ELSEVIER

Research Policy 1596 (2002) 1–21

research policy

www.elsevier.com/locate/econbase

Citations, family size, opposition and the value of patent rights

Dietmar Harhoff [a,b,d,*], Frederic M. Scherer [c], Katrin Vopel [d]

[a] Ludwig-Maximilians-Universität Munich (LMU), Munich, Germany

[b] CEPR, London, UK

[c] John F. Kennedy School, Harvard University, Harvard, UK

[d] Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim, Germany

Accepted 16 October 2002

Abstract

We combine estimates of the value of patent rights from a survey of patent-holders with a set of indicator variables in order to model the value of patents. Our results suggest that the number of references to the patent literature as well as the citations a patent receives are positively related to its value. References to the non-patent literature are informative about the value of pharmaceutical and chemical patents, but not in other technical fields. Patents which are upheld in opposition and annulment procedures and patents representing large international patent families are particularly valuable.

Keywords: Patent rights; Patent-holders; Indicator variables

1. Introduction

For some decades, patents and patent statistics have been under intensive scrutiny by economists and policy-makers alike. In academic studies, both the prospect of studying incentive effects associated with the patent system[1] as well as the possibility of using patents to analyze particular aspects of the innovation process[2] (such as output, information spillovers, the direction of research activities, etc.) have attracted the attention of researchers.[3] In the public policy debate, many government agencies regularly interpret the number of patents or patent applications held by domestic firms and individual inventors as a measure of their nation's technological prowess. It is generally accepted by now that patent counts themselves do not constitute a good measure of inventive output. But the naïve use of patent statistics is continuing due to a lack of practical alternatives. A theoretically appealing solution would be to weight patents by their importance or value, thus generating value-weighted patent counts. Having a reliable construction of this type would be of considerable value for research in a

* Corresponding author. Present address: University of Munich, Munich School of Management, Institute for Innovation Research and Technology Management, Kaulbachstr. 45, D-80539 Munich, Germany. Tel.: +49-89-2180-2239; fax: +49-89-2180-6284.
E-mail address: harhoff@bwl.uni-muenchen.de (D. Harhoff).

[1] It is more appropriate to speak of patent systems, since national differences do persist. Patent rights are always subject to national jurisdiction and legislation, and even a patent obtained through the European Patent Office for Germany is a patent according to German patent law. The relatively high degree of homogeneity of European patent rights is a consequence of reasonably harmonized national patent laws.

[2] See, e.g. Trajtenberg et al. (1993) and Jaffe and Trajtenberg (1996).

[3] See Griliches (1990) for a comprehensive survey about the use of patents as economic indicators.

0048-7333/02/$ – see front matter © 2002 Published by Elsevier Science B.V.
PII: S0048-7333(02)00124-5

number of areas, among them productivity studies and the analysis of the industrial organization of technologically advanced sectors and firms. How one could generate an assessment of the value of patent rights from publicly available data is the central question of this paper.

The task of assessing the value of patent rights is a particularly difficult one, since the distribution of these values is highly skew. The skewness property has been discussed by numerous authors, e.g. Scherer (1965), Pakes and Schankerman (1984), Pakes (1986), and Griliches, 1990.[4] Summarizing the insights from several studies on this point, Griliches (1990, p. 1702) concludes: "These findings, especially the large amount of skewness in this distribution, lead to rather pessimistic implications for the use of patent counts as indicators of short-run changes in the output of R&D." Any attempt to cast more light on the value of patent portfolios must therefore turn to additional information which is correlated with the value of patent rights. Such correlates could conceivably be used to construct quality- or value-weighted patent counts which would measure inventive output with much greater accuracy than unweighted count statistics.

Using information contained in the renewal behavior of patent-holders has been one attempt to solve the problem described here. Studies in the patent renewal literature exploit the fact that it is expensive to holders of European patents to renew patent protection for an additional year.[5] The value measures obtained in this literature approximate the return to continued patent protection, given that the patent has already been published. Pakes and Schankerman (1984), Pakes (1986), and Schankerman and Pakes (1986) have been the first to develop and estimate models in which the observed renewal decisions are used to estimate the distribution of patent values. Lanjouw (1998) has refined this approach to the estimation of patent values. However, the results of these studies rest on assumptions regarding the unobserved value distribution of the most valuable patents—those which are renewed to full statutory term.

Another strategy is to use a set of variables correlated with value and to estimate a regression function that can be used to approximate patent value and test hypotheses on its determinants. For example, Lerner (1994) uses the market value of biotechnology firms as a measure of the value of the respective patent portfolio. He relates the value measure to the number of international patent classifications (IPCs) referred to in the patent. He argues that this variable captures the scope of the patented invention and reports a positive and sizable correlation between the firm's market value and the average scope of its patents. Trajtenberg (1990) computes a measure of social returns to innovation in the computer-tomography scanner industry and relates that measure to citation indicators, finding a positive and significant correlation. Putnam (1996) points out that the number of jurisdictions in which patent protection is sought for a particular invention is likely to be correlated with the value of the invention and thus with the value of any single national patent right. A hope frequently expressed in the patent valuation literature is that the value of patent rights can be approximated with sufficient reliability by combining these and other indicators.

We follow this approach in the empirical part of our paper. We use a unique dataset with value assessments coming directly from a survey of patent-holders. These data allow us to circumvent the need for using indirect measures of patent value. Moreover, since we observe the private value of patents in the hitherto "unseen tail"[6] of the value distribution, we also circumvent a major problem of the renewal literature. The value concept adopted in our study differs considerably from the one implied by previous patent renewal studies. Failure to renew a patent means that the covered subject matter will move into the public domain, allowing it to be used by both the original patent-holder and others. In our survey, however, we measure the value of a patent right as the price for which the original inventor would be willing to sell the patent right. The sale of all rights in a patent to a third party implies that the buyer can prevent the original patent-holder from practicing the subject invention or demand license fees approaching the value of profits foregone. For broad patents that cover key features of products or processes—a case found in interviews to

[4] A detailed analysis of the data used in this paper strongly supports the view that the patent value distribution is highly skew. See Harhoff et al. (2003).

[5] Following the European examples, the US initiated a system of renewal fees for patents that were applied for after 1980. See Griliches (1990, p. 1681).

[6] Griliches (1990, p. 1681).

be common for the most valuable patents—the sale of rights puts at risk the whole stream of quasi-rents realizable from a product or process. Or at minimum, the sale of rights can impose upon the seller the profit sacrifice from foregoing key patented features or the cost of inventing around them. Therefore, higher valuations are expected under our approach than under the renewal approach.

Using our survey estimates, we embark on a systematic attempt to model patent right values in terms of observable correlates. We use a broad set of indicators to model the respective valuations, including

- the number of citations a patent has received within the German patent system;
- the analogous measure of citations received from subsequent applications in the European Patent Office;
- the number of references to prior patents, generated during the search and examination process;
- and analogously, the number of references made to the non-patent literature, i.e. mostly to scientific journals.

  These measures (also referred to as forward citations for the first two and backward citations in the latter cases) have been discussed intensively in the patent literature, but have not yet been included jointly in a study. We complement these indicators by using data on

- the outcome of opposition proceedings, a kind of first-instance challenge suit attacking the patent's validity;
- patent "family size", computed as the number of jurisdictions in which patent protection was sought for the same invention;
- and the number of different four-digit IPC classifications which has been taken to provide a measure of the scope of the patent.

The latter measure follows Lerner's (1994) example, while the "family size" variable has been proposed by Putnam (1996). Our indicator generated from the outcome of opposition cases has not been used before, and to the best of our knowledge, the opposition procedure has not been discussed in detail in the economics literature either.

Since our survey estimates of patent value were obtained using interval scales, our econometric approach reflects this form of scaling. We use an ordered probit specification with known thresholds which allows us to obtain point estimates of the coefficients and of the variance of the error term of the conditional value distribution. Given the notorious problems in assessing the value of patent rights, our specifications are surprisingly successful. Almost all of the earlier-mentioned correlates have explanatory power, and the size of the coefficients is well in line with a number of ex ante expectations. Our results suggest that both the number of backward citations (either to the patent or non-patent literature) as well as the citations a patent receives are positively related to a patent's value. The number of different four-digit IPC classifications is not informative about patent value. Patents which are upheld against opposition and patents representing large international patent families are particularly valuable.

In the remainder of the paper, we first turn to the question of what we want to measure in our survey of patent-holders. We consider various value constructs and compare them. We then discuss in Section 3 our survey of German patent-owners in which estimates for the monetary value of German patents were obtained.[7] These survey estimates will function as our dependent variables in the modeling exercise. In Section 4, we describe in more detail the RHS variables listed previously, and we discuss in detail the theoretical rationale for including them in our estimation equation, and in some cases our ex ante expectations as to the coefficient signs and sizes. In Section 5, we turn to our empirical results. We first discuss descriptive statistics of the value correlates and specify our regression function. A discussion of our multivariate results follows. Finally, in Section 6, we conclude with a summary of our results and a discussion of further research.

2. Theoretical issues in measuring the value of patent rights

Value constructs are not always precisely defined in the patent literature. In order to demonstrate the importance of such a definition, it is helpful to con-

[7] Since our study focuses on data from the German patent system, a brief description of features unique to this German patent system is presented in Appendix A.

Table 1
Value definitions

Cases	Definition A "renewal value of the patent" (V_A)	Definition B "asset value of the patent" (V_B)
I. Standard case, no cumulative invention, no blocking	$\Pi_1(q+q_1, q+(1-\lambda)q_1) - \Pi_{N+1}(q+q_1)$	$\Pi_1(q+q_1, q+(1-\lambda)q_1) - \Pi_N(q+(1-\lambda)q_1, q+q_1)$
II. Cumulative invention with blocking power	$\Pi_1(q+q_1+q_2, q+(1-\lambda)(q_1+q_2)) - \Pi_1(q+q_1+q_2, q+q_1+(1-\lambda)q_2))$	$\Pi_1(q+q_1+q_2, q+(1-\lambda)(q_1+q_2)) - \Pi_N(q+(1-\lambda)(q_1+q_2), q+q_1+(1-\lambda)q_2)$
III. Substitute technology (sleeping patent)	$\Pi_1(q+q_1, q+(1-\lambda)q_1) - \Pi_{N+1}(q+q_1)$	$\Pi_1(q+q_1, q+(1-\lambda)q_1) - \Pi_2(q+q_1, q+(1-\lambda)q_1)$

sider various value constructs in the context of a simple, yet fairly general theoretical model. We focus on the *private* value of patent rights and consider two concepts here: the value of renewed patent protection and the asset value of the patent right.[8] Since patents may serve different purposes, we compute these value measures for three scenarios of innovation which are likely to be relevant empirically. In the first scenario, the patent protects a quality improvement of a product, but there is no interaction between this particular and other patent rights. In the second scenario, we allow for such interactions as they occur in cumulative research processes. In such cases, control over one patent may affect the value of other patent rights as well, e.g. if the owner of one patent can block the use of another one. Finally, in the third scenario, we consider the case of multiple patents covering technologies that are perfect economic substitutes. We will comment on the empirical relevance of these cases later.

Ex ante, we consider a symmetric oligopoly with $N+1$ firms, all of which offer a product with quality q. Products may be differentiated horizontally. Ex post, one firm holds a patent on a technology which allows the firm to increase its product quality by q_1. We allow patent protection to be less than perfect. Imperfect patent protection implies that all other firms will be able to enjoy a costless improvement of their own product quality by $(1-\lambda)q_1$ with $\lambda \in [0, 1]$. Patent protection is perfect for $\lambda = 1$ and completely ineffective for $\lambda = 0$.

[8] A third value concept could be considered as well: the value of the patent right to a "stand-alone" inventor who compares her profit in the case of technical leadership to the profit gained in some ex ante state of the industry. Since this construct neglects strategic aspects completely, we do not include it here.

For each of the three scenarios considered, we describe the value definitions in terms of the profits that the patent-holder receives contingent on the quality of its own and other firms' products. Let $\Pi_{N+1}(a)$ be the profit (conceivably equal to zero) that each of the $N+1$ firms receive when their product quality is equal to a. If one firm has product quality a and all other firms have a lower product quality b, let the leading firm's profit be given by $\Pi_1(a, b)$ and the profit of each of the N other firms by $\Pi_N(b, a)$. Note that by definition $\Pi_1(a, a) = \Pi_N(a, a) = \Pi_{N+1}(a)$. We assume further that $\Pi_1(a, b)$ and $\Pi_{N+1}(a)$ are monotonically increasing in a; and that $\Pi_1(a, b)$ and $\Pi_N(b, a)$ are monotonically decreasing in b and a, respectively. Finally, in one of our three scenarios, the case may arise that two firms own patents protecting different technologies, but yielding the same extent of product improvement. Let the profit of the two technology leaders then be given by $\Pi_2(a, b)$, and the profits of each of the $N-2$ laggards be given by $\Pi_{N-1}(b, a)$, where $a > b$ by assumption. Based on these simple conventions, we can demonstrate important differences between the value concepts under consideration. We summarize the results of our discussion in Table 1.

Consider the first innovation scenario (Case I) for which we assume that issues of cumulative research, patent blocking and "sleeping patents" are absent. Ex ante, all firms have profits equal to $\Pi_{N+1}(q)$. Ex post, the patent-holding firm earns $\Pi_1(q+q_1, q+(1-\lambda)q_1)$ while all other firms have profits equal to $\Pi_N(q+(1-\lambda)q_1, q+q_1)$. If the patent lapses into the public domain (i.e. if it is not renewed), then all firms will earn profits equal to $\Pi_{N+1}(q+q_1)$ ex post. If the patent is sold by the original patent-holder to another firm in the industry, then the inventor firm's ex post profit is given by $\Pi_N(q+(1-\lambda)q_1, q+q_1)$. From these terms, we can compute the respective values for the patented invention as summarized in Table 1. For the case of a duopoly ($N = 1$), it is easy to verify from these results that $V_B \geq V_A$, i.e. that the asset value of the patent dominates the renewal value. For increasing N, the same logic applies, although the difference between V_B and V_A is likely to decrease as N grows. Note that as patent protection gets weaker ($\lambda \to 0$), V_B also converges to V_A. The logic of this comparison is obvious: in the case of the renewal value, the counterfactual is a situation in which all firms have access to the patented technology. In the case of the asset value construct, technological leadership is transferred to another firm, imposing a much greater opportunity cost from the loss of the patent on the patent-holder than he perceives when all firms (including himself) get access to the technology.

Case II allows for cumulative invention processes and patent blocking in the following sense: we assume that the patent-holder has first obtained a patent protecting quality improvement q_1, and then a second patent covering a further quality improvement q_2. The second patent builds cumulatively on the first, and the second patented quality improvement can only be used fully by the firm also holding the first patent. In this stylized example, the holder of the first patent has blocking power over the second patent. Many observers have argued that cumulative invention is an important feature of advances in science and technology.[9] Again, both improvements are subject to spillovers due to imperfect patent protection. Ex ante, all firms have again profits equal to $\Pi_{N+1}(q)$. Ex post, the patent-holding firm earns $\Pi_1(q + q_1 + q_2, q + (1 - \lambda)(q_1 + q_2))$ while all other firms have profits equal to $\Pi_N(q + (1 - \lambda)(q_1 + q_2), q + q_1 + q_2)$.

If the first patent lapses into the public domain, but the second one does not, then the original patent-holder will still be able to make full use of the second invention. Hence, the patent-holder will earn profits equal to $\Pi_1(q + q_1 + q_2, q + q_1 + (1 - \lambda)q_2))$ while all other firms will earn profits equal to $\Pi_N(q + q_1 + (1 - \lambda)q_2, q + q_1 + q_2)$. Since the patent lapses into the public domain, issues of blocking do not arise. Thus, in addition to the differences discussed in the first scenario, the renewal value concept will typically not capture the blocking value of patents as discussed here. Conversely, if the first patent is sold by the original patent-holder to another firm in the industry, then the second patent can no longer be used fully by the inventor. In this case, the inventor firm's profit is given by $\Pi_N(q + (1 - \lambda)(q_1 + q_2), q + q_1 + (1 - \lambda)q_2)$. Again, it is easy to verify that $V_B \geq V_A$. Moreover, with weakening patent protection, we have again that $V_B \to V_A$.

In order to demonstrate that the ranking of values may be different under other circumstances, consider Case III which allows for "sleeping patents," i.e. patent rights that are never licensed or used in production by the patent-holder. Hence, there is no *direct* value that these patents have, say by generating above-average profits. Nonetheless, there may be a strategic advantage of owning the patent right, since such patents can possibly be used to exclude other firms from using technologies which are substitutes for the patent-holder's own patented product or process. To clarify this point, suppose that one firm (the patent-holder) owns two patents protecting two different technologies leading to product improvements q_1 and q_2, respectively. Assume further that both patents are substitutes and that they cannot be used in conjunction. Moreover, the patent rights can be exercised independently, i.e. owning the first patent does not grant any blocking power over the second, and vice versa. For simplicity, suppose that $q_1 = q_2$. In this case, the patent-holder's profit is given by $\Pi_1(q + q_1, q + (1 - \lambda)q_1)$. If the first patent lapses into the public domain, the patent-holder and the other firms may be using different technologies, but the oligopolistic outcome is still symmetric. All firms will earn $\Pi_{N+1}(q + q_1)$ since control over the second patent does not allow the patent-owner to exclude other firms from using the substitute technology.

If the patent is sold to another firm, the situation is more complex: now we have two firms with access to different, but equally effective product improvements. The profit of each of the two leaders is now be given by $\Pi_2(q + q_1, q + (1 - \lambda)q_1)$, while the other $N - 2$ firms earn $\Pi_{N-2}(q + (1 - \lambda)q_1, q + q_1)$. We would expect that without collusion among the two leading firms, a single patent-owner will earn higher profits than any of the two firms simultaneously producing the

[9] For a discussion of blocking power in the semiconductor industry see von Hippel (1982). The recent surge of patenting in that industry has been analyzed by Hall and Ziedonis (2001) who argue that the potential of blocking forces firms to patent excessively.

high-quality product. Thus, $\Pi_1(q+q_1, q+(1-\lambda)q_1) > \Pi_2(q+q_1, q+(1-\lambda)q_1)$. Moreover, it is plausible to assume that $\Pi_2(q+q_1, q+(1-\lambda)q_1) \geq \Pi_{N+1}(q+q_1)$ with equality binding for the duopoly case where $N+1=2$. Thus, for this case we conclude that $V_B \leq V_A$. The logic here is again that the renewal concept captures the value of the patent being kept away from the public domain, while the asset value reflects the logic of transferring one of the two substitute patents to a competitor, thus generating two leading firms. However, in this case, the renewal value may be greater than the asset value, since it is better to have only one competitor matching one's own technology than to have many equally skilled adversaries.

These simple calculations have several implications. One can see easily that the renewal value of the patent is equivalent to the value of licensing the patent right to all other N firms in the market when the patent-holder maintains the right to use the patented technology. Thus, the former patent-holder may lose the leadership position previously enjoyed, but no other firm can dominate the industry ex post. In computing the asset value, we implicitly assume that leadership is transferred to the buyer of the patent right, including all rights to block other patent rights which are contingent on the acquired one. Obviously, there is no single concept of private value that is optimal for all purposes. But to the extent that blocking power is an important phenomenon (as the patent literature suggests), the asset value construct seems preferable over the renewal concept. Our own survey has produced ample evidence that blocking power is indeed an important phenomenon. In 69 interviews with holders of particularly important patents (see Harhoff et al., 2003), we find evidence of some blocking phenomena in about one-third of them. Conversely, the case of patenting several substitute technologies also occurs in our data, but only in two cases.

The consideration of the first scenario reveals another reason why the asset value construct is theoretically more appealing than the renewal value: it approximates the prize that the winner of a patent race (with subsequent imperfect patent protection) will perceive. If several firms compete for the new patent right, their actions will be guided by the difference in profits from (i) having the patent and being the leader and (ii) not obtaining the patent and some other firm becoming the leader. This is exactly what the asset value captures. It is therefore also a reasonable reflection of the incentives implicit in a competitive innovation process.

3. Estimates of patent value

In the survey upon which this paper is based, we obtained value estimates that were meant to capture the asset values of patent rights, i.e. measures that do explicitly include strategic aspects and the value of blocking power. The survey was directed at German patent-holders who were asked to assess the asset value of their patent rights. The survey was conducted in 1996, and the data were used to study the distribution of patent rights in detail in Harhoff et al. (2003). The survey considered all patent grants with a 1977 German priority date which were renewed to full term, i.e. expired during 1995. For 772 patents, value estimates were obtained in direct surveys of patent-holding firms.[10]

The German Patent Office supplied us with data on all 4349 patents that were entitled to a 1977 priority and were renewed to full term and expired in 1995. Of these, 1431 patents were held by German patent-holders.[11] Of these 1431 full-term German patents, it was possible to trace 1325, or 92.3%, to surviving firms or individual inventors. Most of the untraced patent-owners were individual inventors or firms too small to be located through standard business directories. The 684 firms or individuals owning the 1352 traced patents were contacted by telephone to identify the most appropriate respondent, and a questionnaire was dispatched, usually by facsimile, on each relevant patent. Its essence was a single substantive counter-factual question, translated as follows:

> If in 1980 you had known how its contribution to the future profitability of your enterprise would unfold, what is the minimum price for which you would have sold the patent, assuming that you had a good-faith offer to purchase?

[10] Details on the survey procedures used are presented in Harhoff et al. (2003). The subsequent discussion of the data builds on this paper.

[11] We report further details on the 1977 application cohort in Section 4 of the paper.

Respondents were asked to place their patent within one of five broad minimum selling price ranges: less than DM 100,000, 100–399,999, 400–999,999, 1–5 million, and more than DM 5 million. After extensive follow-up, positive responses were obtained on 772 patents (57.1% of the total on which contacts were made) held by 394 organizational entities and individual inventors (including 10 unaffiliated inventors).

We then sought to conduct detailed interviews with the holders of the 99 patents that were associated with counterfactual sales prices in excess of DM 5 million. We conducted a total of 69 personal interviews, each of them taking between 1 and 2 h. In addition to questions pertaining to the invention process, we asked our respondents to answer the previous question as precisely as possible.[12] Thus, for a large number of particularly valuable patents we obtained more precise information on the patent right's value. We then proceeded to obtain separate value estimates from profit flow data. The flow value estimates were computed from annual sales and profit ratio data multiplied by a correction factor accounting for the contribution of the patent,[13] with all values converted to 1995 price levels and then discounted back to the year 1980 at a 0.05 real discount rate. In these interviews, useable value responses were obtained on 69 patents originally valued at DM 5 million or more. For another 10 patents we were able to obtain rough estimates of bounds between which the true value of the patent is expected to fall.

Among the 69 interview cases, profit flow estimates were available in 54 cases; counter-factual asset sale price estimates were available in 38 cases; and in 23 cases, both flow and asset sale estimates were obtained. In those 23 cases, the geometric mean value was DM 11.1 million per invention with flow estimation and DM 19.1 million in the asset sale counter-factual. The differences can presumably be explained by the strategic value of the patents which was not fully captured in our flow profit calculations. Although the differences appear sizeable, they are not significant at the 0.05 level ($t = 1.21$) in a test of logarithmic means. In what follows, flow value estimates are used in all but the 15 cases in which they were unavailable and counter-factual estimates were substituted. In the interview cases, best estimate values were accompanied by an error range, whose average single-side magnitude was 25.05% of the best estimate, with a median value of 22.66%.[14]

Table 2
Respondents' valuation of patents with full term—results after interviews

Valuation of patent	Cases	Percent
Less than DM 100,000	203	27.0
DM 100,000–399,999	200	26.6
DM 400,000–999,999	154	20.5
DM 1–5 million	129	17.2
DM 5–10 million	28	3.7
DM 10–20 million	16	2.1
DM 20–40 million	15	2.0
DM 40–80 million	5	0.7
More than DM 80 million	2	0.3
Total	752	100.0

Note: the survey also produced data for 20 other patents which were assessed by respondents of our written survey to be worth more than DM 5 million. In these cases, no additional information was available. See the text for explanations.

The distribution of the value of patent rights is summarized in Table 2. In our estimation procedure, we will also assume that the 9346 German-owned patents which did not reach full-term status can be grouped together and that they are uniformly less valuable than the patents reaching full term. Thus, these patents form an additional value category. As one would expect from the discussion in Section 2, the value estimates obtained in our survey are considerably larger than value estimates from the renewal literature. For details, see Harhoff et al. (2003). But as we discussed in the Section 2 of this paper, this result does not mean that the renewal-based value estimates are erroneous. Renewal studies employ a different value construct, and our theoretical results let us expect that average values from renewal studies are lower than asset values. This expectation is indeed borne out by the data.

[12] As in the telefax survey, respondents in the more detailed interviews frequently asked us whether they should assume that the patent would be sold to a competitor. It was quite clear that this consideration mattered considerably for their value estimates.

[13] To obtain this factor, we asked respondents to estimate the share of total profits that could not have been earned without having ownership of the patent right.

[14] The results reported below are robust in the sense that using either counterfactual asset values or value estimates from our flow profit calculation do not change the results in a major way.

4. Correlates of patent value

4.1. Patent scope

The theoretical patent literature in economics has long since discovered that the scope of a patent may be an important determinant of the efficacy of patent protection (see, e.g. Scotchmer, 1991, 1996). However, as Merges and Nelson (1990) point out, the economics of patent scope are rather complex. Moreover, the scope of a patent is difficult to operationalize and measure. We follow Lerner's approach and generate a measure of scope computed as the number of different four-digit IPC classification codes in the application document.

4.2. Citations received from subsequent patents

It has long been argued that the value of patents can be assessed in a similar way as the impact of scientific publications, i.e. by looking at the frequency of citations that a particular contribution receives from subsequent works. This suggestion received considerable support in Trajtenberg's study of medical scanning devices (1990). Using data on a clearly defined set of products (computer tomography scanners), he showed that estimates of the social value of the invention were highly correlated with the incidence of subsequent citation. Harhoff et al. (1999) found that the number of citations received within the German patent system is highly correlated with the patent right's value, but that the relationship is quite noisy.

Since we study German-owned patents, the most natural choice for the reference group of patents which can conceivably cite a given patent in our sample are other German patents. Thus, for each of the German patents held by German patent applicants, we compute the number of instances in which other patents and patent applications refer to the 1977 patents we are interested in. The European Patent Office administers a domain which is considerably larger (in terms of patents issued) than the German system. Hence, within this system one would expect to find higher instances of citation if the number of citations is computed in the same way as for the German Patent Office domain. Moreover, one would expect that these citations reflect the importance of the cited patent in international competition. Our expectation is therefore to find an even stronger partial correlation between EPO citations and value than in the case of DPA citations.[15] Citations that occurred by July 1997 were included in our DPA citation count, while the EPO data include citations up to February of 1998.

4.3. References to other patents (backward citations)

Turning around the logic of citations received, it is plausible that a relatively small scope and—ceteris paribus—low monetary value should characterize a patent whose examination report contains a large number of backward citations. After all, the logic of these references (*Entgegenhaltungen*) is to present subject matter that is held against the claims of the application. Several patent lawyers and examiners whom we confronted with this logic were not supportive of it. They pointed out that a patent application seeking to protect an invention with broad scope might induce the examiner to delineate the patent claims by inserting more references to the relevant patent literature. We may therefore expect backward citations to reflect broad scope as well as the existence of subject matter that may restrict the scope of the patent. Absent a measure of the scope of patent claims (such as their number), it is therefore not clear whether the coefficient should be positive or negative.[16]

4.4. References to the non-patent literature

Patents may be based in part or fully on new scientific knowledge.[17] Since published research results can be used to document the state of the art against which the application has to be evaluated, patent examiners

[15] A distinction between self-citations and citations by other patent-holders would be helpful, but is not possible with the data at hand.

[16] Lanjouw and Schankerman (1997) include the number of claims and backward citations per claim in their probit analysis of litigation. The first variable turns out to have a positive and significant coefficient, the coefficient of the latter one is not significantly different from zero. The absence of a count of the number of claims in our data is due to the fact that PATDPA did not include claims in their database in 1977.

[17] The growing importance of the linkage between private patenting activities and scientific knowledge has been documented by Narin et al. (1997). See also Grupp and Schmoch (1992).

will then search for relevant references in the scientific literature. Again, the logic of these references is to document the material that is held against the application. As in the case of references to the patent literature, a relatively high number of references to the scientific literature may therefore indicate patents of relatively high value.

The PATDPA database contains this information and allows us to compute the number of references to the non-patent literature included in the examiner's report. Inspection of these references reveals an interesting picture. Based on an evaluation of 100 patent document records containing such references, about 60% of the references refer to scientific and technical journals. The remainder is made up largely by references to trade journals, to firm publications or to standard texts in the respective technical field, e.g. for the classification of chemical substances or specific mechanical designs.

The fact that not all non-patent references refer to scientific sources is well-known. Thus, the number of non-patent references is not a direct measure of the strength of a patent's science linkage. This problem has been studied in detail by Schmoch (1993). A survey of the literature on this topic is contained in Meyer (1999). However, the number of non-patent references is considerably easier to compute than the number of explicit links to the scientific literature. Moreover, we also expect that "science-based" patents contain a relatively high number of non-patent references. This is actually borne out by the data (see later). Thus, we maintain the easily available indicator which simply counts the references to the non-patent literature and expect despite of the measurement problem that such references have greater explanatory power in science-based industries, such as pharmaceutical and chemical products than in less science-oriented areas. This expectation is also confirmed in our estimates.

4.5. Family size

Putnam (1996) and subsequently a number of authors have argued out that information on family size may be particularly well suited as an indicator of the value of patent rights. The studies by Putnam (1996) and Lanjouw et al. (1998) have shown that the size of a patent family, measured as the number of jurisdictions in which a patent grant has been sought, and the survival span of patents, i.e. the time from application to non-renewal or to expiration, are highly correlated. To account for the potential explanatory power of "family size", we obtained the number of nations in which protection for a particular invention was sought from Derwent's World Patent Index (WPI) database for each of the patents in our database.

4.6. Outcome of opposition cases

While the opposition process has not been discussed in the economics literature, its importance has been noted by legal scholars and practitioners. Merges (1999) argues that the opposition system of the European Patent Office appears to be employed far more frequently than the USPTO's reexamination procedure and may thus be far more effective in weeding out weak patents. van der Drift (1989) points out that opposition to patents granted by the European Patent Office (feasible within 9 months after the grant) can be helpful in assessing the value of patent rights. On average, 8% of all EPO patents are opposed, and 14% of the patents thus attacked are revoked. However, opposition rates and outcomes for EPO patents vary considerably. Leading companies have their patents opposed far more often than on average. For example, 23% of all Unilever patents in van der Drift's data have been opposed, and 16% of the patents opposed have ultimately been revoked. Companies like Procter and Gamble, ICI, Union Carbide and BASF face opposition rates far in excess of 10% of their EPO patent grants.[18] Personal interviews with patent examiners suggest that similar differences characterize the opposition process at the German Patent Office.

Table 3 shows the actual outcomes of opposition and annulment procedures in the case of the 1977 application year cohort. In the sample used here, 8.4% of all patents encounter opposition. The annulment

[18] van der Drift computes opposition indicators, which attempt to measure the extent and success of opposition activity, but he is not able to relate them to actual estimates of patent value. Nonetheless, the essence of his comments imply that opposed patents are likely to be valuable, and that a successful defense of the patent against opposition is an interesting (and early) indicator of patent value. Given that the opposition procedure at the EPO follows the corresponding German institution, these comments confirm our view that patents which survived opposition are likely to be particularly valuable. Opposition at the EPO is also studied in Merges (1999).

Table 3
Outcome of opposition and annulment cases (1977 Priority Cohort)

	Cases	Percent
Opposition procedure (*Einspruchsverfahren*)		
Rejected (opposition not admitted)	26	1.3
Patent restricted	328	16.1
Patent fully upheld	482	23.7
Patent revoked	638	31.3
Patent withdrawn/lapsed	526	27.6
Total	2036	100.0
Annulment procedure (*Nichtigkeitsverfahren*)		
Patent upheld	52	71.2
Patent held invalid	11	15.1
Other	10	13.7
Total	73	100.0

Note: there were 11 cases with opposition and subsequent annulment procedure, i.e. 62 of the annulment cases had not been not subject to opposition.

procedure (*Nichtigkeitsverfahren*) occurs at a much lower frequency in 0.3% of all cases in which a patent was granted initially. Opposition may be held inadmissible in which case it has no consequences for the patent-holder; it may lead to a restriction of the scope of the patent; or it may lead to the patent being upheld completely. These cases will be considered successful outcomes for the patent applicant in the analysis later, and they account for 41.1% of opposition cases. Alternatively, the patent may be revoked completely (31.3%). Moreover, the patent-holder may decide to let the patent lapse (by not paying renewal fees) or to withdraw the patent (27.6%). Attacks via the annulment procedure (*Nichtigkeitsverfahren*) are less frequent (73 cases) and the outcomes are more difficult to classify from the PATDPA data used in this study. However, it is clear from the data that requests for annulment are less successful than opposition cases: in 52 out of 73 cases the patent-holder prevails.

For the purpose of this study, we identify two groups of patents: those that withstood an attack in the regular opposition procedure (*Einspruchsverfahren*), and those that survived the more complex and less frequent annulment procedure (*Nichtigkeitsverfahren*) which is often a consequence of patent litigation.[19] In some of the descriptive statistics, these are pooled under the label of patents fully or partially upheld in the case of opposition or annulment. From interviews with patent attorneys, we know that the cost of an opposition procedure can be substantial for the attacker. Cost estimates including attorney fees range between DM 20,000 and 50,000. However, these figures are dwarfed by the expenses incurred for an annulment process where the attacker may easily have to spend several DM 100,000. Accordingly, we anticipate that successfully withstood annulment should be a stronger indicator of the patent's value than successfully defeated opposition.

5. Data, specification and estimation results

5.1. The 1977 sample of applications

While our survey targeted the population of German-held full-term patents, we discuss in this section the full cohort of 1977 applications in order to gain further insight into the patent granting process in Germany.[20] Table 4 summarizes the composition of the 1977 application year cohort. Of the total of 57,782 patent applications, only 24,116 (41.7%) were initially (prior to opposition) granted. The rate at which patents are initially granted by the German Patent Office differs considerably between German and foreign applicants (column 2). This effect is expected, since obtaining patent protection in other than the own national jurisdiction is typically expensive. Applicants will therefore seek international patent protection only for their most valuable inventions (Putnam, 1991). Thus, foreign patents should also be more likely to pass the examination process. US patent applications are awarded patent grants in 38% of the cases, and French applicants have 40.9% of their applications approved. Although the pattern is confirmed for all non-German applications except the British applications, the performance of Japanese applications is stunning: almost 64% of Japanese patent applications receive patent grants.

Once granted, 8.7% of the patent grants are challenged in the opposition process, and in 57.8% of these opposition cases, the challenger ultimately

[19] In Germany, questions of patent validity (annulment challenges) and of infringement are dealt with separately. Validity cases are delegated by the civil courts to the central German Patent Court.

[20] To generate the statistics discussed here, we used the PATDPA data source. See STN International (1990) for details.

Table 4
Type and outcomes of DPA applications with priority year 1977 by applicant nation

Applicant nation	(1) Patent applications	(2) Patent applications withdrawn or patent not granted (% of (1))	(3) Patents initially granted (% of (1))	(4) Patents opposed (% of (3))	(5) Opposed patents fully or partially upheld (% of (4))	(6) Patents surviving oppostion or not opposed (% of (3))	(7) Patents renewed to full term (% of (6))
DE	27,954	16,483 (59.0%)	11,471 (41.0%)	1145 (10.0%)	454 (39.7%)	10,780 (94.0%)	1431 (13.3%)
JP	4,469	1,582 (35.4%)	2,887 (64.6%)	207 (7.2%)	98 (47.3%)	2,778 (96.2%)	936 (33.7%)
US	10,207	6,227 (61.0%)	3,980 (39.0%)	284 (7.1%)	108 (38.0%)	3,804 (95.6%)	900 (23.7%)
FR	2,675	1,496 (55.9%)	1,179 (44.1%)	87 (7.4%)	44 (50.6%)	1,136 (96.4%)	221 (19.5%)
CH	2,509	1,462 (58.3%)	1,047 (41.7%)	83 (7.9%)	46 (55.4%)	1,010 (96.5%)	214 (21.2%)
GB	2,451	1,813 (74.0%)	638 (26.0%)	55 (8.6%)	26 (47.3%)	609 (95.5%)	166 (27.3%)
Other	7,517	4,603 (61.2%)	2,914 (38.8%)	237 (8.1%)	109 (46.0%)	2,786 (95.6%)	481 (17.3%)
Total	57,782	33,666 (58.3%)	24,116 (41.7%)	2098 (8.7%)	885 (42.2%)	22,903 (95.0%)	4349 (19.0%)

Notes: Patents with priority year 1977. Opposition (column 4) includes patents attacked in a *Patentnichtigkeitsverfahren* (annulment) as well as the more frequent *Einspruchsverfahren* (opposition). See the text for explanations. Source: PATDPA (August 1997), authors' computations.

Table 5
Descriptive statistics for value indicators by outcome of application and opposition proceedings (patents of german applicants only) mean (S.E. of the mean)

Variable		(1) All patents initially issued	(2) Patents opposed		(3) Patents not renewed to full term		(4) Patents renewed to full term	
			Held invalid or withdrawn	Upheld	Never opposed	Opposed and upheld	Never opposed	Opposed and upheld
Number of Separate 4-digit IPC classes (“scope”)	SCOPE	1.36 (0.01)	1.41 (0.03)	1.33 (0.03)	1.35 (0.01)	1.31 (0.04)	1.37 (0.02)	1.36 (0.05)
Citations received in DPA patents by 7/1997	CIT_DPA	0.52 (0.01)	0.69 (0.05)	0.89 (0.08)	0.46 (0.01)	0.72 (0.08)	0.67 (0.04)	1.18 (0.16)
Citations received in EPO patents by 2/1998	CIT_EPO	0.57 (0.01)	0.76 (0.05)	0.83 (0.06)	0.52 (0.01)	0.77 (0.08)	0.79 (0.04)	0.92 (0.10)
Family size	FAMSIZE	3.59 (0.03)	3.96 (0.15)	4.17 (0.18)	3.40 (0.04)	3.82 (0.20)	4.57 (0.11)	4.74 (0.32)
References to the patent literature	REFPAT	1.37 (0.02)	1.43 (0.08)	3.41 (0.16)	1.20 (0.02)	2.98 (0.18)	1.86 (0.08)	4.12 (0.31)
References to the non-patent literature	REFNPAT	0.30 (0.01)	0.27 (0.02)	0.68 (0.06)	0.27 (0.01)	0.52 (0.06)	0.42 (0.03)	0.96 (0.14)
Observations		11471	691	454	9066	283	1260	171

Notes: see Table 4. Source: PATDPA (August 1997), authors’ computations.

prevails (columns 5 and 6). Again, patents owned by non-German applicants are attacked less frequently than German patents, and foreign patent-holders are more successful than their German counterparts in defending the patent grant. The only exception to this rule are US patents which survive opposition at about the same rate as German patents (38.0 and 39.6%, respectively). Of the remaining 22,898 patents, 19.0% reach full-term status. There are again major differences between German-owned and other patents. Only 13.3% of the German-owned patents are renewed to full term, while the full-term renewal rate ranges between 33.7% in the case of Japan and 17.3% for the residual group of applicant nations.

5.2. Descriptive statistics

The sample studied here are the 11,471 patents that were initially granted. Table 5 presents mean values and standard errors (S.E.s) for the indicator variables described before, and reports them separately for different groups of patents. The main result of this table is that patents which defeated opposition turn out to differ with respect to most indicators from patents that were held invalid or were never opposed.

In column 2, we compare German patents that were held invalid, revoked or withdrawn to patents that were upheld (in either amended or unamended form) in opposition cases. The latter group has more DPA citations, EPA citations, larger patent families and more references to the patent and non-patent literature. With the exception of the family size variable, all of the differences turn out to be statistically significant. A second comparison focuses on patents that were never opposed versus patents that were opposed and subsequently upheld. We perform this comparison for patents that were not renewed to full term in column 3, and for full-term patents in column 4. While the scope variable shows little variation across these groups, the other indicators turn out to be significantly higher for patents which were opposed. Moreover, a comparison of patents that were never opposed in column 3 to the same group in column 4 shows that unopposed full-term patents receive considerably more citations, contain more references and are part of larger patent families than unopposed patents which were not renewed to full term. The same result holds for the analogous comparison of patents that were opposed and subsequently upheld.

Table 6
Value ranges for scope and citation measures

Variable	Mean	Q25	Q50	Q75	Minimum	Maximum
SCOPE	1.354	1	1	2	1	9
CIT_DPA	0.504	0	0	1	0	15
CIT_EPO	0.563	0	0	1	0	20
FAMSIZE	3.564	1	2	5	1	24
REFPAT	1.367	0	0	2	0	27
REFNPAT	0.302	0	0	0	0	18

Notes: $N = 10{,}780$. Q25, Q50, and Q75 refer to the lower quartile, the median, and the upper quartile, respectively.

Table 6 contains information on the moments, range and distribution of the scope and citation measures. The sample used here consists of the 10,780 patents that either survived or never encountered opposition. Clearly, most of the indicator variables have skew distributions, with the mean always considerably larger than the median. Some of the mean values should be surprising to readers familiar with citation indicators from the US patent system. As reported in a previous paper (Harhoff et al., 1999), we find that the citation counts, both in the German and the European system, are spectacularly low by USPTO standards.[21] There are two possible explanations. First, both the EPO and the DPA systems contain fewer applications and granted patents (per year) than the USPTO. Hence, if citations are affected by a “home bias” there are fewer candidates for a potential citation in our data. But more importantly, applicants at the EPO are not required to supply a full list of prior art—this requirement presumably leads applicants at the USPTO to cite excessively. A detailed discussion of these differences in citation behavior is presented in Michel and Bettels (2001, 191f.).

A separate analysis of these descriptive statistics by technical field is not reported here, but demonstrates that these comments apply across the broadly defined technical areas chemicals and pharmaceuticals, electronics, mechanics and a residual group.[22]

[21] The maximum number of USPTO citations for US patents in the study by Harhoff et al. (1999) was 169, the mean number of German Patent Office citations for German-owned patents issued in 1977 was 6. Hall et al. (2000) report that the maximum number of citations in their study of US patents is on the order of 200.

[22] The definition of these groups is presented later.

Table 7
Pearson product–moment correlation matrix

Variable	SCOPE	CIT_DPA	CIT_EPO	FAMSIZE	REFPAT	REFNPAT
SCOPE	–					
CIT_DPA	0.049	–				
CIT_EPO	0.043	0.201	–			
FAMSIZE	0.029	0.085	−0.017	–		
REFPAT	0.015	0.117	0.052	0.054	–	
REFNPAT	0.059	0.052	0.045	0.061	0.247	–

Notes: $N = 10{,}780$.

However, some interesting particularities emerge, in particular for patents in the area of chemicals and pharmaceuticals. These patents are considerably more often cited in EPO patents than in German patents, and family sizes are on average much larger than for the other technical fields. Moreover, references to the non-patent literature, e.g. to scientific journals and publications, are more common for pharmaceutical and chemicals patents. These have on average 0.38 references to the non-patent literature. Again on average, electronics patents contain only 0.28, patents in mechanical fields 0.19, and other patents only 0.14 such references, respectively. These differences between the group means are highly significant.

Table 7 concludes the descriptive statistics with a summary of correlation coefficients for the scope and citation measures. The correlation coefficients between our scope and citation variables are quite small, indicating that these variables carry largely orthogonal information. Notable exceptions are the correlation between references to the patent and references to the non-patent literature ($\rho = 0.247$), the correlation between the two citation measures (CIT_DPA and CIT_EPO, $\rho = 0.201$); and the correlation between citations in the German patent system and the number of references to the patent literature (CIT_DPA and REFPAT, $\rho = 0.117$).

5.3. Multivariate specification

We combine the previous indicators to model the mean value of patent rights as a function of observables. We abstract from discussions of causality in this exercise, and we will also leave a number of endogeneity problems untouched. Our position is that of a researcher who has observed the respective indicators and is simply interested in approximating the value of a particular patent. Presumably, issues of endogeneity would matter greatly for a more structural exercise. For example, opposition is likely to lead to changes in the scope of the patent, its references to the patent and non-patent literature, and the citations that the opposed patents receive. At the same time, the likelihood of opposition is presumably a function of the patent right's prospective value. At this point, little is known about these processes in the European context.

The structure of the data at hand is somewhat more complex than in a standard regression framework. For most of the patents surveyed, we do not know point estimates of the patent's value, but only upper and lower bounds. In order to use all of the available information, we apply an ordered probit framework in which some of the threshold values are known. In this framework (as in ordinary linear least squares), we can actually recover all coefficients. For 752 patents, we have information on the patent-holders' valuations of the patent rights. For another 20 patents, we know that they were assessed to be worth more than DM 5 million in our first-stage survey.[23] In 659 cases, we were unable to obtain patent valuations for patents renewed to full term. Moreover, in the vast majority of cases (9349 patents), we only observe that the patents were not renewed to full-term. We treat these cases in the following way. We assume that the value of full-term patents is delineated by a lower bound α which we treat as a parameter to be estimated. At the same time, this parameter α is considered the upper bound for the value of all patents which were not re-

[23] See Harhoff et al. (2003) for details on the distributional properties of these data.

newed to full-term. To maintain a full-term patent, a patent-holder must spend about DM 20,000 on application and renewal fees plus an estimated amount of DM 10,000 for patent attorney services. Since a large number of our patents (even those that are not renewed to full term) are actually part of an international patent family, the cost of obtaining and maintaining the patent family might even be higher. We therefore expect the estimated value of α to be in excess of DM 30,000.[24]

The econometric model starts by specifying the logarithm of patent valuation $\ln(V_i)$ as the sum of a linear function $X_i\beta$ of observables and an error term ε_i. X_i is a vector of variables charaterizing patent i and β is the vector of parameters to be estimated

$$\ln(V_i) = X_i\beta + \varepsilon_i. \quad (1)$$

We assume that the error terms are distributed i.i.d.[25] Moreover, we assume normality of the error term such that the probability of observing a patent in the value interval of, say, between γ_1 and γ_2 (where $\gamma_2 > \gamma_1$) is given by $\Phi(\ln(\gamma_2)/\sigma - X_i\beta/\sigma) - \Phi(\ln(\gamma_1)/\sigma - X_i\beta/\sigma)$ where σ is the standard error of the disturbances ε_i and $\Phi(\cdot)$ is the cumulative standard normal distribution. Thus the log-likelihood contribution for a patent for which we observe finite interval bounds (denoted as group A) is given by

$$\ln L_{Ai}\left(\beta, \alpha, \frac{\sigma}{X_i}\right) = \ln\left(\Phi\left(\frac{\ln(\gamma_2)}{\sigma} - \frac{X_i\beta}{\sigma}\right) - \Phi\left(\frac{\ln(\gamma_1)}{\sigma} - \frac{X_i\beta}{\sigma}\right)\right). \quad (2)$$

For observations with value greater than some known amount δ, but no data on a potential upper bound (group B patents), the log-likelihood contribution is

$$\ln L_{Bi}\left(\beta, \alpha, \frac{\sigma}{X_i}, \delta\right) = \ln\left(1 - \Phi\left(\frac{\ln(\delta)}{\sigma} - \frac{X_i\beta}{\sigma}\right)\right). \quad (3)$$

Those patents that were renewed to full-term with unknown valuation (group C) contribute

$$\ln L_{Ci}\left(\beta, \alpha, \frac{\sigma}{X_i}\right) = \ln\left(1 - \Phi\left(\frac{\ln(a)}{\sigma} - \frac{X_i\beta}{\sigma}\right)\right). \quad (4)$$

Finally, the log-likelihood contribution of those 9349 patents that were not renewed to full-term (group D) is given by[26]

$$\ln L_{Di}\left(\beta, \alpha, \frac{\sigma}{X_i}\right) = \ln\left(\Phi\left(\frac{\ln(a)}{\sigma} - \frac{X_i\beta}{\sigma}\right)\right). \quad (5)$$

Estimates of the parameters can be obtained via maximum-likelihood, i.e. by maximizing the sum of the individual log-likelihoods with respect to the parameter β, α, and σ. Note that all of these coeffients are identified, since most of the threshold values are known. Thus, our coefficients can also be compared directly across various sub-samples. Besides obtaining the usual maximum-likelihood test statistics, we also compute a pseudo-R-squared measure as $1 - (s^2/\tau^2)$ where s is the estimate of σ from the unrestricted specification and τ is the estimate of σ from a restricted specification in which only a constant term is allowed for.

5.4. Empirical results

We summarize our estimation results in Table 8. Column (1) displays the coefficient estimates and standard errors for the overall sample. In columns (2)–(5), we split the sample by technology field in order to test the robustness of the overall results and in order to study between technology differences.

The scope variable as used by Lerner (1994) is consistently insignificant in these specifications. The divergence between his and our result may be due to

[24] Note also that our counterfactual survey question asked respondents to take all information into account that they had learned during the life span of the patent. Given that the renewal decision had to be made on an annual basis without this knowledge, the total renewal fees may actually overestimate the ex post value of the patent.

[25] This assumption may look innocent for a cross-section of patents. However, some of the inventions in our cohort of patents may build on each other, and hence the economic value of some patents may be influenced by the value of others. We have to ignore this problem here, since we cannot test deviations from the assumption.

[26] Note that the likelihood contributions in (4) and (5) are those of the probit estimator for patents being renewed to full term among all patents that were not covered in the survey.

Table 8
Ordered probit specifications coefficient (standard error)

Independent variable	Full sample (1)	Drugs and chemicals (2)	Electronics (3)	Mechanical (4)	Other (5)
ln(SCOPE)	−0.150 (0.084)	−0.383 (0.497)	0.050 (0.109)	−0.237 (0.260)	−0.537 (0.566)
ln(1 + CIT_DPA)	0.505 (0.135)	0.523 (0.502)	0.556 (0.230)	0.461 (0.190)	0.812 (0.427)
ln(1 + CIT_EPO)	0.893 (0.132)	1.670 (0.398)	0.583 (0.217)	0.793 (0.202)	0.903 (0.406)
ln(FAMSIZE)	0.811 (0.077)	1.178 (0.244)	0.577 (0.129)	0.780 (0.115)	0.673 (0.222)
ln(1 + REFPAT)	0.751 (0.092)	0.749 (0.307)	0.466 (0.164)	0.804 (0.130)	1.216 (0.286)
ln(1 + REFNPAT)	0.448 (0.158)	1.131 (0.447)	0.459 (0.257)	0.319 (0.268)	−1.001 (0.621)
OPPOSITION	2.415 (0.284)	2.113 (0.946)	2.508 (0.502)	2.263 (0.394)	2.920 (0.828)
ANNULMENT	3.753 (0.782)	0.188 (3.410)	4.436 (1.810)	3.296 (0.998)	5.623 (1.913)
$\alpha/1000$	45.144 (2.913)	41.644 (7.721)	43.332 (5.118)	46.647 (4.482)	55.404 (8.563)
σ	4.174 (0.159)	4.974 (0.466)	3.656 (0.266)	4.114 (0.238)	4.143 (0.441)
Pseudo-R-squared	0.139	0.172	0.133	0.118	0.159
LR	512.3	90.6	104.9	236.7	83.6
$\log L$	−5,308.4	−782.1	−1456.8	−2450.4	−597.1
N	10,780	1301	3153	5026	1300

Note: FIML estimates from an ordered probit specification with partially known thresholds. The technology classification is described in the text. The a pseudo-R-squared measure as $1 - (s^2/\tau^2)$ where s is the estimate of σ from the unrestricted specification and τ is the estimate of σ from a restricted specification in which only a constant term is allowed for. The likelihood ratio test statistic LR is based on the log-likelihoods of the two specifications used for computing the pseudo R-squared (d.f. = 8).

the use of patents which cover a broad set of technical areas while his study focuses on biotechnology patents. There may also be important differences in the way the German and the US Patent Offices assign the IPC classification.[27] However, our results are clearly in line with Lanjouw and Schankerman (1997) who have also reported estimates according to which the scope measure calculated from IPC classifications does not positively affect the probability of infringement litigation. They even detect a small and significant negative effect in their study while the respective coefficient is always insignificant in our results.

All other variables included in the specification turn out to have some explanatory power. We turn to the overall results in column (1) first before commenting on technology-specific differences. Both citation counts within the DPA patent database as well as the analogous measure from EPO patents are positive and highly significant. However, the point estimate for the latter variable is significantly larger, consistent with our expectations. Family size, the number of jurisdictions for which patent protection was granted, also carries the expected positive sign and is again highly significant. Lanjouw and Schankerman (1997) report in their analysis of patent litigation that their measure of backward citations is not a significant determinant of the probability that a patent will be subject to litigation. We find that backward citations are positively correlated with the patent's value in our study, and that the coefficient is again estimated with high precision. Moreover, references to the scientific literature are also informative about the patent's value, though the average effect across all technology areas is smaller than for backward citations of patents, and the estimate is less precise. Finally, the indicators summarizing the outcome of the opposition and annulment process turn out to be quite large and highly significant. A patent which has defeated opposition in the more frequently encountered opposition procedure (*Einspruchsverfahren*) is considerably more valuable (by a factor of 11.2) than a patent that was never attacked. If the patent has been under attack in the more expensive annulment procedure, its

[27] Schmoch (1990) cites evidence that the primary IPC classifications of about 50 percent of all US patents reaching the German Patent Office are being revised. He also argues that the IPC classification in US patent documents is generated through a computerized reference list, and the US examiners primarily work with the USPTO classification. The latter are revised every 6 months, while IPC classifications are updated in 5-year intervals.

value is again much higher than the value of unchallenged patent rights, in this case by a factor of 42.6, ceteris paribus. The upper bound for the value of patent rights not renewed to full term is estimated to be DM 45,144 (standard error of DM 2913). As anticipated, this value is higher than our benchmark of DM 30,000 which only encompasses renewal fees and the cost of patent attorneys.

In columns (2)–(5), the same specification is applied to patents within a particular field[28] of technology. Qualitatively, very similar results emerge from these regressions. The scope variable is never significant in these regressions, but some intriguing differences are visible for the other variables. Consider first the results in column (2) which apply to patents in the area of pharmaceuticals and chemical substances. The information content in national citations appears to be low and also imprecisely estimated. However, citations within the EPO system have a coefficient (standard error) of 1.670 (0.398) which is the largest value among the technology-specific results. As already discussed, given the global nature of competition in the respective industries, this result is not too surprising. Consistent with the view that the coefficient size is driven by the extent of global competition, the family size variable also carries the highest coefficient of all technology-specific sets of results. We also argued in the previous sections that scientific content of the patent's subject matter is likely to be high in the case of pharmaceuticals and chemicals. This is borne out in the relatively high coefficient for references to the non-patent literature. Opposition is again informative, while results from annulment procedures are not. However, this may simply be due to the relatively small number of annulment cases—which again may reflect the relatively "water-tight" nature of patent protection in these technical fields.

The results in columns (3)–(5) for patents in the remaining three areas (electronics and electrical circuitry, mechanical and other) come close to the ones for the overall sample. Forward citations are again informative about patent value, but family size appears to play a considerably less important role than in the field of drugs and chemicals. The importance of backward citations varies across these fields, with the highest coefficient (standard error) of 1.216 (0.286) for the residual group, and the lowest coefficient of 0.466 (0.164) for electronics and electrical circuitry. Interestingly, references to the scientific literature do not have a statistically significant coefficient for any of the three groups. The coefficients for the opposition and annulment indicators are again quite large and highly significant.

Considering these results together, there is clearly some variation across technology groups. But the results are remarkably consistent with respect to their qualitative implications. Indeed most of the regressors in this study are of similar size in the various technological fields and the effect sizes are typically estimated with considerable precision. That should be taken as an encouraging sign for future studies.

6. Conclusions and further research

Determining the value of patent rights is a difficult task, but even slight improvements leading beyond the simple patent counts frequently used nowadays should be considered a success. This paper has attempted to use information from patent applications, examination reports and from the opposition process to model the value of patent rights. Since most of the patent literature has originated in the US, the particularities of European systems have been somewhat neglected. Our analysis focuses on German patents, taking into account the specifics of the German patent system which is quite similar to the procedures applied by the European Patent Office and other national patent offices in European countries. The value data used in this paper come from a detailed survey of west German patent-holders who assigned monetary values to particularly important patents. Thus, we are not compelled to use latent variable constructs or to rely strongly for the most valuable patents on identifying assumptions as they are typically made in the patent renewal literature.

Our econometric analysis of these data has been quite promising: we have established clear evidence

[28] The classification is the one used by Lanjouw (1998). Based on IPC classifications, she distinguishes between drugs and health patents (A61 and A01N), chemical patents (A62, B31, C01–C20), electronics patents (G01–G21, H), mechanical patents (B21–B68 excl. B31, C21–C30, E01–F40), and a residual group (A excl. A61 and A01N, B01–B20, F41–F42, G21), referred to here as "Other". We aggregate the first two groups in order to have reasonably large subgroups for the analysis.

that a number of indicators are significantly correlated with patent value. In a previous study using the data employed here, we found a significant correlation between patent value and citations received from subsequent patents (Harhoff et al., 1999). We confirm this result, but we can also show in this paper that other correlates of patent value have additional explanatory power. The measure for references to the patent literature (backward citations) carries significant positive coefficients in all technical fields. Measures of family size and observed outcomes of opposition cases also contribute to an approximation of the patent right's value. A successful defense against opposition and annulment claims is a particularly strong predictor of patent value. Presumably, valuable patents are more likely to be attacked in this process, and the stronger patent rights survive, amounting to a two-tiered selection process with a highly informative outcome. Contrary to previous results, we find that the number of four-digit IPC classifications does not have any explanatory power. At least for the European context, it does not appear to be a good approximation of patent scope. As to the science linkage of patents: in science-oriented fields such as pharmaceuticals and chemicals, references to the non-patent literature carry explanatory power; in the other technical fields studied here there is no evidence of a statistically significant relationship.

Our results have a number of implications for the measurement of patent value. First, we show that relying on citations received from later patents alone is not likely to lead to the best possible approximation of patent value. Other measures, such as citations to previous patents and the scientific literature, the size of the international patent family or the success in the face of patent opposition, are also important in statistical terms. But they are even more appealing on purely practical grounds, since they are available relatively soon after the patent has been granted. Backward citations are part of the patent office's research report. Information on family size is also available relatively early, since applications made in foreign jurisdictions are based on union priority claims, and these lapse 1 year after the national application has been filed.

A second implication from this paper concerns the relevance of the opposition procedure which does not exist in the US or UK, but is part of the patent granting process at the EPO. The outcomes of opposition cases, which prove to be highly informative in our data, are not available immediately. Moreover, in the German patent system applicants may delay examination for strategic reasons for 7 years. Assuming that it may take another 5 years for examination and subsequent opposition procedures, these indicators may not be observable for all patents of a given application cohort before 12 years have passed since the application was submitted. However, in the ever more important EPO system, patents are examined *automatically* after the application has been submitted, and the delay in the EPO system will therefore be comparatively short. Hence, EPO opposition data may yield very attractive indicators for an approximation of patent value rights.

Clearly, some of our results pose a number of questions for further studies. We cannot claim that the set of value correlates used here is complete, and additional variables or refinements of those we used already should be tested. For example, data on the timing of backward citations should be used in order to refine this particular regressor in our study.[29] Moreover, some indicators, such as renewal of the patent to full-term, are easily observed ex post, but they only become available a long time after the application has been filed. Other indicators, such as the number of jurisdictions in which patent protection is sought for a particular invention, may be available around the time of application, but it is not known exactly how well they reflect the value of a patent. Citation measures could also be used to construct measures of how "general" or "basic" a patented invention is.[30] We will consider those measures in future research.

Finally, it seems of some importance to study the determinants and effects of the opposition procedure in more detail. Opposition may replace some forms of patent litigation observed in the US, but it is not clear which legal system is more efficient in terms of maintaining incentives for R&D or suppressing incentives for strategic behavior, such as predatory litigation. Since the link between legal and economic issues is far less understood in the European context than in

[29] See Hall et al. (2000) for a study in which extensive US data on citations is used. We note again that citations in the US patent system are often generated by the applicant and may therefore have different informational content than citations in European patents.

[30] Cf. Trajtenberg et al. (1997) who operationalize the concept of an invention's "basicness".

the US, further research in this particular area may also be helpful in analyzing the impact of opposition and litigation on R&D incentives.[31]

Uncited references

Jaffe et al. (1993), Scherer and Harhoff (2000), Scherer et al. (2000).

Acknowledgements

Financial support for this study came from the Zentrum für Europäische Wirtschaftsforschung (ZEW) and the National Science Foundation (NSF). Comments from seminar participants at NBER, the University of Munich, the University of California at Berkeley and Hebrew University are gratefully acknowledged. We have profited from comments and suggestions by Zvi Griliches, Adam Jaffe, Jenny Lanjouw, Ariel Pakes, Suzanne Scotchmer and Ulrich Schmoch. We also thank Johannes Zitzenzier and Horst Hermann Zitt at the German Patent Office (DPA) who provided us with the data on full-term patents. Birgit Knauer, Rainer Stuike-Prill and Friedemann Böhm at the Fachinformationszentrum (FIZ) supported us in obtaining the citation and family size data. The usual disclaimer applies.

Appendix A. A brief overview of German patent law

Since our data collection takes place in Germany, we summarize a number of particularities of the German patent system which set it apart from the better known US system.[32] Fig. 1 presents a graphical depiction of the patent granting process at the German Patent Office. Contrary to the US system, all German patent applications are published 18 months after the application date. Thus even the subject matter of applications which are rejected reaches the public domain. Until recently, US patents were only published once the patent has been granted, thus maintaining secrecy for those inventors whose applications have not been successful. The American Inventors Protection Act (1999) now requires publication of all applications after 18 months but excepts applicants opting to make a declaration that a patent will not be sought in a foreign jurisdiction requiring 18 months publication (35 USC §122).

During the priority year (see Fig. 1), patent applicants can decide to submit their application to other national patent offices where the date of the German application will be taken as the priority date. Thus, only the state of the art developed up to the priority date will be held against the patent application to determine the degree of novelty. Patent applicants in Germany may delay the actual examination of their application for up to seven years. However, payment of annual fees commences in any case at the beginning of the third year. Even prior to the official examination, applicants may ask for a research report which offers them the patent office's assessment of the state of the art (e.g. earlier patents). In the later examination process, these earlier patents are likely to be used to limit the scope of the patent, e.g. in form of backward citations to the patent literature. Such references are called *Entgegenhaltungen*, i.e. literally, material that is held against the patent application.

Another source of differences between the US and the German system is the opposition process at the German Patent Office. Within 3 months after a German patent has been granted by the German Patent Office, any person or firm may register its opposition to the patent grant with DPA (*Einspruchsverfahren*). In the 1977 application cohort, 8.3% of all granted patents were subject to this form of opposition. A second, though less often used possibility to attack a patent allows interested parties to demand that the patent be declared void (*Nichtigkeitsverfahren*—annulment). This process may only be initiated once the time period for the regular opposition has passed. Only 0.3% of the patents granted were opposed using the annulment procedure.

[31] In a few papers, researchers have embarked to study these issues. Harhoff and Reitzig (2002) study the characteristics of EPO patent grants that have attracted opposition. Graham et al. (2002) compare the properties of patent re-examination at the USPTO and of EPO opposition proceedings.

[32] Naturally, we can only cover selected features of the German patent system and law. For details, see Bernhardt and Krasser (1986). Issues of opposition and patent litigation are covered in Liedel (1979) and Straus (1996). Stauder (1989) provides descriptive statistics on patent litigation cases in Germany.

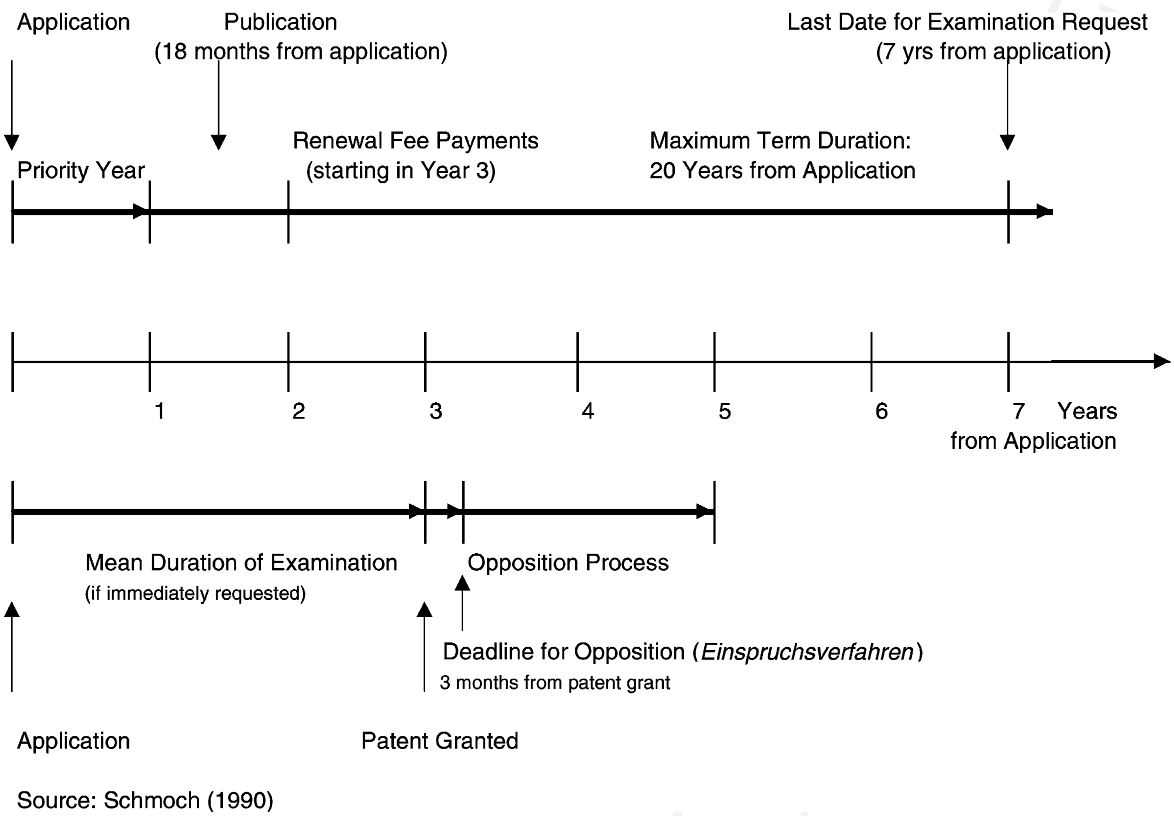

Fig. 1. Patent examination and granting process at the German Patent Office.

On average, the patent examination process at the German Patent Office will take 3 years. If examination is requested at the date of application (see Fig. 1), then the patent is typically granted after 3 years. Our patent data describing the application cohort of 1977 shows that the lag from application to patent grant is at the median 6 years. Decisions in opposition cases are typically rendered within 2 years. In some cases, however, they may take 6 years or more to be concluded.

References

Bernhardt, W., Krasser, R., 1986. Lehrbuch des Patentrechts. C.H. Beck, München.

Graham, J.H., Hall, B.H., Harhoff, D., Mowery, D.C., 2002. Post-Issue Patent Quality Control: A Comparative Study of US Patent Re-Examinations and European Patent Oppositions, NBER Working Paper No. 8807. National Bureau of Economic Research, Cambridge, MA.

Griliches, Z., 1990. Patent statistics as economic indicators: a survey. Journal of Economic Literature 28, 1661–1707.

Grupp, H., Schmoch, U., 1992. Wissenschaftsbindung der Technik/Panorama der internationalen Entwicklung und sektorales Tableau für Deutschland. Physica, Heidelberg.

Hall, B.H., Ziedonis, R.H., 2001. The patent paradox revisited: an empirical study of patenting in the US semiconductor industry, 1979–1995. Rand Journal of Economics 32, 101–128.

Hall, B.H., Jaffe, A., Trajtenberg, M., 2000. Market Value and Patent Citations: A First Look, NBER Working Paper No. 7741. National Bureau of Economic Research, Cambridge, MA.

Harhoff, D., Reitzig, M., 2002. Determinants of Opposition against EPO Patent Grants—The Case of Biotechnology and Pharmaceuticals, Unpublished Discussion Paper. Ludwig-Maximilian-University Munich, Munich School of Management, Munich.

Harhoff, D., Scherer, F.M., Vopel, K., 2003. Exploring the tail of the patent value distribution. In: Grandstrand, O. (Ed.), The Economics of the Patent System, in press.

Harhoff, D., Narin, F., Scherer, F.M., Vopel, K., 1999. Citation frequency and the value of patented innovation. Review of Economics and Statistics 81 (3), 511–515.

Jaffe, A.B., Henderson, R., Trajtenberg, M., 1993. Geographic localization of knowledge spillovers as evidenced by patent citations. Quarterly Journal of Economics 108, 577–598.

Jaffe, A.B., Trajtenberg, M., 1996. Flows of Knowledge from Universities and Federal Labs: Modelling the Flow of Patent Citations over Time and Across Institutional and Geographic Boundaries, NBER Working Paper, No. 5712. National Bureau of Economic Research, Cambridge, MA.

Lanjouw, J.O., 1998. Patent protection in the shadow of infringement: simulation estimations of patent value. Review of Economic Studies 65, 671–710.

Lanjouw, J.O., Schankerman, M., 1997. Stylized facts of patent litigation: value, scope, ownership, NBER Working Paper No. 6297. National Bureau of Economic Research, Cambridge, MA.

Lanjouw, J.O., Pakes, A., Putnam, J., 1998. How to count patents and value intellectual property: uses of patent renewal and application data. Journal of Industrial Economics XLVI (4), 405–433.

Lerner, J., 1994. The importance of patent scope: an empirical analysis. RAND Journal of Economics 25 (2), 319–333.

Liedel, D., 1979. Das deutsche Patentnichtigkeitsverfahren: eine Bestandsaufnahme. Schriftenreihe zum gewerblichen Rechtsschutz, Max-Planck-Institut für Ausländisches und Internationales Patent-, Urheber- und Wettbewerbsrecht, No. 46. Heymanns, Köln.

Merges, R.P., 1999. As Many as six impossible patents before breakfast: property rights for business concepts and patent system reform. Berkeley Technology Law Journal 14 (2), 577–616.

Merges, R.P., Nelson, R.R., 1990. On the complex economics of patent scope. Columbia Law Review 90 (4), 839–916.

Meyer, M., 1999. Does science push technology? Patents citing scientific literature. Research Policy 29 (3) (2000) 409–434.

Michel, J., Bettels, B., 2001. Patent citation analysis—a closer look at the basic input data from patent search reports. Scientometrics 51, 185–201.

Narin, F., Hamilton, K.S., Olivastro, D., 1997. The increasing linkage between US technology and public science. Research Policy 26, 317–330.

Pakes, A., 1986. Patents as options: some estimates of the value of Holding European Patent Stocks. Econometrica 54, 755–784.

Pakes, A., Schankerman, M., 1984. The rate of obsolescence of patents, research gestation lags, and the private rate of return to research resources. In: Griliches, Z. (Ed.), R&D, Patents, and Productivity. University of Chicago Press, Chicago, pp. 73–88.

Putnam, J., 1996. The value of international patent rights. Ph.D. Thesis. Yale University, Yale.

Schankerman, M., Pakes, A., 1986. Estimates of the value of patent rights in European countries during the post-1950 period. Economic Journal 97, 1–25.

Scherer, F.M., 1965. Firm size, market structure, opportunity, and the output of patented inventions. American Economic Review 55, 1097–1125.

Scherer, F.M., Harhoff, D., 2000. Policy implications for a world with skew-distributed returns to innovation. Research Policy 29, 559–566.

Scherer, F.M., Harhoff, D., Kukies, J., 2000. Uncertainty and the size distribution of rewards from technological innovation. Journal of Evolutionary Economics 10, 175–2000.

Schmoch, U., 1990. Wettbewerbsvorsprung durch Patentinformation—Handbuch für die Recherchepraxis. Verlag TÜV Rheinland, Köln.

Schmoch, U., 1993. Tracing the knowledge transfer from science to technology as reflected in patent indicators. Scientometrics 26 (1), 193–211.

Scotchmer, S., 1991. Standing on the shoulders of giants: cumulative research and the patent law. Journal of Economic Perspectives 5 (1), 29–41.

Scotchmer, S., 1996. Protecting early innovators: should second-generation products be patentable? RAND Journal of Economics 27 (2), 322–331.

Stauder, D., 1989. Patent- und Gebrauchsmusterverletzungen in der Bundesrepublik Deutschland, Großbritannien, Frankreich und Italien: eine rechtstatsächliche Untersuchung. Schriftenreihe zum gewerblichen Rechtsschutz, Max-Planck-Institut für Ausländisches und Internationales Patent-, Urheber- und Wettbewerbsrecht, No. 79. Heymanns, Köln.

STN International, 1990. PATDPA—Deutsche Patentdatenbank—Datenbankbeschreibung. STN International, Karlsruhe.

Straus, J., 1996. Die Aufrechterhaltung eines europäischen Patents in geändertem Umfang im Einspruchsverfahren und ihre Folgen. In: Straus, J. (Ed.), Aktuelle Herausforderungen des geistigen Eigentums. Köln, pp. 171–184.

Trajtenberg, M., 1990. A penny for your quotes: patent citations and the value of inventions. RAND Journal of Economics 21, 172–187.

Trajtenberg, M., Henderson, R., Jaffe, A.B., 1997. University versus corporate patents: a window on the basicness of invention. Economics of Innovation and New Technology 5 (1), 19–50.

van der Drift, J., 1989. Statistics of European patents on legal status and granting data. World Patent Information 11, 243–249.