{3}$$

$$\text{with } \hat{\omega}_N = arg\,\min_{\omega} A(\omega)\,\|h_N - \eta_N(\omega)\|$$

[12] Simulation results have shown that for the stochastic specification we use for estimation the condition for $\hat{g}_t^{l+}(r)$ to be decreasing in $t$ is always satisfied.

[13] In this way we are avoiding the selection bias caused by patents which were dropped during the grant proceedings which might take more than 10 years.

- $h_N$ is the vector of sample or true hazard proportions,

- $\eta_N(\omega)$ is the vector of simulated hazard proportions (predicted by the model),

- $A(\omega) = diag\left(\frac{\sqrt{n_j/N}}{h_j}\right)$ is the weighting matrix. $n_j$ is the number of patents in the sample for the relevant age-cohort $j$ and $h_j$ is the corresponding sample hazard. $N$ is the sample size.[14]

In particular, $h_N$ consists of three types of hazard proportions:

- $HR^X_{NoLOR}(t)$ is the percentage of patents that expire in year $t$ given that they were active and not endorsed LOR in the previous period $t-1$,

- $HR^L(t)$ is the percentage of patents which declare LOR in year $t$ given that they were active and not endorsed LOR in the previous period $t-1$, and

- $HR^X_{LOR}(t)$ is the percentage of patents that expire in year $t$ given that they were active and endorsed LOR in the previous period $t-1$.

In order to calculate the hazard rates predicted by the model for a parameter set $\omega$ in the first step we will calculate the cut-off value functions $\{\hat{r}_t\}_{t=1}^T$, $\left\{\hat{g}_t^{l+}(r_t)\right\}_{t=1}^T$, and $\left\{\hat{g}_t^{l-}(r_t)\right\}_{t=1}^T$. Then, we proceed recursively by first calculating the value functions in the last period, $\widetilde{V}^K(T, r_T)$ and $\widetilde{V}^L(T, y_T)$, and the corresponding cut-off functions $\hat{r}_T$, $\hat{g}_T^{l+}(r_T)$, and $\hat{g}_T^{l+}(r_T)$. Subsequently, using these cut-off functions, we approximate the value functions for the year $T-1$. The cut-off value $\hat{r}_T$ is easily computed. However, to calculate the cut-off functions $\hat{g}_{T-1}^{l+}(r_{T-1})$ and $\hat{g}_{T-1}^{l-}(r_{T-1})$ we must equate the respective value functions on an M-point grid of points $\overrightarrow{r} \equiv \{r_1 < r_2 < ... < r_M\}$ and approximate the function at all points via interpolation.[15] We then proceed in the same recursive manner until the first year. Once we have calculated the cut-off functions for all periods, we simulate $S$ populations of granted patents.[16] Each population consists of $3 \cdot N$ patents. For each one we take pseudo random draws from the initial distribution and from the distributions of both types of growth rates, $g_t^k$ $(t \in 2, ..., T)$ and $g_t^l$ $(t \in 1, ..., T)$. Afterwards, we pass the initial draws through the

[14] We follow previous patent renewal studies and use a diagonal matrix that weights each moment according to the number of observations in each sample hazard to improve the efficiency of the estimator. Since the hazard proportions of LOR declarations are at least ten times smaller than the hazard proportions of expiration, we further divide each element in the diagonal matrix by its corresponding sample hazard. This will give more weight to the distance between the sample and true hazard proportions of declaration $HR^L(t)$. This will improve the estimation efficiency of the parameters that determine the distribution of the LOR growth rates.

[15] For all calculations we have used MATLAB (matrix laboratory), a numerical computing environment developed by MathWorks.

[16] We set $S = 5$.

stochastic process, compare them with the cut-off values in each period and calculate the vector of simulated hazard proportions. We then average the simulated moments over $S$ populations. The vector of the average simulated hazard proportions $\eta_N(\omega)$ is then inserted into the objective function (3). The objective function is minimized using global optimization algorithms for non-smooth problems implemented in MATLAB.[17] The standard errors are calculated using parametric bootstrap described in Appendix A.3.

## 3.2 Stochastic Specification

Similar to previous patent renewal studies (Pakes 1986; Schankerman and Pakes 1986; Deng 2011; Serrano 2011) we assume that the initial returns $r_1$ of all granted patents are lognormally distributed with mean $\mu_{IR}$ and variance $\sigma_{IR}$:

$$log(r_1) \sim Normal(\mu_{IR}, \sigma_{IR}) \tag{4}$$

With probability $1-\theta$ a patent can become obsolete in the beginning of each period, which corresponds to an extreme form of value depreciation.

We follow the specification in Schankerman and Pakes (1986) and Serrano (2011) to model the distributions of the growth rates for the returns from full patent protection, $g_t^k$. We assume a constant growth rate, or more precisely a constant rate of value depreciation, $g_t^k = \delta < 1$. We refer to this as the deterministic approach, since the growth rate for all future periods will be determined already in the first period.[18]

The growth rates associated with the LOR regime $g_t^l$ are drawn from an exponential distribution:

$$q^l(g^l \mid t) = \frac{1}{\sigma_t^l} exp(-\frac{g^l}{\sigma_t^l}) \tag{5}$$

We allow the standard deviation of these distributions to change monotonically with a patent's age $t$, $\sigma_t^l = (\phi^l)^t \sigma_0^l$. The parameter $\phi^l$ is not bounded and may exceed 1. This allows us to test whether the probability to have a high LOR growth rate is decreasing with a patent's age.

[17]Since the objective function is supposed to be non-smooth we apply the Simulated Annealing algorithm and the Genetic algorithm in the first step. Both are probabilistic search algorithms (see description of the Global Optimization Toolbox for MATLAB). In the second step we apply a Nelder-Mead-type search algorithm called *fminsearch* to find the local minimum.

[18]We also estimate a model with a different specification for the distributions of the growth rates for the returns from full patent protection, $g_t^k$, where we explicitly allow for learning. This more stochastic approach follows closely the model specification in Pakes (1986), Lanjouw (1998), and Deng (2011) and is presented in Appendix A.4.

We fix the discount factor $\beta = 0.95$ to ease the computational burden. Thus, our vector $\omega$ consists of six structural parameters:

$$\mu_{IR}, \sigma_{IR},\ \theta,\ \phi^l, \sigma_0^l,\ \delta$$

## 3.3 Identification

The structural parameters are identified by the size of and the variation in renewal fees, both across ages and different regimes, as well as the highly non-linear form of the model. Different parameter values imply different cut-off values, which in turn imply different aggregate behavior, and thus different hazard proportions. Nevertheless, since our model is based on the assumption that patentees will renew patent protection as long as the expected returns exceed the corresponding renewal fees, we are unable to directly identify the right tail of the patent value distribution. The value of patents which are renewed until the statutory patent term is only indirectly identified by the functional form assumptions for the distributions of initial returns and the growth rates.

All structural parameters are jointly estimated. The parameters $\phi^l$ and $\sigma_0^l$ determine the distribution of the LOR growth rates and are identified by the variation in all three types of hazard proportions, $HR^X_{NoLOR}(t)$, $HR^L(t)$, and $HR^X_{LOR}(t)$. If $\sigma_0^l$ is small, fewer declarations will be made throughout all ages. Patents endorsed LOR will expire earlier, increasing the drop out proportions for intermediate ages and decreasing them for higher ages. Furthermore, more patent owners of patents not endorsed LOR will choose not to declare LOR and let their patents expire. $\phi^l$ particularly determines the shape of the $HR^L(t)$ curve. For relatively low values of $\phi^l$ the hazard proportions are sharply decreasing with patent age, whereas for relatively high values of $\phi^l$ (values close to or above one) they may be increasing throughout all patent ages.

The parameter $\theta$ is identified by the proportions of expiration, $HR^X_{NoLOR}(t)$ and $HR^X_{LOR}(t)$. Contrary to all other parameters, $\theta$ shifts the entire curves up or down and determines the size of the proportions especially early in the life of a patent, when renewal fees are relatively low. Given the renewal fees schedule $\delta$ and the parameters that determine the initial distribution of returns, $\mu_{IR}$, and $\sigma_{IR}$, are jointly identified by the variation in all three types of hazard rates. In particular, higher values of $\sigma_{IR}$ imply a more skewed distribution of patent returns which cause higher dropout rates for intermediate ages and lower dropout rates for higher ages, when renewal fees are highest. Lower values of $\sigma_{IR}$ have the opposite effect. $\delta$ mainly determines the variation in hazard proportions when patents get closer to their expiration date.

# 4 Data

We use data on German patent applications provided by the German Patent and Trademark Office (DPMA) updated as of Dec. 24, 2008.[19] This data set contains information on all legal events, especially about patent renewals and declarations of the willingness to license according to Sec. 23 of the German Patent Act. For estimation, we use granted patent applications with effect in Germany from cohorts 1983-1988 for which we observe the full patent term.[20] Since we do not explicitly model the application and examination stages which precede the patent stage, we do not consider renewal and declaration decisions in the years the patent has not been granted. Usually high lump-sum costs are involved in both stages and the patent system offers several additional options to the patent applicants, too. One of them is the possibility to defer the examination of the patent for up to seven years. Another one is to stop or accelerate examination during the grant procedure. The consequence of these additional costs and options which are not captured by our model is that they could create a selection effect in the data even in the periods after grant. At any age, the probability of observing an expiration decision is likely to differ between patents which have just been granted and those that had been granted many years ago. The same applies to the probability to observe the decision to declare LOR. To avoid these biases in the calculation of the sample hazard proportions we have excluded the decisions in the first two years after grant, too.[21]

After excluding patents which expired within the first two years after they had been granted (12% of all granted patents) we were left with 211,869 patents divided in six cohorts. LOR has been declared for 12,878 (6.08%) of them. For 3,557 patents the LOR declaration was made when the patent application was still pending or within the first two years after grant. These LOR declarations were not considered for the calculation of the hazard proportions. For 35,410 (16.7%) patents, protection has been renewed for the full patent term.

The weighted sample hazard proportions obtained for patent ages 5 to 20 (respectively 6 to

[19]Due to legal provisions, the DPMA has to announce the publication of certain legal documents and events, e.g., publications of patent applications, patent grants, translations of European and PCT patent claims, as well as their changes. The announcement itself is made by a notice that appears in the weekly published Patent Gazette. All the information used for the publication in the Patent Gazette is stored in the PU-Band, tagged with the date the particular event was announced in the Patent Gazette (on average 3 months after the event). The first entry in the data we use dates back to 31 March 1981.

[20]Besides truncation issues, the reason for not choosing younger cohorts was a legal amendment in 1992 which allowed applicants to withdraw the LOR declaration as long as there had not been any request for a license. This option is not incorporated in our model. Nevertheless, in the chosen cohorts willingness to license was withdrawn only in 10 cases, which leaves our model assumption of the declaration being irrevocable still justifiable.

[21]The hazard proportions did not change considerably when we excluded the first three or four years after grant.

20) are presented in Figures 4-6.[22] The theoretical model predicts that the hazard proportions of expiration for patents endorsed, as well as for patents not endorsed LOR should be monotonically increasing in patent age due to the selection effect. However, this is not the case for some intermediate ages. Furthermore, there is a sharp increase for older ages. The explanation is easily found by looking at the disaggregated hazard proportions of expiration. For each cohort there are two kinks in the elsewise monotonically increasing curves which can be attributed to the events surrounding the dot-com bubble in Germany. The sharp decline in hazard proportions in 1998 can be associated with the emergence of the New Economy, whereas the jump in 2002 can be associated with its burst. Both events significantly affected the overall economic development in Germany. To capture the impact of these shocks we allow the obsolescence rate $1-\theta$ to differ in 1998 ($1-\theta_{1998}$) and 2002 ($1-\theta_{2002}$). We assume that both shocks were unexpected by the patent owners.[23] The hazard proportions of LOR declarations follow an inverted-U-shaped curve. They increase from 0.53% in year 5 to 0.81% in year 13, decrease for the following years, and reach the minimum in year 20 with 0.37%.

The patent renewal fee schedule for the time span under consideration is provided in Appendix A.2. There was one major change to the fee structure in Jan. 1, 2000. The renewal fee for each year was increased by 15%. Following Lanjouw (1998) we assume that the changes were anticipated by the patentees such that they always have correct expectations about the renewal fee schedule that they will face in the future.[24]

# 5 Estimation Results

The estimation results are presented in Table 1.[25] We begin with a discussion of the overall fit of the model and then turn to the interpretation of the parameter estimates. In the previous literature two measures were used to evaluate how well the estimated model fits the data. First, one can look at how well the curves of the simulated hazard proportions calculated using the estimated parameters mimic the curves of the true hazard rates. In Figures 4-6 we plot the true and the weighted simulated hazard rates for the cohorts 1983-1988. As expected, the model fits the curves of hazard proportions particularly well for ages which received the highest weight in the estimation. However, it fails to capture the rather sharp

[22]Since patent examination takes at least two years and due to subsetting we do not observe hazard proportions for the first 4, respectively 5 years.

[23]Alternatively, we could have implemented these shocks as a change in the distribution of the growth rates. However, this would considerably complicate the model and increase the computational burden.

[24]To avoid solving the dynamic optimization problem for each cohort separately we decided to calculate a single renewal fee schedule as a weighted average of the renewal fee schedules of all cohorts. We are aware that this simplification may potentially bias our estimates.

[25]We provide the estimation of the stochastic model with learning in Appendix A.4. The main results do not differ significantly.

| Parameter | Model 1 | (s.e.)† |
|---|---|---|
| $\beta$ (fixed) | 0.950 | |
| $\mu_{IR}$ | 8.286 | (0.0630) |
| $\sigma_{IR}$ | 1.435 | (0.0239) |
| $\theta$ | 0.924 | (0.0006) |
| $\theta_{1998}$ | 0.985 | (0.0011) |
| $\theta_{2002}$ | 0.835 | (0.0020) |
| $\delta$ | 0.968 | (0.0030) |
| $\phi^l$ | 0.973 | (0.0002) |
| $\sigma_0^l$ | 0.204 | (0.0009) |
| Age-Cohort Cells | 282 | |
| Sample Size | 211,869 | |
| Simulation Size | 635,607 | |
| $MSE_{All}$‡ | 0.000923 | |
| $Var_{All}(h_N)$ | 0.0055 | |
| $1 - MSE_{All}/Var_{All}(h_N)$ | 0.8323 | |

†Calculated using parametric bootstrap.

‡Calculated as the sum of squared residuals divided by the number of age-cohort cells.

Table 1: Parameter Estimates

increase in the hazards of expiration in the final ages. Regarding the hazard proportions of declaration the model slightly underestimates them but captures the decrease for higher ages reasonably well. Another performance indicator is the fraction of the variation in the true hazard rates that can be explained by the model. Therefore, we calculate the Mean Square Error (MSE) defined as the sum of squared residuals divided by the number of age-cohort cells. A low MSE relative to the variance in the sample hazard proportions suggests a good fit. With a MSE value of $9.23\,e^{-4}$ the model is able to explain 83.23% of the overall variation in the hazard proportions.[26]

**Depreciation dynamics** The distribution of the initial returns is determined by the parameters $\mu_{IR}$ and $\sigma_{IR}$. The mean initial return was 16,019€ (1,417€).[27] The distribution was skewed with a median initial return of 5,714€ (348€). The parameters $\delta$ and $\theta$ together determine the depreciation of the value of patent protection over time. The obsolescence rate, defined as $1 - \theta$, was 7.60% meaning that 50.91% of all patents became worthless to

[26]The unweighted MSE is somewhat higher than reported in other patent renewal studies where the explained variation typically exceeds 90%. This is reasonable, since we have used a different weighting scheme. The weighting matrix $A(\omega)$ in the objective function was constructed such that hazard proportions of LOR declaration have received relatively higher weights. The reported MSE does not take this weighting scheme into account.

[27]All monetary values are in units of 2002€ calculated for cohort 1983. Standard errors are reported in parentheses.

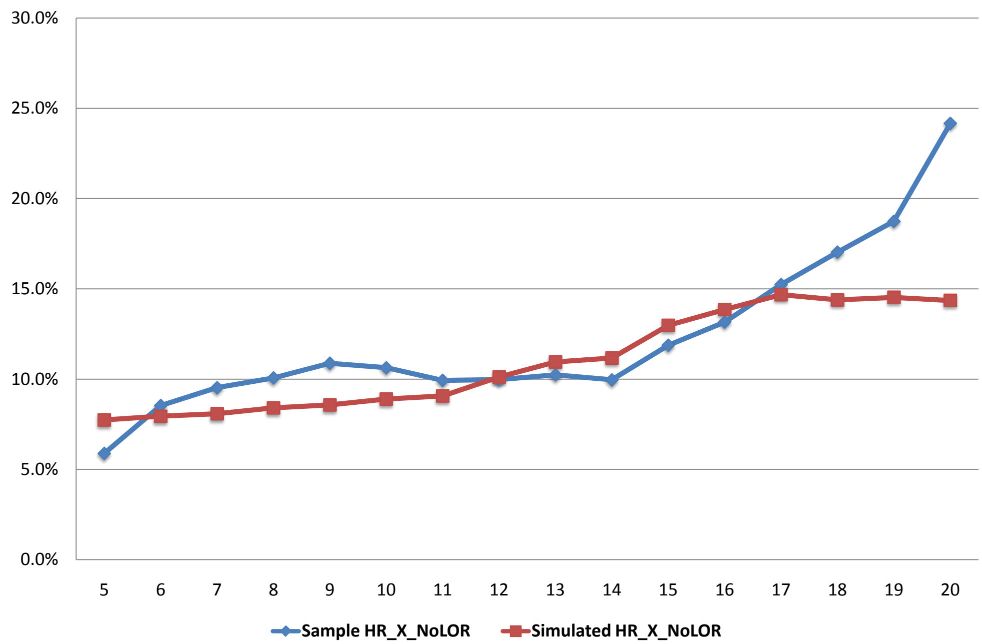


Figure 4: Hazard Proportions of Expiration - Patents Not Endorsed LOR

their owners after ten years. Additionally, we confirm the finding by Schankerman (1998) that economic shocks, positive as well as negative, significantly influence the value of patents. The estimated obsolescence rates for the years 1998 and 2002, $1-\theta_{1998}$ and $1-\theta_{2002}$, are higher, respectively lower. In 1998, during the economic upturn, only 1.52% of patents and in 2002, when the economic crisis became most severe, as many as 16.49% of patents were considered obsolete. If the patents did not become obsolete the returns depreciated by 3.2% each year. This is a relatively small value. However, the obsolescence rate already accounts for a large part of the overall depreciation in patent value.

**Distribution of the value of exclusivity** One of the major contributions of this paper is the estimation of the distribution of the value of exclusivity. This was defined as 1 minus the fraction of returns from patent protection that remain if the patentee declares LOR, maintaining only a right to reasonable remuneration. The estimated parameters $\phi^l$ and $\sigma_0^l$ determine this distribution across all German patents. One can see in Table 2 that in the first year, 2.23% of the patent owners would still be able to realize 75% of the returns from full patent protection even if they gave up exclusivity. For 0.63% of the patents the returns could even be increased if they waived their exclusive right. The declaration of the LOR

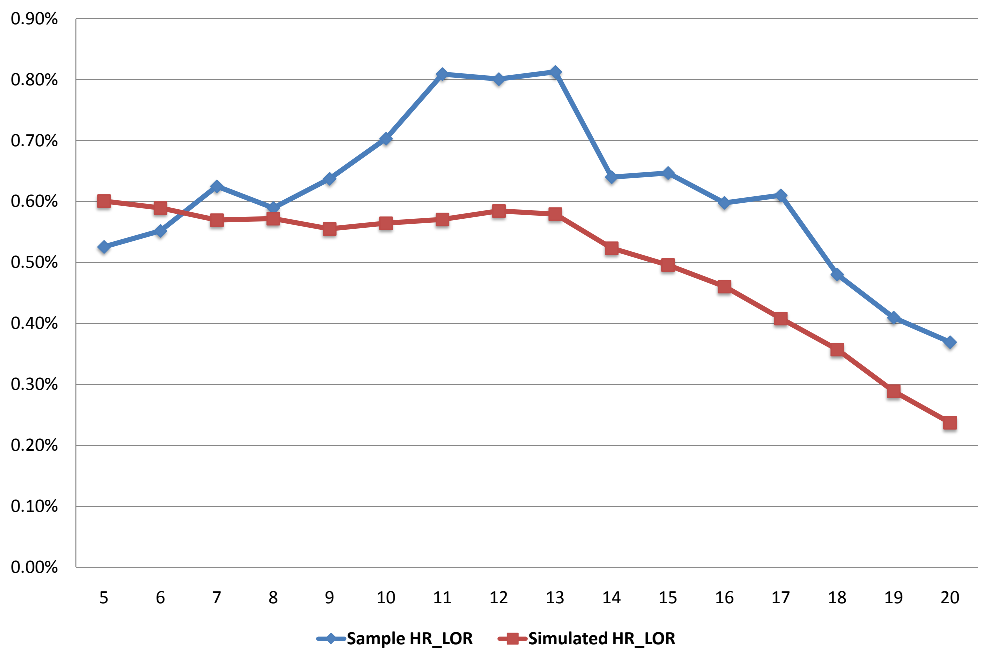


Figure 5: Hazard Proportions of LOR Declaration

is a binding commitment to make licenses available at a reasonable fee. This commitment may increase the diffusion of the technology, and hence the licensing revenues. Especially if the setup costs required for using a technology are high, a guarantee that licenses will be available at a reasonable price could foster the demand for the technology (Shepard 1987; Farrell and Gallini 1988).

Since $\phi^l$ is smaller than 1 the probabilities to draw relatively high LOR growth rates are decreasing with patent age. For patents still alive at age 20 the likelihood of being able to realize higher returns after declaring LOR than with full patent protection falls to only 0.02% and the likelihood of being able to realize 75% of the returns, to 0.16%. As many as 1.38% of the patents would still be able to retain at least 50% of the returns if they gave up exclusivity. In reverse, this means that exclusivity becomes relatively more important for returns appropriation with patent age. The older the patent the bigger is the fraction of returns to holding a patent which is associated with the right to exclude others and foreclose competition. Although returns to patent protection decrease with patent age, patents' contribution to static inefficiency, i.e., welfare losses, increases in relative terms. Older patents are likely to be more detrimental to the society. This result confirms previous findings (e.g., Cornelli and Schankerman 1999; Baudry and Dumont 2009) that the optimal patent renewal

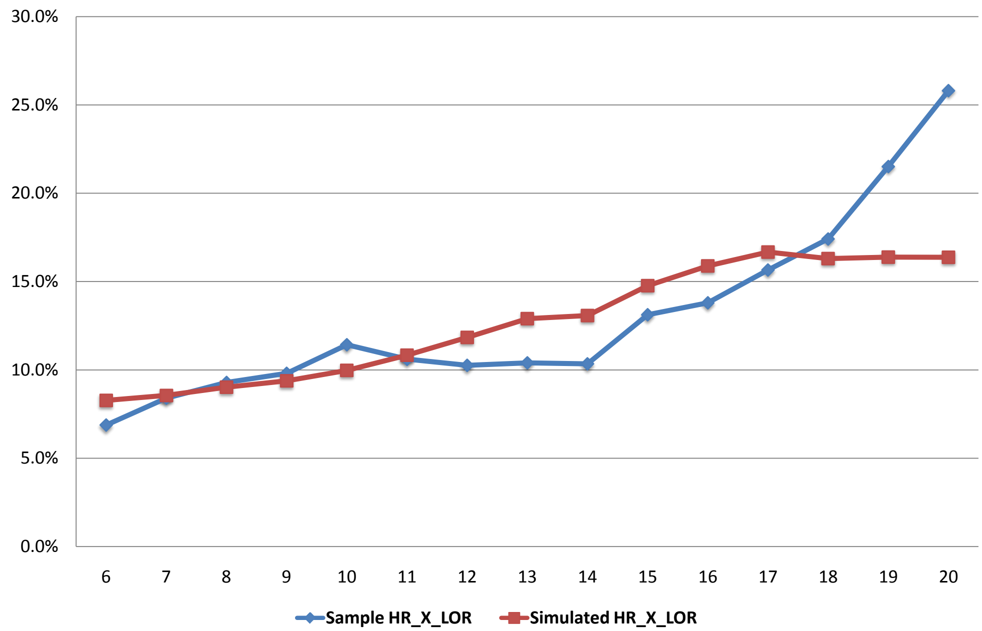


Figure 6: Hazard Proportions of Expiration - Patents Endorsed LOR

fees should be sharply increasing towards the end of patent life to minimize the social cost.

# 6 Policy Implications

## 6.1 The Value of Patent Rights

We use the estimated parameters to calculate the distribution of the value of patent rights for patents from cohort 1983. To do this, we draw a population of 500,000 patents from the initial distribution and pass them through the model. We then use German deflation factors to calculate the discounted present value of the stream of returns, net of discounted renewal fees for each patent.

In Table 3 we report the distributions at three different ages, at age 1, which corresponds to the overall value of patent protection, at age 5, and at age 10. For the distribution of the overall patent value we distinguished between the value of patents for which LOR has been declared and patents which have never been endorsed LOR. As already reported in previous studies, we observe that the distribution is very skewed with most of the value generated by only a small fraction of patents. The average patent value was 122,925 with 50% being worth

| Age | $Pr(g_t^l \geq 1.00)$ | $Pr(g_t^l \geq 0.75)$ | $Pr(g_t^l \geq 0.50)$ |
|---|---|---|---|
| 1 | 0.63% (0.0144)$^\dagger$ | 2.23% (0.0383) | 7.93% (0.0907) |
| 2 | 0.55% (0.0125) | 2.01% (0.0345) | 7.39% (0.0847) |
| 3 | 0.47% (0.0108) | 1.80% (0.0310) | 6.87% (0.0789) |
| 4 | 0.41% (0.0094) | 1.61% (0.0278) | 6.37% (0.0735) |
| 5 | 0.35% (0.0081) | 1.43% (0.0249) | 5.90% (0.0684) |
| 6 | 0.30% (0.0069) | 1.27% (0.0222) | 5.45% (0.0635) |
| ... | ... | ... | ... |
| 18 | 0.03% (0.0009) | 0.23% (0.0049) | 1.74% (0.0248) |
| 19 | 0.02% (0.0007) | 0.19% (0.0043) | 1.55% (0.0229) |
| 20 | 0.02% (0.0006) | 0.16% (0.0037) | 1.38% (0.0211) |

$^\dagger$Standard errors in parentheses.

Table 2: Evolution of LOR Growth Rates

less than 32,845€. Only 5% of the patents were worth more than 493,017€ and for 1% the value even exceeded 1,392,057€. The distribution gets more skewed at age 5 and even more so at age 10 after many patents have become obsolete.

We estimate somewhat higher patent values compared to previous patent renewal studies. Using patent data for cohorts 1950-1979 Pakes (1986) reports a mean value per German patent of 46,560€. Lanjouw (1998), using patents from cohorts 1953-80 in four technological areas, reports somewhat lower average values for patents in computers and textiles, and higher values for patents in engines and pharmaceuticals. However, both studies were using stochastic models which allowed for learning. The only study directly comparable to ours is Schankerman and Pakes (1986). Using the same data as in Pakes (1986) but a deterministic model they estimate a mean patent value at age 5 of 55,069€ for the 1970 cohort. According to our results, the average value of patent protection at age 5 for the 1983 cohort was higher, with 69,026€. We have used a sample of German patents from cohorts 1983-1988 for estimation. There are several explanations for the discrepancy. Schankerman (1998) and Schankerman and Pakes (1986) indicate that patent values have been increasing over time. Furthermore, data on German patents used for estimation in previous studies preceded the German reunification in 1990 whereas our data almost exclusively cover the post-reunification era. The increased market size should have had a significant effect on the private value of German patent rights. There are several explanations for this discrepancy. Schankerman and Pakes (1986) and Schankerman (1998) indicate that patent values have been increasing over time. Furthermore, data on German patents used for estimation in previous studies preceded the German reunification in 1990 whereas our data almost exclusively covers the post-reunification era. The increased market size should have had a significant effect on the private value of German patent rights.

| | at Age 10 | at Age 5 | at Age 1 | | |
|---|---|---|---|---|---|
| Percentile | All | | All | No LOR | Endorsed LOR |
| 50 | 0 | 9,838 | 32,845 | 33,383 | 26,366 |
| (s.e.) | (0) | (396) | (1,730) | (1,775) | (1,239) |
| 75 | 12,781 | 50,402 | 103,687 | 105,982 | 71,885 |
| (s.e.) | (466) | (2440) | (6,199) | (6,348) | (4,290) |
| 90 | 65,505 | 159,192 | 277,082 | 281,885 | 198,308 |
| (s.e.) | (2,909) | (9115) | (18,933) | (19,248) | (15,263) |
| 95 | 136,858 | 299,285 | 493,017 | 499,854 | 362,173 |
| (s.e.) | (7,052) | (19022) | (36,531) | (37,096) | (30,341) |
| 99 | 455,827 | 900,290 | 1,392,057 | 1,400,844 | 1,236,523 |
| (s.e.) | (30,200) | (70386) | (122,695) | (123,907) | (115,550) |
| 99.9 | 1,599,868 | 2,987,310 | 4,468,806 | 4,469,337 | 4,418,714 |
| (s.e.) | (131,764) | (285310) | (473,114) | (481,255) | (483,024) |
| Mean | 29,260 | 69,026 | 122,925 | 124,601 | 96,898 |
| (s.e.) | (1,738) | (4,673) | (9,236) | (9,379) | (7,472) |

Table 3: Value Distributions in 2002€

Patents endorsed LOR are on average more valuable than patents which have never been endorsed LOR. This confirms the result in Rudyk (2012) where he used regression analysis to show that a declaration is less likely for patents of presumably higher value. The average value of a patent endorsed LOR was 96,898€, 22.23% lower than the average value of a patent never endorsed LOR. The median value was 26,366€ and 10% of all patents for which LOR has been declared were even worth more than 198,308€. Since LOR can be declared throughout the whole patent life, we subtract the returns generated before the LOR declaration and calculate the distribution of the value from patent protection which has been generated during the LOR regime. This distribution looks even more skewed with a mean value of 62,312€ and a median value of 8,474€ (see Table 4). 10% of patents endorsed LOR were even able to accumulate more than 130,074€ in net returns during the LOR regime. The result is surprising, since the common opinion is that LOR is declared only for patents which are peripheral or have already become worthless to their owners. Our estimates, however, suggest that a substantial part of the value of patents for which LOR had been declared, on average 64.31%, was generated after the declaration.

| Percentile | 50 | 75 | 90 | 95 | 99 | 99.9 | Mean |
|---|---|---|---|---|---|---|---|
| Value | 8,474 | 39,279 | 130,074 | 255,510 | 886,023 | 3,188,420 | 62,312 |
| (s.e.) | (472) | (2,337) | (9,171) | (19,981) | (86,983) | (384,581) | (4,777) |

Table 4: Value Realized During the LOR Regime in 2002€

## 6.2 Counterfactual Analysis

**License of right** We perform a counterfactual policy experiment where we ban the possibility to declare LOR from the patent system. We then look at how the overall value provided by the German patent system would change, as well as the consequences for the revenues of the German patent office. According to our calculations, the option value of the LOR system is positive. The value of all patents in the simulated cohort falls by 0.51% (0.02%), once we exclude the option to declare LOR from the model. The mean patent value drops by 620€ (52€). However, the amount of total renewal fees paid by the patentees increases by 2.21% (0.05%). Hence, the LOR system is associated with costs for the German patent office. Nevertheless, these costs correspond to only 12.16% of the additional private value it creates. Overall, the results indicate that a license of right provision can contribute to a better functioning of a patent system. It increases access to patented inventions without depriving patent owners of their returns. Although it encourages to maintain patent protection for a longer period licenses are available at reasonable terms to any third party. Furthermore, the legislator can design the LOR incentive structure in a way as to discourage welfare decreasing declarations.

Of the 500,000 simulated patents for cohort 1983, 6.05% (0.05%) have declared LOR. The average declaration in the sample data was 6.08%. Now, we divide patents endorsed LOR according to the motives of declaration. A declaration is assigned to the cost-saving motive if the primary reason for the declaration was to profit from the cost reduction such that the patent would not have been renewed otherwise. These declarations can be considered as unambiguously welfare decreasing. A declaration is assigned to the commitment motive if the choice for the patentee was either to renew with full patent protection or to declare LOR. In this case the patent would have existed even without the possibility to declare LOR at least for one more year, maintaining the right to exclude others. Instead, the patentee commits to license his invention non-exclusively. These declarations can potentially be welfare increasing. According to the simulation results presented in Table 5, only less than 4.41% of all declarations were unambiguously welfare decreasing. In contrast, 95.59% of the declarations were made because the patentee expected higher profits in the LOR regime compared to the regime with full patent protection. However, this division is not constant for all patent ages. In the first 5 years, 99.70% of all declarations could be assigned to the commitment motive. This is not surprising since the renewal fees in the first five years are almost negligible. In contrast, of all declarations made in the last five years of the statutory patent term, only 80.25% could be assigned to the commitment motive and 19.75% to the cost-saving motive. Since the renewal fees in Germany are increasing progressively, they are highest in this five-year period. The corollary from this result is that the present cost structure that guarantees

| Age | 1-5 | 6-10 | 11-15 | 16-20 | 1-20 |
|---|---|---|---|---|---|
| Cost-Saving Motive | 0.30% | 4.07% | 12.51% | 19.75% | 4.41% |
| Commitment Motive | 99.70% | 95.93% | 87.49% | 80.25% | 95.59% |
| (s.e.) | (0.05%) | (0.30%) | (0.58%) | (1.05%) | (0.18%) |

Table 5: Motive for LOR Declaration

a 50% fee reduction for all declarations might not be welfare optimizing. To improve welfare one could decrease the fee reduction rate for late LOR declarations and increase it for early ones. The older the patent for which LOR is declared the lower should be the subsidy. This would incentivize early declarations and discourage welfare decreasing declarations for older patents.[28]

**Compulsory licensing** In our second counterfactual experiment we measure the cost of compulsory licensing (CL) requirements for the patent owners. We adapt our model and oblige every patent to declare LOR on the day of application, making licensing compulsory. Again, using the estimated parameters for German patent data we calculate the patent value assuming a 50% reduction in renewal fees. Compared to the present patent system in Germany the introduction of the compulsory licensing requirement for all patents would lead to a decrease in overall value by 81.00% (0.17%) or 99,572€ (7,344€) on average. We are aware that this result might overstate the real losses. First, patentees facing a compulsory licensing could adjust their strategies, e.g., by protecting their invention via secrecy, and avoid the burden of compulsory licensing. For example they may intensify the use of other means of IP protection like trade secrets or design patents. Secondly, our results depend on the functional form assumption for the distribution of the growth rates in case of LOR. We have chosen an exponential probability distribution which is a constantly decreasing function. This makes very low LOR growth rates, and hence low returns in case of CL very probable. Nevertheless, the results indicate that making licensing compulsory to all patent holders may deprive the system of much of its incentive power. Contrary to license of right it might not be advisable to apply compulsory licensing to the patent system as a whole. However, it can be beneficial to society to require licenses being available at reasonable terms for standard-related patents for interoperability purposes.[29] The same applies to patents in cumulative innovation fields. In some cases providing access to patented technology that

[28]Theoretically, one could use the model developed in this article and the estimated parameters to calculate the welfare optimizing fee structure. The results would highly depend on the employed welfare function. These welfare function should relate the welfare derived from an invention protected by a patent with full patent protection to the welfare derived from the same invention protected by a patent without the exclusive right and to the welfare without any patent protection. We leave this to future research.

[29]Hilty and Geiger (2005) propose a mandatory license of right declaration for patents in component technologies such as the software sector.

follow-on inventions build upon might benefit welfare by far more than the losses in private value from patent protection if exclusivity is removed.

# 7 Conclusion

The main empirical findings can be summarized as follows. We confirm the result from previous patent renewal studies that the distribution of the private value from patent protection is very skewed. Additionally, we estimate that the distribution of the value of exclusivity is very skewed, too. We define the value of exclusivity as those returns that the patent owner would forfeit by giving up his right to exclude others in return for only a right to reasonable remuneration. Less than 7.93% of all patents would be able to maintain at least 50% of the returns from patent protection if they gave up exclusivity in the first year, and only 2.23% would be able to maintain at least 75%. Interestingly, a small fraction of patents, estimated to be around 0.63%, can even profit from a commitment to make licenses available to everyone. Furthermore, the value of exclusivity becomes more important with patent age. The older the patent the lower is the probability that the patentee will be able to retain a larger part of his revenues without the possibility to exclude others.

Moreover, the model allowed us to identify declarations which were unambiguously welfare decreasing. We estimate for the 1983 cohort of patents that 4.41% of all declaration were made only because of the 50% reduction in maintenance fees. Without the LOR option these patents would not have been renewed. The fraction of such declarations was almost negligible for young patents but has increased rapidly for older ones.

On average, patents endorsed LOR were less valuable to their owners than patents never endorsed LOR by 22.23%. However, a major part of the value of patents endorsed LOR has been generated during the LOR regime.

Future research should look at the differences between technological areas. We know that LOR is mostly never used in discrete technologies like chemistry or biotechnology whereas it is widely used in complex technologies. LOR was declared for almost 11.41% of patents in electrical engineering and 8.02% in mechanical engineering. For some subclasses of these technology fields the numbers were even higher. The results would show how the distribution of the value of exclusivity differs across different complex technologies. Besides, the higher usage rates could help to improve the identification of the model parameters.

The results from the counterfactual experiments which we have performed using the estimated parameters show very useful insights, too. Although, as we argue, the estimated loss in private returns from patent protection of 81.00% that would follow an introduction of a compulsory licensing system constitutes only an upper bound, the sheer number is astonish-

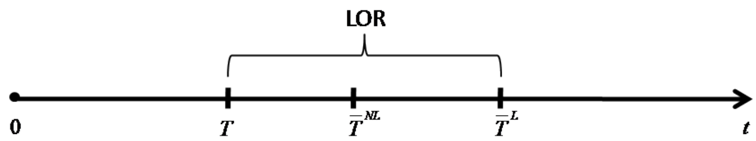


Figure 7: Time Line

ing. Compulsory licensing would have considerably undermined the incentive effect of the patent system.

The possibility to declare LOR in the German patent system has somewhat different implications. Without this option, the private returns from patent protection of all patents would have fallen by 0.51%. However, the renewal fees collected by the German patent office would have risen by 2.21%. A LOR system is costly to implement for the patent office but these costs are only a fraction of the additional private value created in the patent system. The model and the estimated distributions could further be used to precisely assess the effects on the social welfare as well as to determine the welfare optimizing design of the LOR system. Certainly, the findings should differ across technology areas.

The basic trade-off is that on the one hand the LOR system provides incentives to open the access to patented inventions. On the other hand, the reduction in renewal fees, which are increasing with a patent's maturity, might result in too strong incentives to maintain patent protection. We observe that on average LOR was declared 8.5 years after the application date and the patents were renewed for additional 6 years, resulting in longer-living patents (2.5 years longer compared to patents without LOR).

Consider a simple model. Assume for simplicity the patentee has full information about all future returns from patent protection at the filing date. Without the possibility to declare LOR the patent owner would choose to let his patent expire at time $\overline{T}^{NL}$. Alternatively, the patent owner can also opt to declare LOR. The LOR regime is associated with an optimal time $T$ for the declaration and an optimal time $\overline{T}^{L}$ for the expiration (see Figure 7). The difference $\overline{T}^{NL} - T$ denotes the period when the welfare effect from LOR will be positive, since exclusivity will be removed. The difference $\overline{T}^{L} - \overline{T}^{NL}$ denotes the period when the welfare effect will be negative, since patent protection would have been extended. Even if during this period the patent were endorsed LOR a situation without any protection would increase welfare.

If the patentee indeed chooses to declare LOR he will do it earlier ($T$ decreases) and let the patent expire later ($\overline{T}^{L}$ increases) the higher will be his returns from patent protection during the LOR regime and the higher the reduction in renewal fees. Assuming a welfare function for the different regimes of protection–no patent protection, patent protection with exclusivity, patent protection without exclusivity (LOR)–such that one could relate the welfare increasing effects to the welfare decreasing effects, one ought to be able to calculate the welfare optimizing fee reduction rate (currently 5). If the government sets only a low discount rate it will only attract patents with a positive welfare contribution into the LOR regime. But the discount rate will be too low for the patent owners to choose the optimal time of declaration. Many patentees will choose too declare later than socially optimal, or choose not to declare LOR at all. On the other hand, if the government sets a high discount rate it will allow patents with a higher welfare contribution to choose the socially optimal time for the declaration. But it would also encourage patents with negative welfare contributions into the LOR regime. This optimal discount rate should balance those effects.

In this setting one could also analyze whether there are other applicable incentive mechanisms besides a uniform discount rate which could discourage patents with negative welfare contribution to declare LOR, but maintain the incentives for patents with a positive one. One possibility is to design individual contracts for each patent owner combining high discount rates for early declarations with an early commitment to non-exclusive licensing, and low discount rates for declarations for older patents. A practical implementation would be to reduce the discount rate with the age of the patent at declaration. This mechanism could possibly ensure that patent owners take welfare optimizing decisions.

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# A Appendix

## A.1 Proofs

### Proof of Lemma 1

For the proof of parts *(i)* and *(ii)* it suffices to show the properties for $\widetilde{V}^L(t, y_t)$ and $\widetilde{V}^K(t, r_t)$ in $r_t$. For a given LOR growth rate $g_t^l$ the same properties apply for $y_t$.

Let $a$ be the year of declaration (if chosen). Remember, $F_{g^k}(u^k \mid t)$ and $F_{g^l}(u^l \mid t)$ are independent of returns and $y_t = g_a^l r_t = g_a^l g_t^k r_{t-1}$.

Proofs are done by induction.

*(i)*

Let's look at the last period $t = T$:

$\widetilde{V}^K(T, r_T) = r_T - f_T$ and $\widetilde{V}^L(T, y_T) = y_T - \frac{f_T}{2} = g_a^l r_T - \frac{f_T}{2}$ are clearly increasing in $r_T$.

Now, let's look at the periods $t < T$:

Assume that for an arbitrary $r < r'$: $\widetilde{V}^L(t+1, g_a^l g_{t+1}^k r) < \widetilde{V}^L(t+1, g_a^l g_{t+1}^k r')$ .

Then, $\widetilde{V_L}(t+1, g_a^l g_{t+1}^k r) \leq \widetilde{V_L}(t+1, g_a^l g_{t+1}^k r')$
and $E\left[\widetilde{V_L}(t+1, g_a^l g_{t+1}^k r)\right] \leq E\left[\widetilde{V_L}(t+1, g_a^l g_{t+1}^k r')\right]$.

Then,
$\widetilde{V}^L(t, g_a^l r) = -\frac{f_t}{2} + g_a^l r + \beta E\left[\widetilde{V_L}(t+1, g_a^l g_{t+1}^k r)\right] <$
$< -\frac{f_t}{2} + g_a^l r' + \beta E\left[\widetilde{V_L}(t+1, g_a^l g_{t+1}^k r')\right] = \widetilde{V}^L(t, g_a^l r')$.

Now, assume that for $r < r'$: $\widetilde{V}^K(t+1, g_{t+1}^k r) < \widetilde{V}^K(t+1, g_{t+1}^k r')$.

We know from above that $\widetilde{V}^L(t+1, g_t^l g_{t+1}^k r) < \widetilde{V}^L(t+1, g_t^l g_{t+1}^k r')$.

This means that $\widetilde{V_K}(t+1, g_{t+1}^k r, g_t^l g_{t+1}^k r) \leq \widetilde{V_K}(t+1, g_{t+1}^k r', g_t^l g_{t+1}^k r')$

and $E\left[\widetilde{V_K}(t+1, g^k_{t+1}r, g^l_t g^k_{t+1}r)\right] \leq E\left[\widetilde{V_K}(t+1, g^k_{t+1}r', g^l_t g^k_{t+1}r')\right]$.

Then,
$\widetilde{V}^K(t,r) = -f_t + r + \beta E\left[\widetilde{V_K}(t+1, g^k_{t+1}r, g^l_t g^k_{t+1}r)\right] <$
$< -f_t + r' + \beta E\left[\widetilde{V_K}(t+1, g^k_{t+1}r', g^l_t g^k_{t+1}r')\right] = \widetilde{V}^K(t,r')$.

*(ii)*
$\widetilde{V}^L(T, y_T)$ and $\widetilde{V}^K(T, r_T)$ are clearly continuous in $r_T$. To prove continuity in $r_t$ for all $t$ assume that $\widetilde{V_K}(t, r_t, y_t)$ and $\widetilde{V_L}(t, y_t)$ are continuous in $r_t$ for an arbitrary $t$.

$\widetilde{V_K}(t-1, r_{t-1}, y_{t-1})$ and $\widetilde{V_L}(t-1, y_{t-1})$ will be continuous in $r_{t-1}$ if $\widetilde{V}^K(t-1, r_{t-1})$ and $\widetilde{V}^L(t-1, y_{t-1})$ are continuous in $r_{t-1}$. In turn, $\widetilde{V}^K(t-1, r_{t-1})$ and $\widetilde{V}^L(t-1, y_{t-1})$ will be continuous in $r_{t-1}$ if their option values $E\left[\widetilde{V_K}(t, r_t, y_t) \mid r_{t-1}\right]$ and $E\left[\widetilde{V_L}(t, y_t) \mid r_{t-1}, g^l_a\right]$ are continuous in $r_{t-1}$.

The option values will be continuous in $r_{t-1}$ if for every sequence $(r^n_{t-1})$, such that $lim(r^n_{t-1}) = r_{t-1}$, we can show that

$$\lim_{r^n_{t-1} \to r_{t-1}} E\left[\widetilde{V_K}(t, r_t, y_t) \mid r^n_{t-1}\right] = E\left[\widetilde{V_K}(t, r_t, y_t) \mid r_{t-1}\right] \text{ and}$$

$$\lim_{r^n_{t-1} \to r_{t-1}} E\left[\widetilde{V_L}(t, y_t) \mid r^n_{t-1}, g^l_a\right] = E\left[\widetilde{V_L}(t, y_t) \mid r_{t-1}, g^l_a\right].$$

Since $F_{g^k}(u^k \mid t)$ and $F_{g^l}(u^l \mid t)$ are independent of $r_t$, it must be that

$$\lim_{r^n_{t-1} \to r_{t-1}} E\left[\widetilde{V_K}(t, r_t, y_t) \mid r^n_{t-1}\right] =$$

$$= \int\int \lim_{r^n_{t-1} \to r_{t-1}} \left[\widetilde{V_K}(t, g^k_t r^n_{t-1}, g^l_t g^k_t r^n_{t-1})\right] dF_{g^k}(du^k \mid t) dF_{g^l}(du^l \mid t) =$$

$$= \int\int \left[\widetilde{V_K}(t, g^k_t r_{t-1}, g^l_t g^k_t r_{t-1})\right] dF_{g^k}(du^k \mid t) dF_{g^l}(du^l \mid t).$$

The last equality follows because $\widetilde{V_K}(t, r_t, y_t)$ is continuous in $r_{t-1}$ (remember that $y_t = g^l_t g^k_t r_{t-1}$ and $r_t = g^k_t r_{t-1}$ are both continuous in $r_{t-1}$).

The proof for

$\lim_{r_{t-1}^n \to r_{t-1}} E\left[\widetilde{V_L}(t, y_t) \mid r_{t-1}^n, g_a^l\right] = E\left[\widetilde{V_L}(t, y_t) \mid r_{t-1}, g_a^l\right]$ is identical.

*(iii)*:

In $t = T$ the option value is always 0. The option value in $t = T - 1$ must be at least 0 since the patentee has always the choice to let the patent expire (X). Let's hold $r$ and $g^l$ fixed. Since the renewal fees are increasing in $t$, it must be that $\widetilde{V}^K(T-1, r) \geq \widetilde{V}^K(T, r)$ and $\widetilde{V}^L(T-1, y) \geq \widetilde{V}^L(T, y)$.

By assumption, $F_{g^l}(u^l \mid t)$ and $F_{g^k}(u^k \mid t)$ are increasing in $t$ (in the sense of first-order stochastic dominance) making higher growth rates less likely for older patents. Thus, the property that $\widetilde{V}^K(t-1, r) \geq \widetilde{V}^K(t, r)$ and $\widetilde{V}^L(t-1, y) \geq \widetilde{V}^L(t, y)$ must hold for the general case:

Assume that $\widetilde{V}^L(t+1, y) \leq \widetilde{V}^L(t, y) \Rightarrow \widetilde{V_L}(t+1, y) \leq \widetilde{V_L}(t, y)$.

Thus,

$E\left[\widetilde{V_L}(t+1, g^l g_{t+1}^k r)\right] \leq E\left[\widetilde{V_L}(t, g^l g_t^k r)\right]$, since $F_{g^k}(u^k \mid t) \leq F_{g^k}(u^k \mid t+1)$.

Then,

$$\widetilde{V}^L(t, y) = -\tfrac{f_t}{2} + y + \beta E\left[\widetilde{V_L}(t+1, g^l g_{t+1}^k r)\right] \leq$$
$$\leq -\tfrac{f_{t-1}}{2} + y + \beta E\left[\widetilde{V_L}(t, g^l g_t^k r)\right] = \widetilde{V}^L(t-1, y).$$

Now, assume that $\widetilde{V}^K(t+1, r) \leq \widetilde{V}^K(t, r)$.

We know that $\widetilde{V}^L(t+1, y) \leq \widetilde{V}^L(t, y)$ and thus it must be that

$\widetilde{V_K}(t+1, r, y) \leq \widetilde{V_K}(t, r, y)$.

Therefore,

$$E\left[\widetilde{V_K}(t+1, g^k_{t+1}r, g^l_{t+1}g^k_{t+1}r)\right] \leq E\left[\widetilde{V_K}(t, g^k_t r, g^l_t g^k_t r)\right],$$

since $F_{g^k}(u^k \mid t) \leq F_{g^k}(u^k \mid t+1)$ and $F_{g^l}(u^l \mid t) \leq F_{g^l}(u^l \mid t+1)$.

With $f_{t-1} < f_t$, we can easily conclude that

$$\widetilde{V}^K(t,r) = -f_t + r + E\left[\widetilde{V_K}(t+1, g^k_{t+1}r, g^l_{t+1}g^k_{t+1}r)\right] \leq$$
$$\leq -f_{t-1} + r + E\left[\widetilde{V_K}(t, g^k_t r, g^l_t g^k_t r)\right] = \widetilde{V}^K(t-1, y).$$

**Proof of Proposition 1**

*(i)*

In this case the patentee is indifferent between (L) and (X). We know that the value function $\widetilde{V}^L(t, g^l_t r)$ is weakly increasing in returns $r$. Thus, if the per period returns from full patent protection are increasing, $\hat{g}^{l-}$ must be decreasing with $r$ to maintain the equality in $\widetilde{V}^L(t, \hat{g}^{l-}_t r) = 0$.

*(ii)*

The patent owner has to choose between (K) and (L).

Consider the last period $T$:

One can easily calculate that $\hat{g}^{l+}_T = 1 - \frac{f_T}{2r}$ and increasing in $r$.

The higher $r$, the smaller is the cost reduction relative to possible losses in patent returns due to the LOR declaration.

Now, consider period $t < T$:

$\hat{g}^{l+}_t$ is defined as

$$\widetilde{V}^K(t,r) - \widetilde{V}^L(t, \hat{g}^{l+}_t r) = -\frac{f_t}{2} + r - \hat{g}^{l+}_t r +$$
$$+\beta\left\{E\left[\widetilde{V_K}(t+1, g^k_{t+1}r, g^l_{t+1}g^k_{t+1}r)\right] - E\left[\widetilde{V_L}(t+1, g^k_{t+1}r, \hat{g}^{l+}_t g^k_{t+1}r)\right]\right\} = 0.$$

After applying the implicit function theorem:

$$\frac{\partial \hat{g}_t^{l+}}{\partial r} = -\frac{\partial(\widetilde{V}_t^K(.)-\widetilde{V}_t^L(.))/\partial r}{\partial(\widetilde{V}_t^K(.)-\widetilde{V}_t^L(.))/\partial \hat{g}_t^{l+}} = \frac{1-g_t^l+\beta\frac{\partial\left\{E\left[\widetilde{V_K}(.)\right]-E\left[\widetilde{V_L}(.)\right]\right\}}{\partial r}}{r+\beta\frac{\partial E\left[\widetilde{V_L}(.)\right]}{\partial \hat{g}_t^{l+}}}$$

The expression will be positive if and only if

$$1+\beta\frac{\partial\left\{E\left[\widetilde{V_K}(.)\right]-E\left[\widetilde{V_L}(.)\right]\right\}}{\partial r} > \hat{g}_t^{l+}.$$

As long as this inequality holds, $\hat{g}_t^{l+}$ will be increasing in $r$. This will in turn depend on the exact stochastic specification of the model, especially on how we model the distributions of the growth rates.

**Proof of Proposition 2**

Take an arbitrary $g^l$. The cut-off value $\hat{r}_t$ is defined as $\widetilde{V}^K(t,\hat{r}_t) = 0$ and $\hat{r}_{t+1}$ as $\widetilde{V}^K(t+1,\hat{r}_{t+1}) = 0$. From Lemma 1 we know that $\widetilde{V}^K(.)$ is increasing in $r$ and non-increasing in $t$. Thus, to maintain equality in both equations it must be that $\hat{r}_{t+1} \geq \hat{r}_t$ .

**Proof of Proposition 3**

*(i)*

In this case the patent owner is indifferent between (L) and (X). We know from Lemma 1 that $\widetilde{V}^L(t,y_t)$ is increasing in $r_t$ and non-increasing in $t$. Thus, if we take the same returns $r_t = r_{t+1} = r$ in two consecutive periods, then $\hat{g}_t^{l-}(r)$, which is defined as the solution to

$$\widetilde{V}^L(t,y) = \hat{g}_t^{l-}r - \tfrac{1}{2}f_t + \beta E\left[\widetilde{V_L}(t+1,\hat{g}_t^{l-}g_{t+1}^k r)\right] = 0,$$

must be at least as large as $\hat{g}_{t-1}^{l-}(r)$.

*(ii)*

The patent owner is indifferent between (L) and (K) if $g_t^l = \hat{g}_t^{l+}$. The cut-off function $\hat{g}_t^{l+}(r_t)$ is implicitly defined in

$$\widetilde{V}^L(t,\hat{g}_t^{l+}r_t) = \hat{g}_t^{l+}r_t - \tfrac{1}{2}f_t + \beta E\left[\widetilde{V_L}(t+1,\hat{g}_t^{l+}g_{t+1}^k r_t)\right] =$$
$$= r_t - f_t + \beta E\left[\widetilde{V_K}(t+1,g_{t+1}^k r_t, g_{t+1}^l g_{t+1}^k r_t)\right] = \widetilde{V}^K(t,r_t).$$

Let's look at the last two periods and assume $r_{T-1} = r_T = r$ and $y_{T-1} = y_T = y$ ($g^l_{T-1} = g^l_T$).

The option values in the last period are always 0 and we can easily calculate:

$\hat{g}^{l+}_T(r_T) = 1 - \frac{f_T}{2r}$.

Let's look whether $\hat{g}^{l+}_T(r) \leq \hat{g}^{l+}_{T-1}(r)$.

Since $E\left[\widetilde{V_L}(T, g^l_{T-1} g^k_T r)\right]$ is increasing in $g^l_{T-1}$ we have to show that

$\widetilde{V}^K(T-1, r) - \widetilde{V}^L(T-1, \hat{g}^{l+}_T r) \leq 0$ (with $\hat{g}^{l+}_T(r) = 1 - \frac{f_T}{2r}$).

We know that

$\widetilde{V}^K(T-1, r) - \widetilde{V}^L(T-1, \hat{g}^{l+}_T r) =$
$r - f_{T-1} + \beta E\left[\widetilde{V_K}(T, g^k_T r, g^l_T g^k_T r)\right] - \hat{g}^{l+}_T r + \frac{f_{T-1}}{2} - \beta E\left[\widetilde{V_L}(T, \hat{g}^{l+}_T g^k_T r)\right] =$

after inserting $\hat{g}^{l+}_T(r_T) = 1 - \frac{f_T}{2r}$

$= \frac{f_T}{2} - \frac{f_{T-1}}{2} + \beta \left\{E\left[\widetilde{V_K}(T, g^k_T r, g^l_T g^k_T r)\right] - E\left[\widetilde{V_L}(T, (1 - \frac{f_T}{2r}) g^k_T r)\right]\right\} =$

$= \frac{f_T}{2} - \frac{f_{T-1}}{2} + \beta \left\{E\left[\widetilde{V_K}(T, g^k_T r, g^l_T g^k_T r)\right] - E\left[\widetilde{V_L}(T, g^k_T (r - \frac{f_T}{2})\right]\right\}$.

Already for the last two periods we see that whether $\hat{g}^{l+}_T(r) \leq \hat{g}^{l+}_{T-1}(r)$ will depend on whether the term $E\left[\widetilde{V_K}(T, g^k_T r, g^l_T g^k_T r)\right] - E\left[\widetilde{V_L}(T, g^k_T (r - \frac{f_T}{2})\right]$ will exceed cost difference $\frac{f_T}{2} - \frac{f_{T-1}}{2}$. This in turn will depend on the exact stochastic specification as well as the fee structure.

## A.2 Renewal Fee Schedules for Cohorts 1983-1988

| year | before January 01, 2002 | after January 01, 2002 |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0 | 0 |
| 3 | 51.13 | 70 |
| 4 | 51.13 | 70 |
| 5 | 76.69 | 90 |
| 6 | 115.04 | 130 |
| 7 | 153.39 | 180 |
| 8 | 204.52 | 240 |
| 9 | 255.65 | 290 |
| 10 | 306.78 | 350 |
| 11 | 409.03 | 470 |
| 12 | 536.86 | 620 |
| 13 | 664.68 | 760 |
| 14 | 792.50 | 910 |
| 15 | 920.33 | 1060 |
| 16 | 1073.71 | 1230 |
| 17 | 1227.10 | 1410 |
| 18 | 1380.49 | 1590 |
| 19 | 1533.88 | 1760 |
| 20 | 1687.26 | 1940 |

Table 6: Renewal Fee Schedules in €

## A.3 Parametric Bootstrap

Since we do not know the empirical distribution of the observed hazard rates we will apply a parametric bootstrap method to estimate the standard errors of the parameters $\omega$. Instead of simulating bootstrap samples that are i.i.d. from the empirical distribution as it is done in non-parametric bootstrap methods, we simulate bootstrap samples that are i.i.d. from the estimated parametric model. Following Efron and Tibshirani (1993) we apply the following bootstrap algorithm:

1. Use the estimated parameters $\hat{\omega}^*$ and generate a random sample of $N$ patents.
2. Simulate the decisions resulting from the model specification and obtain the sequence of pseudo hazard rates $\eta(\hat{\omega}^*)$.
3. Minimize the loss function in function 3 using $\eta(\hat{\omega}^*)$ instead of $h_N$ and obtain $\hat{\omega}^*_b$.
4. Repeat steps 1.-3. $B$ times.
5. Calculate the parametric bootstrap estimate of standard error:

$$\hat{se}_B = \left\{ \frac{\sum_{b=1}^{B} \left[\hat{\omega}^*_b - \hat{\omega}^*(.)\right]^2}{(B-1)} \right\}^{\frac{1}{2}}, \text{ where } \hat{\omega}^*(.) = \frac{\sum_{b=1}^{B} \hat{\omega}^*_b}{B}$$

## A.4 Model with Learning

In our second approach, we allow for learning. The difference to the deterministic model is that the growth rate of returns from full patent protection $g_t^k$ is not constant anymore. We assume that the patentee can discover a new use or another way how to exploit his invention and increase his returns. This dynamic approach follows closely the models in Pakes (1986), Lanjouw (1998), and Deng (2011). In this specification the growth rate $g_t^k$ may exceed the minimum growth rate $\delta < 1$. Therefore, we model $g_t^k$ as the maximum of either the constant growth rate $\delta$, or an alternative growth rate $u^k$, such that $g_t^k = max(\delta, u^k)$. We assume that $u^k$ is drawn randomly from an exponential distribution:

$$q^k(u^k \mid t) = \frac{1}{\sigma_t^k} exp(-\frac{u^k}{\sigma_t^k}) \tag{6}$$

Since the probability of getting higher returns is supposed to decrease with a patent's maturity, the standard deviation of the random growth rate $u^k$ is set to $\sigma_t^k = (\phi^k)^t \sigma_0^k$, with $\phi^k \leq 1$ and $t \in 1, ..., T$.

The parameters $\phi^k$ and $\sigma_0^k$ both determine how fast learning vanishes. Since renewal fees in the early periods are low, they also determine when hazard proportions of expiration start to exceed the obsolescence rate. Besides, if learning vanishes fast, the cost advantage of the LOR declaration will gain in importance throughout all years and this will shift the $HR^L(t)$ curve upwards. The parameter $\delta$ mainly determines the variation in hazard proportions for ages when learning has already vanished or when patents get closer to their expiration date. The variance of the distribution of initial returns, $\sigma_{IR}$, particularly affects the curvature of $HR^X_{NoLOR}(t)$ and $HR^X_{LOR}(t)$. Higher values of $\sigma_{IR}$ imply a more skewed distribution of patent returns which cause higher dropout rates for intermediate ages and lower dropout rates for higher ages, when renewal fees are highest. Lower values of $\sigma_{IR}$ have the opposite effect.

Together with the probability of not becoming obsolete $\theta$, the parameters that determine the distribution of initial returns, $\mu_{IR}$, $\sigma_{IR}$, and the parameters that determine the LOR growth rates, $\phi^l$, $\sigma_0^l$, the model with learning depends on eight structural parameters:

$$\mu_{IR}, \sigma_{IR},\ \theta,\ \phi^l, \sigma_0^l,\ \phi^k, \sigma_0^k, \delta$$

The estimation results are presented in Table 7.

Although the reported mean square error (MSE) is higher compared to the deterministic model the overall model fit is slightly improved. MSE was calculated without using the weights we put on the hazard proportions for estimation (matrix $A(\omega)$ in the objective function (3)). Graphically, the hazard proportions of expiration do not differ much between

| Parameter | Model with Learning (Stochastic) |
|---|---|
| $\beta$ (fixed) | 0.950 |
| $\mu_{IR}$ | 8.787 |
| $\sigma_{IR}$ | 1.654 |
| $\theta$ | 0.920 |
| $\theta_{1998}$ | 0.978 |
| $\theta_{2002}$ | 0.832 |
| $\delta$ | 0.976 |
| $\phi^k$ | 0.202 |
| $\sigma_0^k$ | 0.948 |
| $\phi^l$ | 0.461 |
| $\sigma_0^l$ | 3.399 |
| Age-Cohort Cells | 282 |
| Sample Size | 211,869 |
| Simulation Size | 635,607 |
| $MSE_{All}$ | 0.000973 |
| $Var_{All}(h_N)$ | 0.0055 |
| $1 - MSE_{All}/Var_{All}(h_N)$ | 0.8233 |

Table 7: Parameter Estimates

both models (see Figures 8-10). However, the stochastic model allows the hazard rates of declaration to rise more clearly for the years seven to twelve.

Compared to the deterministic model (see Table 3) we receive higher estimates for the parameters which determine the distribution of the initial returns, $\mu_{IR}$ and $\sigma_{IR}$. The mean initial value (25,638€) and the median initial value (6,534€) are higher. Furthermore, we confirm the result from previous patent renewal studies that learning possibilities for patents, defined as $Pr(g_t^k \geq \delta)$, disappear after age five (see Table 8). Overall, we obtain value distributions with higher mean values for the stochastic model (see Table 9). The average value of patent protection is 300,415€. This is surprising, since in previous patent renewal studies the patent value estimates from the stochastic models (Pakes 1986; Lanjouw 1998) were lower than the ones from the deterministic models (Schankerman and Pakes 1986; Schankerman 1998).

A possible explanation for the discrepancy could be found in how we constructed the weighting matrix $A(\omega)$ in the objective function (3). Since the hazard proportions of declaration are at least ten times smaller than the hazard proportions of expiration we have increased the weight given to the distance between sample and simulated hazard proportions of declaration. Since our focus lies on the license of right system and the value of exclusivity, we tried to improve the efficiency of estimating the distribution of the parameters associated with the LOR growth rates. This might have undermined the efficiency of estimating the parameters that determine the variation in returns from full patent protection, $\mu_{IR}, \sigma_{IR}$ and $\phi^k, \sigma_0^k$. Besides, the stochastic model is computationally more costly, since double integrals

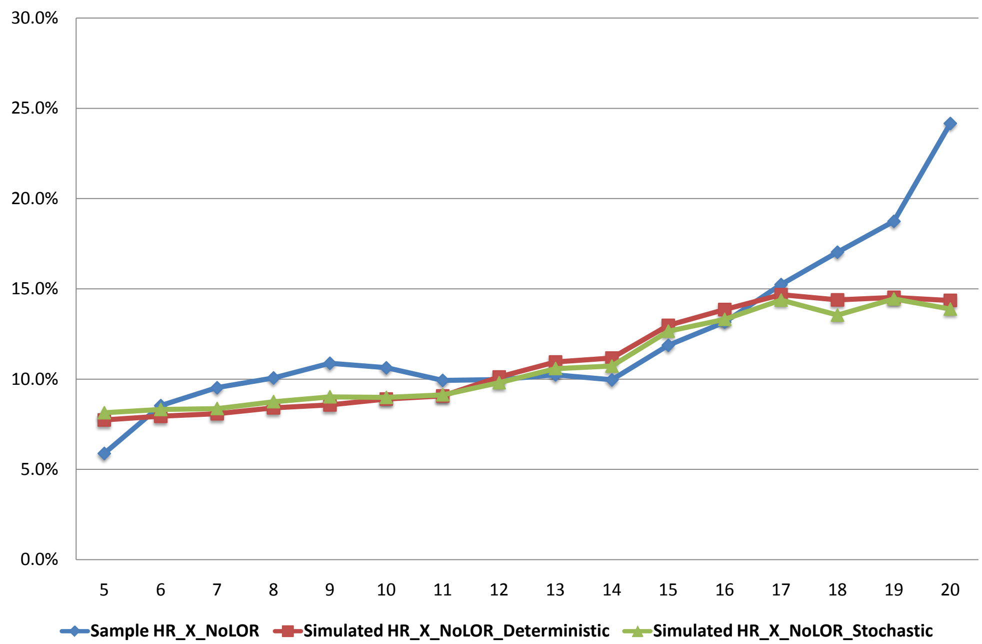


Figure 8: Hazard Proportions of Expiration - Patents Not Endorsed LOR

have to be evaluated numerically. Therefore, it was not possible to run the global optimization algorithms, which rely on random search, enough times to ensure that the estimator did not get stuck in a local optimum. In the deterministic model, in turn, the variation in returns from full patent protection is completely determined by the parameters of the distribution of initial returns, $\mu_{IR}$ and $\sigma_{IR}$. Furthermore, since we do not have to evaluate double integrals we have performed enough runs to believe that we have obtained robust results.

| Age | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| $Pr(g_t^k \geq \delta)$ | 26.88% | 5.77% | 0.21% | <0.01% | 0.00% | 0.00% |

Table 8: Learning and Patent Age

Nevertheless, the main results obtained from the deterministic model remain valid. Patents for which LOR has been declared are on average 21.74% less valuable than patents which have never been endorsed LOR. Furthermore, on average, 64.42% of the value of patents for which LOR had been declared was generated after the declaration. Since the estimated parameters which determine the LOR growth rates, $\phi^l$ and $\sigma_0^l$, do not differ much between both models, we obtain a similar distribution of the value of (non-) exclusivity (see Table 10). Almost 8% of patents could maintain at least 50% of the returns from full patent protection

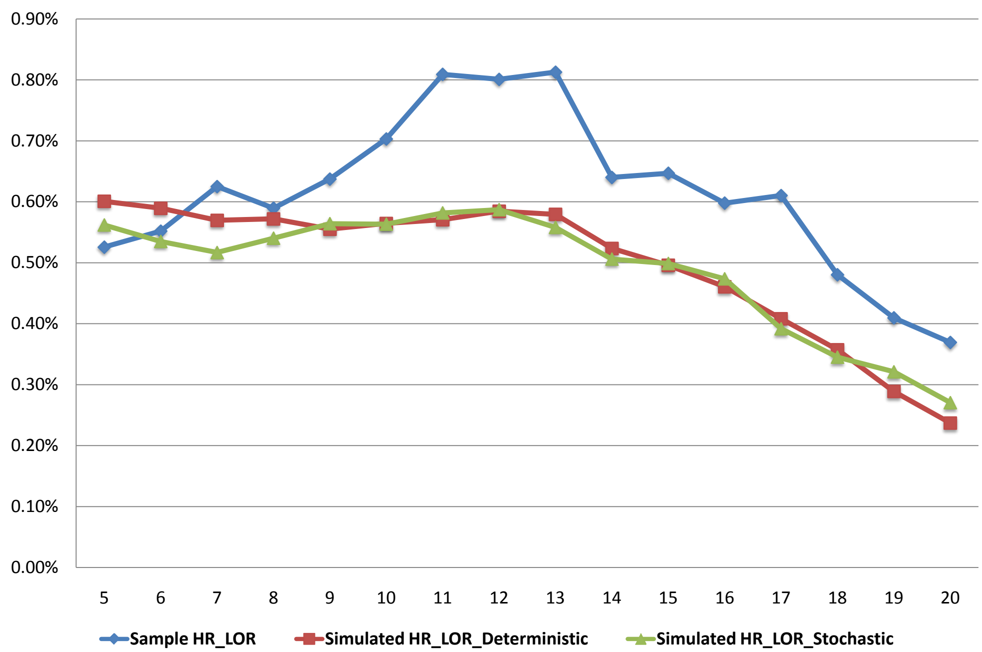


Figure 9: Hazard Proportions of LOR Declaration

if they declared LOR in the first year and only less than 2% if they declared in the twentieth year. Some patents, 0.63%, could even increase their returns if they gave up exclusivity in the first year and less than 0.03% if they gave up exclusivity in the last year.

The welfare implications also do not differ. Compared to the deterministic model the fraction of unambiguously welfare decreasing declarations (Cost-Saving Motive) is somewhat higher for early declarations and lower for declarations made for older patents (see Table 11). If we exclude the possibility to declare LOR from the patent system the aggregated private value of patent rights falls by 0.47% but the patent office's revenues rise by 2.31%. If we make the LOR declaration compulsory for all patents (Compulsory Licensing) the aggregated private value of patent rights falls by 80.44%.

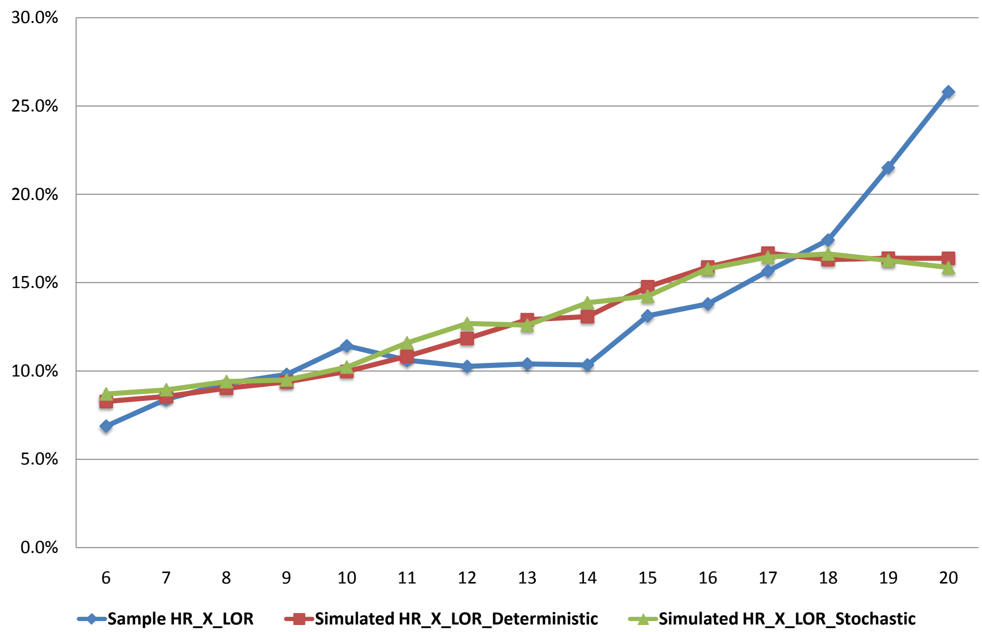


Figure 10: Hazard Proportions of Expiration - Patents Endorsed LOR

| Percentile | at Age 10<br>All | at Age 5<br>All | at Age 1<br>All | at Age 1<br>No LOR | at Age 1<br>Endorsed LOR |
|---|---|---|---|---|---|
| 50 | 0 | 14,405 | 56,144 | 57,569 | 39,082 |
| 75 | 19,256 | 87,867 | 200,108 | 204,275 | 131,080 |
| 90 | 113,525 | 317,003 | 602,521 | 610,462 | 450,369 |
| 95 | 258,759 | 652,934 | 1,164,599 | 1,176,564 | 952,350 |
| 99 | 1,045,241 | 2,370,391 | 3,931,909 | 3,960,412 | 3,495,881 |
| 99.9 | 4,563,423 | 9,798,748 | 15,373,407 | 15,396,543 | 14,666,449 |
| Mean | 62,758 | 160,938 | 300,415 | 304,182 | 238,049 |

Table 9: Value Distributions for Cohort 1983 in 2002€ (Stochastic Model)

| Age | $Pr(g_t^l \geq 1)$ | $Pr(g_t^l \geq 0.75)$ | $Pr(g_t^l \geq 0.5)$ |
|---|---|---|---|
| 1 | 0.63% | 2.25% | 7.96% |
| 2 | 0.56% | 2.04% | 7.48% |
| 3 | 0.49% | 1.86% | 7.01% |
| 4 | 0.43% | 1.68% | 6.56% |
| 5 | 0.38% | 1.52% | 6.14% |
| 6 | 0.33% | 1.37% | 5.73% |
| ... | ... | ... | ... |
| 18 | 0.05% | 0.32% | 2.16% |
| 19 | 0.04% | 0.28% | 1.96% |
| 20 | 0.03% | 0.24% | 1.78% |

Table 10: Evolution of LOR Growth Rates (Stochastic Model)

| Age | 1-5 | 6-10 | 11-15 | 16-20 | 1-20 |
|---|---|---|---|---|---|
| Cost-Saving Motive | 0.31% | 4.44% | 11.12% | 16.57% | 4.17% |
| Commitment Motive | 99.69% | 95.56 | 88.88 | 83.43 | 95.83% |

Table 11: Motive for LOR Declaration (Stochastic Model)