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Conflict Resolution, Public Goods and Patent Thickets

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Abstract

Post-grant validity challenges at patent offices rely on the private initiative of third parties to correct mistakes made by patent offices. We hypothesize that incentives to bring post-grant validity challenges are reduced when many firms benefit from revocation of a patent and when firms are caught up in patent thickets. Using data on opposition against patents at the European Patent Office we show that opposition decreases in fields in which many others profit from patent revocations. Moreover, in fields with a large number of mutually blocking patents the incidence of opposition is sharply reduced, particularly among large firms and firms that are caught up directly in patent thickets. These findings indicate that post-grant patent review may not constitute an effective correction device for erroneous patent grants in technologies affected by either patent thickets or highly dispersed patent ownership.

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Conflict Resolution, Public Goods and Patent Thickets

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Abstract

Post-grant validity challenges at patent offices rely on the private initiative of third parties to correct mistakes made by patent offices. We hypothesize that incentives to bring post-grant validity challenges are reduced when many firms benefit from revocation of a patent and when firms are caught up in patent thickets. Using data on opposition against patents at the European Patent Office we show that opposition decreases in fields in which many others profit from patent revocations. Moreover, in fields with a large number of mutually blocking patents the incidence of opposition is sharply reduced, particularly among large firms and firms that are caught up directly in patent thickets. These findings indicate that post-grant patent review may not constitute an effective correction device for erroneous patent grants in technologies affected by either patent thickets or highly dispersed patent ownership.

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1 Introduction

Over the last three decades the demand for patents has been steadily growing at patent offices around the world. A number of researchers have argued that a large proportion of these new patents may be "weak" or marginal in terms of their contribution to the state of the art (Bessen and Meurer, 2008; Jaffe and Lerner, 2004; Lei and Wright, 2009). Mechanisms, such as opposition and litigation, that complement the efforts of patent offices in examining and stripping out weak patent applications should be welfare-enhancing in such a context (Choi, 2005; Graham and Harhoff, 2009; Graham et al., 2003; Hall et al., 2004; Hall and Harhoff, 2004).

While these mechanisms are often cost effective (Lemley, 2001), several authors have argued that they will be undermined by a public good problem (Farrell and Merges, 2004; Harhoff and Reitzig, 2004; Levin and Levin, 2003). When many parties profit from the revocation or annulment of a patent, private incentives of any single party may no longer be sufficiently strong to initiate such a challenge. We confirm this prediction using data on post-grant review at the European Patent Office. Additionally, we demonstrate that the presence of patent thickets in complex technologies weakens incentives for filing post-grant reviews and that this effect is strongest for patent applications made by firms at the center of patent thickets as well as for larger firms.

Examination and granting processes are the central quality assurance mechanism at patent offices, but they are frequently impaired by errors (Lemley 2001, Harhoff and Reitzig 2004). While patent applicants have various ways of eliminating errors not favorable to them during the examination of their application, errors in their favor are less likely to be corrected by the patent office. Errors made in the granting process are therefore likely to be asymmetric: on average, examination will result in granting exclusion rights that are too strong or broad given the standards that should prevail in the patent system and therefore interests of the public and of rival firms are compromised and social welfare is reduced.

Litigation and post-grant validity challenges at patent offices and courts should ideally provide effective mechanisms to correct the erroneous issue of patents (Farrell and Merges, 2004; Hall and Harhoff, 2004; Levin and Levin, 2003). Both mechanisms allow third parties to bring forward additional evidence on the validity and scope of patent applications. Usually these parties have an interest in reducing the scope of a rival's patent application or having the patent annulled completely, providing a natural counterbalance to the interests of the applicant (Jaffe and Lerner, 2004). The United States Patent and Trademark Office (USPTO) is currently introducing a process of post-grant validity review in order to enhance its ability to weed out weak patents within the America Invents Act (AIA) of 2011.[1]

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1 For more information on the America Invents Act of 2011 see http://www.gpo.gov/fdsys/pkg/BILLS-112hr1249enr/pdf/BILLS-112hr1249enr.pdf, latest visit on 3rd of May 2014.

The effectiveness of validity challenges depends on the strength of third-party incentives to challenge a patent. Previous research shows that the likelihood of litigating patents is positively related to patent and firm level characteristics such as the value of patent applications and the opponent's expectation of winning the case (Harhoff and Reitzig, 2004; Lanjouw and Schankerman, 2001). We extend this line of research by introducing characteristics of the technology space in which patenting takes place. First, we test the strength of the public good effect in post-grant review. Second, we investigate how the presence of and entanglement in patent thickets affects incentives to mount validity challenges. The public good problem arises whenever several firms benefit from the revocation or narrowing of a patent application. The party investing in the invalidation of a granted patent provides a public good to all firms who would see their profits reduced if the patent were to stand. In a technology area with fragmented ownership, an opponent who successfully challenges a patent will profit less on average than in a field with highly concentrated ownership. This reduces incentives to engage in post-grant challenges (Farrell and Merges, 2004). Therefore, we expect the incidence of post-grant validity challenges to be positively related to the concentration of patent holdings.

Moreover, in the presence of patent thickets, in which large numbers of patents with overlapping claims (Shapiro, 2000) are owned by multiple parties, firms' incentives to file costly post-grant validity challenges may be reduced further. Patent thickets arise when many patents are filed concurrently and patent claims are not clearly delineated, resulting in multiple overlapping claims. In such an environment, firms are exposed to the threat of litigation and of subsequent injunctions, which would hold up production. By threatening countersuits patent applicants can prevent other producing firms from challenging their patents and from engaging in patent enforcement (Federal Trade Commission, 2003)[2]. Consequently firms ensnarled in patent thickets have incentives to create large patent portfolios to protect themselves against litigation and injunctions (Hall and Ziedonis, 2001). To avoid an escalation of litigation, firms in patent thickets frequently resolve overlapping claims through non-adversarial means, such as cross-licensing, broad settlement agreements and other out-of-court agreements (Shapiro, 2000).

This suggests that the frequency of post-grant validity challenges in patent thickets will be lower than in technical areas not impaired by thickets. In particular, the reduction in post-grant validity challenges is likely to be stronger for those firms deeply ensnarled in patent thickets – we refer to these firms as patent thicket insiders. Studies of these phenomena have been made difficult by a lack of suitable measures regarding the extent and strength of blocking relationships. Drawing on previous research

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[2] These two forms of litigation may constitute separate or related institutions. Post-grant reviews (called opposition in Europe) only address issues of validity. In some jurisdictions (e.g., in Germany), questions of validity may also be treated by dedicated courts while infringement issues are addressed separately. In the USA, an infringement suit may be answered by an invalidity attack on the plaintiff's patent(s), or by a countersuit alleging infringement by the plaintiff himself, as in the recent case of *Yahoo vs. Facebook*.

(Graevenitz et al., 2011), we use citation data to identify and to measure the intensity of such blocking relationships.

To the best of our knowledge, the main hypotheses of this paper have not been tested empirically before. We use data on opposition proceedings against patents granted at the European Patent Office (EPO). Opposition is relatively frequent – historically, 6.2% of all EPO-granted patents have been opposed. Moreover, the time window for oppositions is narrow so that we can apply precisely timed covariates to capture other potential determinants of opposition. Measures of patent ownership concentration and of mutual blocking relationships between patent holders are used to study the public goods and patent thicket effects on the incidence of post-grant validity challenges. Our empirical results show that incentives to file an opposition against a patent grant are significantly reduced by these two effects: a one standard deviation increase in the concentration of patent holdings is related to an increase in the incidence of patent opposition of roughly 8.1% relative to the average unconditional probability. A one standard deviation increase in our measure of thickets relates to a decrease in the incidence of post-grant validity challenges by 22.2% relative to the average unconditional probability. These findings show that technology areas in which the social value of post-grant validity challenges can be assumed to be particularly high (i.e., where dense patent thickets and/or high fragmentation of patent ownership exist), private incentives to invest in post-grant validity challenges are weaker than in other technology areas.

The remainder of the paper proceeds in five sections. In section 2, we describe the institutional background of oppositions at the EPO. Section 3 summarizes the theoretical arguments regarding drivers of post-grant validity challenges which we use to derive our hypotheses. Data and descriptive statistics are presented in section 4, while section 5 presents the results of our multivariate analyses. We discuss implications for the management of intellectual property and for public policy in the concluding section.

2 Institutional Background and Effects of Opposition against Granted Patents at the EPO

The EPO's activities are based on the European Patent Convention (EPC) which was signed in 1973. Since it commenced its operations in 1978, the EPO has offered a harmonized application path for patent applicants that seek patent protection in one or more signatory states of the EPC. A patent application granted by the EPO does not lead to a single "European patent", but to a bundle of independently enforceable and revocable national patent rights. However, the grant decision of the EPO is subject to a central post-grant review mechanism, which can be initiated by any third party within nine months of the grant date. If no opposition is filed within this time period, the patent's validity can only be challenged under the legal rules of the respective countries where the patent takes effect. Opponents then have to challenge the national patent rights separately in the national courts for each state, which is extremely costly compared to the centralized opposition proceeding.

The opposition procedure at the EPO is a quasi-judicial process taking place in front of an Opposition Division consisting of "three technically qualified examiners, at least two of whom shall not have taken part in the proceedings for grant of the patent to which the opposition relates" (Art. 19 (2) EPC). Opposition may be filed on grounds listed in Art. 100 EPC. These are (i) the subject matter is not patentable under the terms of the EPC Art. 52 to 57[3], (ii) the patent does not disclose the invention clearly enough or in its entirety so that it could be carried out by a person skilled in the art, or (iii) the subject matter of the European patent extends beyond the content of the original application. An opposition can lead to either a rejection of the opposition and thus the maintenance of the patent as it was granted, the maintenance of the patent in amended form (i.e., with more restricted claims), or the complete revocation of the opposed European patent. The outcome of opposition has legal effect for all national rights originating with the EPO patent grant and is subject to appeal to the Technical Boards of Appeal at the EPO.

Most of the literature analyzing post-grant validity challenges has focused on U.S. patent litigation, where the vast majority of cases are settled out of court (Lanjouw and Schankerman, 2004a).[4] For that context, it is quite appropriate to assume that the parties involved will resolve out of court those cases in which the legal issues are transparent. In the opposition context, this consideration is less likely to hold. While there is some settlement activity, most cases actually go to "trial" and are resolved in either opposition or appeal proceedings. This is due both to institutional and financial considerations: settlements during the opposition proceedings are risky as the EPO may pursue the case itself (Rule 84(2) EPC). This restricts settlements to the nine months following the patent's grant, in which an opposition can be filed. Financially, a settlement is unlikely to be much cheaper than attacking or defending the patent in opposition. The average cost of opposing a patent at the EPO has been estimated to range from €6,000 to €50,000 (including patent lawyers' fees) and is therefore considerably lower than the cost of litigating a patent in multiple national courts.[5] Finally, opportunities to drive up the other party's costs are virtually nonexistent in the European setting.

Revoking erroneously granted patents or narrowing patents during opposition proceedings after they have been specified too broadly can prevent welfare losses. These would emerge due to the market power given to a holder of an erroneously granted patent (Graham and Harhoff, 2009). If the patent is revoked in opposition, the gain in welfare equals the welfare loss that society would have incurred in

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3 See EPC Art. 52-57. The subject matter may not be novel (Art. 52(1), 54 and 55 EPC), does not involve an inventive step (Art. 52(1), 56 EPC), cannot be used in an industrial application (Art. 52(1) and 57 EPC), is not regarded an invention (Art. 57 EPC) or is not patentable for reasons stated in Art. 53 EPC.

4 The ongoing reform of the US patent system implements a post-grant review institution which is somewhat comparable to the opposition system at the EPO. See Section 6 of H.R. 1249: America Invents Act, available at https://www.govtrack.us/congress/bills/112/hr1249/text (last accessed on April 20, 2014). However, it is unclear how costly post-grant review at the USPTO will be, since it may involve discovery.

5 An average litigation case will cost around 160.000 EUR in Germany. Costs in France and the Netherlands are similar, litigation in the UK has typically been more expensive. See Harhoff (2009) for estimates of litigation costs in European countries.

the case of the patent being upheld and enforced. The revocation of these patents can have two effects: it effectively eliminates the need for subsequent litigation or it reduces the room for extracting excessive rents from competitors or consumers. It is more difficult to assess the welfare effects of a rejection of an opposition. If the opposition is rejected, then the patent was most likely correctly specified and it is less clear that there is a benefit from the opposition having been brought., There could still be a litigation-reducing effect, if opposition has demonstrated the legal robustness of the patent or clarified its boundaries. If opposition results in an amendment of the patent, then this can be seen as a convex combination of the two polar cases.

The benefits from opposition have to be compared to the resource costs of the opposition and appeals process. Leaving aside the low resource costs of opposition, there are its potential social costs. Judicial processes take time to resolve and during that period uncertainty is not resolved. If the parties to a trial do not anticipate the outcomes perfectly, their incentives to invest in innovation or the production of a product based on a patent will suffer and welfare gains from the introduction of technology are postponed. Without observing actual investment and R&D decisions, it is difficult to assess the likelihood of the FUD (fear, uncertainty and doubt) scenario. These costs will still be much lower than they would be if patents were litigated separately in the national courts.

Assuming that the patent is correctly delineated after opposition, the opposition mechanism should be welfare increasing as long as the expected reductions in welfare losses from errors in the granting process are larger than the total social cost of opposition. Particularly valuable patents have been shown to be more likely to be attacked under opposition than less valuable ones (Harhoff and Reitzig, 2004). This indicates that the opposition procedure also serves as an information revelation mechanism as valuable patents (those causing potentially high welfare losses) are selected based on the information third parties bring to the table. This selection of high-value patents into opposition makes it likely that the overall effect of opposition is welfare-increasing. Detailed analyses of the welfare effects of opposition can be found in Levin and Levin (2003) and Graham and Harhoff (2009). Both papers suggest that patent opposition processes may have significant potential for achieving welfare gains.[6]

3 Incentives to Engage in Post-grant Validity Challenges

In this paper we analyse when a patent is opposed post-grant, with a focus on those characteristics of the patent, the applicant and the technology area that affect the probability of opposition. This analysis is motivated by the expectation that post-grant opposition is not uniformly effective. In this section we discuss a model capturing two effects reducing incidence of opposition. The discussion provides four hypotheses. The model itself is relegated to an appendix.

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[6] Graham and Harhoff (2009) point out that this result depends crucially on the assumption that opposition is not too costly.

The model captures two mechanisms acting on the probability of opposition for a specific patent: the first of these is the patent thicket effect, the second arises when several firms might oppose the patent and opposition by one firm creates a public good for the others. The model shows that the public good effect will only be at work if the patent thicket effect does not prevent opposition. Consequently, there are no interactions between the two effects. As one has to assume that individual firms have incentives to oppose for the public good effect to operate, we first focus on when this precondition might fail due to the existence of patent thickets. We set out three hypotheses derived from the patent thicket effect next, followed by one hypothesis based on the public good effect.

The patent thicket effect reduces opposition in one of two ways: either the potential opponent is worried about retaliation by the applicant if an opposition case is lodged or the applicant has chosen to simultaneously apply for so many very similar patents that opposition is ineffective. In a patent thicket the threat of retaliation is likely to be high as both firms' patent portfolios cover similar technologies leading to overlapping patents. The threat of tit-for- tat opposition creates incentives to cooperate. For instance, the CEOs of two central players in the smart phone industry, Apple and Google, have recently attempted to end a sequence of court cases in bilateral negotiations at the board level.[7] The lack of precision in the language used to describe patents in many high technology industries makes it hard for potential opponents to determine exactly which patents they may be affected by (Federal Trade Commission, 2011). If an applicant submits multiple patents, that might all affect the potential opponent we show that opposition may cease to be cost effective. This suggests our first hypothesis:

Hypothesis 1: Patents in technology areas characterized by patent thickets are less likely to be opposed than patents in other technology areas.

Within a given technology area we distinguish between firms that are part of patent thickets (insiders) and firms that are outside the thickets (outsiders). Outsiders patent technology that is not closely related to the core technologies of the thicket but that is still patented in the same technology area. Concerns over retaliation should matter less to firms contemplating opposition against these outsiders leading to the second hypothesis:

Hypothesis 2: Patents granted to patent thicket "insiders" are less likely to be opposed than patents granted to patent thicket "outsiders".

Finally, we note that the patent portfolio size of an applicant is likely to moderate the effect of the patent thicket on the probability of opposition against its patents. A patent owner with a large portfolio will present a more credible threat of retaliatory opposition or may find it easier to apply simultaneously for multiple patents than a firm with a small portfolio, leading to the third hypothesis:

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7 Apple's CEO Tim Cook and Google's CEO Larry Page have been conducting behind-the-scenes talks about a range of intellectual property matters, including the mobile patent disputes between the companies in August 2012 (for more details see http://www.reuters.com/article/2012/08/30/us-google-apple-idUSBRE87T15H20120830 , last accessed 3rd of May 2014).

Hypothesis 3: Growing patent portfolio size amplifies the negative effect of patent thickets on the likelihood of opposition.

Our theoretical analysis shows that whenever firms have an incentive to oppose a patent application individually, the total probability that the patent application is opposed falls with additional potential opponents. This public good effect is also modeled in Farrell and Merges (2004). Further, Harhoff and Reitzig (2004, fn. 25) point out that the incentives to invest in opposition will be strong when only a small number of firms benefits from the public good, e.g., in tight oligopoly structures, and relatively weak when a large number of firms would benefit from the public good, e.g., in competitive markets. We therefore expect that:

Hypothesis 4: Patents granted to firms whose rivals' patent portfolios are more concentrated are more likely to be opposed.

To test these hypotheses we include covariates that have been previously identified as affecting the probability of patent litigation. Lanjouw and Schankerman (2001) provide an important analysis of the general features of patent litigation in the USA. They compare the characteristics of litigated patents and their owners to those of a control group of patents and owners. They establish the following empirical results: i) more valuable patents are more likely to be litigated; ii) parties with large portfolios are attacked less often, i.e., are presumably able to use settlements instead of litigation; iii) foreign (non-US patent holders) are less likely to be involved in US litigation; iv) litigation risk is much higher in pharmaceuticals than in other technologies.[8] Lanjouw and Schankerman (2004a) confirm that the risk of litigation for patents owned by individuals or firms with small patent portfolios is much higher. They argue that holders of relatively large portfolios of patents are more likely to trade licenses and may engage in other forms of "cooperative" dispute resolution. Hence, these types of patent owners are less likely to pursue infringement suits in court. A significant disadvantage for smaller firms results from this – they face a high risk of litigation, and are less well positioned to resolve cases amicably.

4 Data and Descriptive Statistics

We use data on all patent applications filed at the EPO between 1980 and 2007 to test the hypotheses derived in the previous section. This section provides detailed information on our data sources, a discussion of the variables we derive and descriptive statistics for these variables.

[8] The average incidence of infringement litigation is about one case per 100 patents. But the rate varies between 0.5 cases in chemicals to 2 cases per hundred patents for pharmaceuticals. Lerner (1995) estimates a likelihood of six cases per hundred patents in biotechnology in the time period 1990-1994. Generally, the frequency of litigation decreases as a technical sector matures.

4.1 Data Sources

Our data set was obtained from the PATSTAT[9] database and contains bibliographic and legal information on patents, as well as information on the identity of the patent applicants. We assign patents to applicants based on the applicant information contained in the ECOOM-EUROSTAT–EPO PATSTAT Person Augmented Table (EEE-PPAT), which provides a harmonized set of applicant names for the PATSTAT database.[10] We also applied our own harmonization routines including consolidation of subsidiaries to the 100 most important patent applicants ranked by their total number of patent applications.[11]

In total, we observe 2,194,756 patent applications at the EPO between 1980 and 2007 that resulted in a total of 1,099,782 granted patents to date (see Table 1). It should be noted that many applications are still pending. For example, 70% of patent applications in the 2007 application cohort were still under examination in March, 2011. For 1,044,292 of the granted patents, we can observe whether there was an opposition by the end of the first quarter of 2011. 64,902 oppositions were filed against granted patents, which yield an average opposition rate of 6.2%. Table 1 shows that while the annual number of patent applications has steadily increased over time, both the share of patent applications that led to granted patents, as well as the number of oppositions relative to patents granted remained relatively stable until the mid-1990s. The decline in both grant and opposition rates towards the end of the observation period is due to truncation as the examination of patent applications is lengthy. Grant lags at the EPO are on average about 4.5 years (Harhoff and Wagner, 2009).

INSERT TABLE 1 ABOUT HERE

4.2 Variables

Dependent variable - Opposition. For each granted (focal) patent in our sample, we observe whether an opposition was filed within the statutory period of 9 months after the grant date. This is the dependent variable in our analysis. The reference year *t* for the dependent variable is the year in which the patent is granted by the EPO. All technology and firm-level measures are calculated relative to this grant year, albeit with a lag in some cases. This captures the information set firms have when making a decision to oppose the patent after it is granted. We discuss the lags we adopt in each case below. We deviate from this rule only with respect to the measure of concentration, which captures the public

9 Information on PATSTAT is available at http://www.epo.org/searching/subscription/raw/product-14-24_de.html (last accessed on April 20th, 2014).

10 See du Plessis et al., 2009, Peeters et al., 2009, and Magermann et al., 2009, for a comprehensive description of the harmonization routines.

11 Our results are not depending on the application of our harmonization routine.

good effect. This measure is calculated on the basis of the year of application of the focal patent to reflect the concentration of related technology at the time of invention.

Explanatory variables

Concentration of patent ownership $C_{f,a,ta}$. This measure is used to capture the public good effect. It is constructed as the Herfindahl index of the concentration of rivals' granted patents in a technology area (*a*), if these patents were applied for in the same year (*ta*) as the focal patent. Due to this timing the variable measures concentration in the cohort of technologies submitted to the patent office at the time of application of the focal patent. This choice of timing is based on the assumption that revocation of a patent will primarily benefit applicants of patents applied in the same year and technology area. These applicants will be most affected by a revocation and should be able to extract more value from their own patents if the focal patent is revoked. In calculating the measure, we distinguish 30 different technological areas according to the OST-INPI/FhG-ISI technology classification (OECD, 1994). This firm-area-year level variable measures the strength of the public good effect.

Density of patent thickets – Triples of mutually blocking firms $Tr_{a,t}$. This measure is used to capture the patent thicket effect. Our primary measure of the density of patent thickets in a particular technology area (*a*) is the "triples" measure introduced by Graevenitz et al., (2011; 2012). This measure is based on critical references listed in the search reports of the EPO. Critical references point to prior art that limits the patentability of an invention. For example, the existence of an older, but similar, invention can threaten the patentability of a newer invention because the newer invention is not novel or lacks inventiveness. In these cases, critical documents containing conflicting prior art are referenced in search reports at the EPO as X or Y references (Harhoff et al., 2006). X refers to documents showing that a claimed invention cannot be considered novel or cannot be considered to involve an inventive step. Where a document has to be combined with one or more other documents to show lack of novelty or inventiveness it is classified as a Y reference.[12]

Where the patentability of firm A's inventions is frequently limited by existing patents of firm B, it is reasonable to assume that A is blocked by B to a certain degree. If the inverse is also true, A and B are highly likely to own mutually blocking patents. To capture more complex structures of blocking relationships we follow (Graevenitz et al., 2011) and compute the number of "triples" in which three firms own mutually blocking patents (see Figure 1). Resolving this form of blocking is likely to be costlier and more complex than bilateral bargaining as it may involve three simultaneous bilateral bargaining processes. Even more complex blocking situations can be described as consisting of

[12] Refer to EPO Guidelines for Examination, Part B, Chapter X, Section 9.2.1, available at http://www.epo.org/law-practice/legal-texts/html/guidelines/e/b_x_9_2_1.htm, latest access on 3rd of May 2014. About 46% of all references contained in the population of European patent applications are critical references with X references being twice as frequent as Y references. Our results remain robust if we use only X references for the construction of our triples measure.

multiple triples. Therefore a count of triples can be used as a local measure of network density as proposed by Holland and Leinhardt (1976) and Milo et al. (2002).

INSERT FIGURE 1 ABOUT HERE

In our data blocking pairs and triples are identified as follows: for each firm *i* we analyze all critical patent references contained in search reports pertaining to firm *i*'s patents in a given technology area and grant year *t* over the current and the two preceding years ($t-2$ to t).[13] Pairs are established if firm A is on firm B's list of referenced firms and, at the same time, if firm B is on firm A's list of referenced firms. Finally, triples are formed if firm A and firm B, firm A and firm C, and firm B and firm C form pairs of mutually blocking relationships in the same period (see Figure 1).[14] Having constructed the triples measure at the technology area level we lag the measure by two periods to capture the fact that patents younger than 18 months are not published by the patent office. The lagged measure reflects firms' ability to measure the density of patent thickets only with delay. This area-year variable measures the strength of the patent thicket effect.

In order to test the insider-outside hypothesis (Hypothesis 3), we split the count of triples at the level of a technical area into two components: a firm-level count of the number of triples in which the firm itself is involved (insider triples – $Tr\_i_{a,t}$), and the count of triples present in the technological area without the involvement of the focal firm (rivals' triples – $Tr\_o_{a,t}$). These measures are also lagged by two periods.

Fragmentation $Fr_{f,a,t}$. To control for the impact of fragmentation of prior art we use Ziedonis' (2004) fragmentation index. We construct an index of fragmentation based on X and Y references contained in a focal firm *f*'s annual patent applications as $Fr_{f,a,t} = 1 - \sum_{j=1}^{n} s_{f,a,j,t}^2$, where $s_{f,a,j,t}$ is the share of X and Y references in *f*'s patent applications that point to patents owned by patentee *j*, that are filed in area *a* and the grant year *t* of the focal patent. We apply the correction proposed by Hall (2005b) for this measure and multiply the fragmentation index by $\frac{refs_{i,a,t}}{refs_{i,a,t} - 1}$ where $refs_{f,a,t}$ is the number of references in firm *f*'s patent applications in area *a* and grant year *t*. As with the triples measure we use the second lag of the fragmentation measure relative to the grant year of the applicant's patent to account for the fact that patents younger than 18 months are not yet published. The fragmentation measure is

13 We analyze a time span of three years to account for cumulativeness in technological progress. Relying on a three year window is an arbitrary choice. While the measure differs in its absolute values depending on the time window chosen, its variation across fields is robust w.r.t. different time windows.

14 Note that this measure of triples relies upon all firms referenced on each firm's list of critical references. In contrast von Graevenitz at al. (2011, 2013) rely on only the top ten firms on each list.

frequently used to control for the effects of patent thickets in the literature (Cockburn and MacGarvie, 2011; Galasso and Schankerman, 2010; Schankerman and Noel, 2006; Ziedonis, 2004). Ziedonis (2004) argues that high fragmentation of ownership of a technology among the rivals of a patent holder will exacerbate the problem of negotiating access to the technology. This measure provides no information about the complexity of bargaining as it contains no information about linkages between the patent holder's rivals.

We have found this measure to be weakly correlated with the triples measure and include it as a separate covariate. Our results are robust to the exclusion of the variable[15], but since it is highly significant we report it in our results below.

Covariates

Size of technology area $S_{a,ta}$. We include the total number of patent applications filed in a technology area in the year in which the application for the focal patent is made. This variable captures the possibility that examination quality suffers due to large volumes of applications. If this were the case we might expect a greater volume of applications to increase the probability of opposition. This could counteract the patent thicket effect, making that harder to identify.

Applicant characteristics $F_{f,t}$. For each applicant we compute the natural logarithm of the cumulative number of patent applications filed at the EPO by the year in which the focal patent is granted as a proxy for the size of their patent portfolio. It is reasonable to assume that the likelihood of patent opposition should decrease with the size of an applicant's patent portfolio. Lanjouw and Schankerman (2001) as well as Harhoff and Reitzig (2004) discuss this effect. Moreover, we include dummy variables for an applicant's country of origin, distinguishing applicants from the United States of America, Japan, Europe, and the rest of the world. Europe is used as the reference group in the regressions reported below. We also distinguish between four types of applicants: individuals, government institutions, universities, and a reference group, which consists mainly of private enterprises.

Patent characteristics X_i. Previous research has shown that the likelihood of post-grant validity challenges depends on a number of patent characteristics: the (private) value of patents is positively related to the likelihood of litigation and opposition (Harhoff and Reitzig, 2004; Lanjouw and Schankerman, 2001). We include the number of citations a patent receives over a five-year period (in logarithms) as a (noisy) proxy for its private value (Harhoff et al., 1999). Moreover, we include the number of jurisdictions in which equivalent patents have been filed (Lanjouw and Schankerman, 2004b) and a variable indicating whether a patent was filed via the Patent Cooperation Treaty (PCT)

15 These results are available from the authors on request.

application path to proxy for patent value.[16] Following Harhoff and Reitzig, (2004) and Lanjouw and Schankerman (2004a; 2001), we include the number of claims and variables describing the composition of backward references contained in a patent's search report as further proxies for patent value. At the EPO, references contained in a patent's search report are classified into different categories. X- and Y-type references are discussed above. A-type references summarize prior art without implying a limitation of novelty or inventive step. We use the latter as reference group. Finally, we control for the rigor of the examination process using the duration of patent examination: the time between the filing of the application and the publication of the patent grant. Harhoff and Reitzig (2004) show that both the duration of patent examination and the count of X-type references are positively correlated with the likelihood of opposition.

4.3 Descriptive Statistics

Table 2 presents the number of patent grants, the number of oppositions, as well as the average number of triples, and the average concentration of patent holdings for the 30 different technology fields for the period from 1980 to 2007.

INSERT TABLE 2 ABOUT HERE

While the different technology areas vary considerably in their number of patent applications and grants, we also observe interesting variation in the opposition rates, as well as the existence of patent thickets and the degree patent ownership concentration.

Figure 2 shows the development of opposition rates over time for six main technology areas. For almost all of them, opposition rates have declined since the EPO began its operation with the start of examination in 1978 and the first patent grants in 1980. Opposition rates are lowest for patents in the main technology area of Electrical Engineering. The decline of opposition rates has also been particularly pronounced in this main technology area.

INSERT FIGURE 2 ABOUT HERE

Our measure of the existence and density of patent thickets – the number of triples of mutually blocking relations between patent applicants – is particularly high in complex technologies belonging

[16] A PCT application also allows applicants to postpone decisions regarding the scope of international protection for up to 30 months and might signal the intention to commercialize the protected invention in a large number of national markets.

to the main field of Electrical Engineering, such as Audiovisual Technology, Telecommunications, IT and Semiconductors.[17] Other studies have suggested that these are the technology areas characterized by overlapping patent rights and patent thickets, see for instance Hall and Ziedonis (2001), Schankerman and Noel (2013) and Cockburn and MacGarvie (2011). The areas with the lowest (average) number of triples are Agriculture/Food, Agriculture/Food Processing Machines, Construction Goods, Nuclear Technology and Space Technology & Weapons.

INSERT FIGURE 3 ABOUT HERE

Figure 3 graphs opposition rates and the number of triples over time for the three areas with the highest and the three areas with the lowest triple counts. Increases in the number of triples in Telecommunications and IT are accompanied by a decrease in the respective opposition rates.[18] Both Table 2 and Figure 3 suggest that areas with very dense thickets (high levels of triples) are also characterized by below-average opposition rates. In fact, the coefficient of correlation between the number of triples and the opposition rate is -0.43 and highly significant. We also find a highly significant, but somewhat smaller correlation between the concentration of ownership of granted patents and the opposition rate in a technology field (coefficient of correlation -0.24).

INSERT FIGURE 4 ABOUT HERE

In Section 3 we argued that opposition rates vary between firms within a technical area, depending on the extent to which firms are caught up in the patent thicket. We distinguish between outsiders, whose patents are not part of the thicket, and insiders who may be more or less affected by the thicket. Figure 4 provides information on the relative numbers of insiders and outsiders (size of circles) by technology area and period. The figure demonstrates that even in areas in which thickets are rife the vast majority of firms are not part of the thicket as measured by the triples measure. However, it is also clear from the figure that significant numbers of firms are caught up in many thickets, while only a few firms are caught up in a moderate number of thickets. Over time firms seem to be separating into two groups – one group which is caught up in patent thickets and one which is not. Figure 4 also demonstrates that over time, thickets are both getting more extensive within particular areas (firms caught up in triples

[17] We also find a large number of triples in the field of Pharmaceutical and Cosmetics. See evidence for strategic patenting behavior in cosmetics by Hall and Harhoff (2002).

[18] A similar development can be observed for the Audiovisual as well the Semiconductor areas which are not included in Figure 2, see von Graevenitz et al. (2007) for more complete time series of opposition rates in different technology areas.

are caught up in more of them) and that they are becoming more widespread across technological fields. In the regression analysis below, we further pursue the distinction between insiders and outsiders to determine how these two groups of firms are affected by opposition.

5 Empirical Results

In this section we discuss the specifications we estimate, present results and analyze these.

5.1 Estimation Strategy

We estimate probit models, which relate the probability of opposition against the grant of a focal patent *i*, to characteristics of the focal patent, the owner of the focal patent and the technology area the focal patent is assigned to. The specification used in this paper is:

prob(opposition against patent i)=

$$\Box\left(\beta_0+\beta_C C_{f,a,ta}+\beta_{Tr} Tr_{f,a,t-2}+\beta_{Tr} Fr_{f,a,t-2}+\beta_S S_{a,ta}+\beta'_X X_i+\beta'_F F_{f,t}+\Box_a+\Box_t\right)$$

Above we set out the simplest specification we estimate. In this specification opposition is a function of three explanatory variables and a number of covariates. The explanatory variables are concentration $C_{f,a,ta}$, the number of triples $Tr_{a,t-2}$ and the fragmentation measure $Fr_{f,a,t-2}$. The second main specification we estimate replaces the count of triples at the area level with two measures: the number of triples a firm is involved in $Tr\_i_{f,a,t-2}$ and the number of remaining triples in the technology area $Tr\_o_{f,a,t-2}$ with $Tr_{a,t}= Tr\_i_{a,t}+Tr\_o_{a,t}$.

All models include vectors for patent characteristics X_i and for firm characteristics $F_{f,t}$ as well as the measure of total applications to a technology area in a given year $S_{a,ta}$. In all regressions we cluster standard errors at the level of the firm *f*, technology area *a* and grant year *t*. Moreover, we capture persistent differences across technologies using technology class fixed effects $\Box_a$ and time trends and shocks in specific years using time fixed-effects at the level of the grant year of a patent $\Box_t$.

Conditional on the included covariates, any remaining variation in the data allows us to study the effect of changes in the density of patent thickets and in the concentration of patent holdings in specific technical fields on the incidence of opposition. Nevertheless, in these analyses it is important to rule out endogeneity of the independent variables. One concern might be that the patent thicket effect measure (triples) or the measure of the public good effect might themselves be affected by incidence of opposition, leading to reverse causality. A second concern might be that unobservable determinants of opposition are correlated with the explanatory variables, leading to omitted variables bias. There are two reasons to discount these problems here.

The first relates to the time lags between the measures we use for the patent thicket effect and the public good effect. The patent thicket effect measures capture the state of patent thickets two years prior to opposition, because opponents and applicants will not have more up to date information than this from patent data released by the EPO. Therefore reverse causality is highly unlikely for the patent thicket effect. The public good effect measure is based on the size of the cohort of applications made when the focal patent was submitted to the patent office. This date is on average more than 4 years before the date of a decision to oppose the focal patent (Harhoff and Wagner, 2009). The lag and the associated uncertainty about future opponents strongly reduce the potential for reverse causality here. The second reason to discount endogeneity relates to the level of aggregation: the dependent variable in the regressions reported below is measured at the level of the granted patent and will be affected mainly by patent application specific and firm specific unobservable effects. The measures of the patent thicket effect and of the public good effect average across all firms in a technology area or at least across several firms in that technology area. As such they are much less likely to correlate significantly with firm specific unobservable effects. Note that any technology area specific unobservable effects are captured by time and technology area fixed effects.

5.2 Results and Discussion

In Table 3, we summarize descriptive statistics for the all variables included in our empirical models.

INSERT TABLE 3 ABOUT HERE

INSERT TABLE 4 ABOUT HERE

In Table 4 we report coefficients and marginal effects from estimation of the specifications outlined above.[19] Columns 1 and 2 of Table 4 present a specification including only covariates. In this specification proxies for patent value such as the number of forward citations and the size of the international patent family (equivalents) have a statistically significant positive effect on the incidence of opposition, as expected. An increase by one logarithmic unit in the citation count is associated with an increased incidence of opposition of 2.4 percentage points (at the sample means of other covariates). One additional international patent filing increases incidence of opposition by about 0.09 percentage points. These results are consistent with earlier studies of opposition and of litigation (Harhoff and Reitzig, 2004; Lanjouw and Schankerman, 2004b; 2001). Also, higher generality and originality of patents are associated with increases in the probability of opposition. This suggests that pioneering patents (with high originality) or widely diffusing patents (with high generality) run a higher risk of opposition than other patents, either for technical or strategic reasons.

Following Harhoff and Reitzig (2004), we use the composition of backward references to proxy patent quality. While the total count of backward references is associated with a slight decrease in the

[19] We do not report the estimated coefficients for the time and area fixed effects here for reasons of brevity. The regression results can be obtained from the authors upon request.

likelihood of opposition, an increase in the share of X-type references in the search report has a statistically significant positive effect on the probability of opposition.

We find a statistically significant negative effect of PCT filings on opposition – PCT filings have an opposition incidence that is 0.52% percentage points lower than other filings. PCT filings are typically protected in many jurisdictions, suggesting that this is a subset of all patents selected for their value, their strategic relevance and their high quality. PCT filings provide considerable option value, since the decision which countries to file in can be delayed by up to 30 months after the priority date, adding 18 months of delay compared to "normal" international patent applications. We suspect that PCT applications are of higher quality (applicants have more time to abandon applications not worth pursuing) which lowers the chances for potential opponents to be successful in opposition. The likelihood of observing opposition against PCT applications should therefore be reduced.

As expected, firms with large portfolios experience a lower incidence of opposition. Again, this finding confirms earlier results (Lanjouw and Schankerman, 2001; 2004a) and is consistent with the view that large firms enjoy advantages in the process of resolving disputes over IP. The median size of an applicant's patent portfolio (cumulative number of patent grants until the end of 2007) across all technology areas is 64, the largest patent portfolio is 20,433. The average marginal effect of a one logarithmic unit increase in patents is a reduction in opposition by 0.2 percentage points.

Non-European applicants are significantly less likely to face opposition than European patent holders. This is not surprising, as patent filings from non-European countries have gone through stronger selection filters than patent filings of the local applicants. Some applicant types (individuals, universities and government organizations) experience a significantly lower risk of opposition than other (mostly corporate) patent holders. Again, the effect may be driven by relatively low patent value or the pre-selection of patents of particularly high quality. There is evidence that both arguments apply – Gambardella, Harhoff and Verspagen (2008) report that patents from these three types of applicants are usually of lower commercial value than corporate patents. At the same time, the level of novelty when compared to the state of the art of these filings can be above average making it harder to oppose them on grounds of not reaching the necessary inventive step.

Our main variables of interest are the effects of the triples measure of patent thicket density and the concentration of patent ownership among the applicant's rivals. In column (3) we just include the main variables: triples as a measure of the patent thicket effect with fragmentation as an additional covariate and concentration as a measure for the public good effect.

We find support for Hypothesis 1. The count of technology area triples is associated with a significant reduction in opposition incidence with an effect of -0.0010, which is statistically significant.[20] At the

[20] The number of technology area triples ranges between zero and 7526 in our data, with a median value of 63.

median of all variables a one standard deviation increase in the lagged triple count divided by 100 (13.43) reduces the incidence of opposition by 1.34 percentage points (13.43*-0.0010=-0.0134). That is a 22.2% reduction relative to the unconditional opposition rate. It is worth noting that these numbers understate the effect of a deepening of the patent thicket as the unconditional probability of opposition in technology areas affected by thickets has been below 5% for the last 20 years.

To test Hypothesis 2 we split the count of technology area triples into two separate measures: own triples, which the holder of the focal patent is involved in and rivals' triples which only other firms in the same technical area are involved in. The effect of both variables on opposition is highly significant and negative as is shown in columns 7 and 8 of Table 4. A one standard deviation increase in own triples reduces the probability of opposition by 14.4% (0.7689*-0.0113=0.0087) relative to the unconditional mean, while a one standard deviation increase in rival triples reduces the probability of opposition by 15% relative to the unconditional mean (12.94*-0.0007=0.0091). Note also that one additional own triple reduces the probability of opposition more than if there is an additional triple in the technology area. This means that *ceteris paribus* a patent application submitted by a firm that is a patent thicket insider is less likely to face opposition than a patent application submitted by a firm that is an outsider.

We include the fragmentation variable in our specifications to confirm that the triples variable offers a better way of describing the density of patent thickets than the fragmentation measure that is frequently used in the literature to proxy effects of patent thickets. The coefficient of fragmentation is positive[21] and highly significant. However, the economic effect of a standard deviation change in fragmentation on opposition is much weaker (0.05% at the median of all variables) than that of triples.

Hypothesis 3 posits that patent applications are less likely to encounter opposition in patent thickets if they belong to larger firms as opposed to smaller firms. Testing this hypothesis requires us to include an interaction between the measure of patent thickets (triples) and the measure of firm size. We test the hypothesis in the specification that includes only technology area triples (columns 5 and 6) and in the specification that includes both own and rivals' triples (columns 9 and 10). Figures 5 and 6 show that the interaction term is associated with a significant reduction in the probability of opposition for larger firms in both specifications. We reject the null hypothesis that size does not matter for either model, although Figure 6 indicates that the effect is only significant for firms with patent portfolios which are larger than the median portfolio, when we distinguish between own and rival's triples.

Finally, Hypothesis 4 states that concentration should have a positive sign if there is a public good effect. The average marginal effect of concentration of 0.51 is statistically significant, lending support

[21] If the fragmentation measure is also a measure oft he patent thicket effect, conditional on the triples measure we would expect it to have a negative sign. In unreported results we have found that the square of the fragmentation measure has a significant negative effect on the probability of opposition. For high values of fragmentation the overall effect is negative but economically very weak as indicated above.

to this hypothesis. At the median of all variables a one standard deviation increase (0.0096) of concentration leads to an increase in the probability of opposition by 0.49 percentage points (0.096*0.51=0.0049). This effect is also economically important as it translates to a 8.1% increase in the opposition rate relative to the unconditional opposition rate.

Overall, we find that the hypotheses set out in Section 3 are supported using the data we employ here. The results indicate that patent thickets have a strong dampening effect on the incidence of opposition, while the public good effect has dampening effect too, but is much smaller in effect size.

6 Conclusions and Further Research

Strong demand for patent rights combined with errors in patent offices' examination and grant procedures result in increasing numbers of "weak" and overlapping patent rights. As a result companies are increasingly confronted with serious challenges when trying to develop and commercialize technology in the presence of patent thickets. Litigation and post-grant validity challenges have been considered as a way of eliminating erroneously granted patent rights - with post-grant patent review typically being cheaper than litigation. Discussing the America Invents Act (AIA), enacted at the end of 2011, Graham and Vishnubhakat (2013) highlight three avenues for post-grant validity challenges that have recently been introduced in the United States with the explicit aim of raising patent quality. These are post-grant review, "covered business method patents" (or third party) review, and *inter partes* (or third party) review.[22]

We argue, as do previous studies, that post-grant opposition is likely to lose its effectiveness where multiple opponents fail to engage in opposition due to a public good effect. This study is the first to document the empirical importance of this effect. Moreover, the patent thicket effect, which we propose and document, results in fewer patent opposition cases in technologies affected by patent thickets. The rate of patent opposition at EPO has been stable for 20 years at around 8% in the technology area of Chemistry which is characterized by a relatively high concentration of patent ownership and is thus less likely to be affected by the public good effect. As in other discrete technologies, the incidence of "triples" is low in Chemistry. Meanwhile the opposition rate in Electrical Engineering has fallen by 50% in the same period, from a starting level of 5.5% in 1990. Electrical Engineering is the technology area most affected by patent thickets, and ownership concentration is low. Our results indicate that the public good and patent thicket effects are at work in increasing numbers of technology areas.

[22] The new post-grant review mechanism at the USPTO allows opponents to challenge patents on all grounds, including eligibility and clarity. The "covered business method" review procedure allows third parties that face the threat (or are actually sued) to challenge its validity independently of the issue date of the potentially infringed business method patent. Finally, the "inter partes", or third-party submission, allows any member of the public to participate by submitting documents and commentary for use by patent examiners. See (S. Graham and Vishnubhakat, 2013) for details.

These findings are of high relevance for the users of patent systems and for those concerned with the governance of such systems. Unfortunately, our results show that in complex technologies, in which the need for a corrective seems to be highest, private incentives to engage in post-grant validity challenges are particularly low. This demonstrates that a focus on examination quality is especially important for such complex technologies and that "rational ignorance" of patent offices (Lemley et al. 2001) is not a particularly effective approach in these technologies. It remains to be seen whether the relatively recent establishment of defensive patent aggregators (Hagiu and Yoffie, 2013) will reverse the patent thicket effect in complex technology areas and will lead to effective use of the mechanisms created by the America Invents Act. This act certainly has created scope for more collective activity of this kind. However, our analysis suggests that it will have to be smaller applicants who contribute to ensuring that weak patents are kept off the register or removed from it when first asserted. Collectively, their interests in such a mechanism working are much stronger than those of larger firms at the heart of thickets whose cooperative actions through cross-licensing do not remove weak patents from the patent register. Further work on whether the interests of the many patent thicket outsiders can be harnessed in their and the interests of society seems warranted.

Our results also raise important questions for the management of patent rights at the firm level. The choice between adversarial and collaborative means of conflict resolution becomes blurred when the problems discussed in this study arise. "Navigating thickets" can require considerable brinkmanship. To date, scholarly research can provide little guidance for firms' operational or strategic patent management in such a context. While we have not studied the dynamics of opposition, it is conceivable that periods of collusion are sometimes terminated by "patent wars". The analogy to collusive price-setting and intermittent price wars is obvious. In our case, controversies surrounding singularly important patents or divergent opinions about optimal firm strategy may lead patent-holders to resort to court interaction in some cases, possibly triggering counteractions by other parties. Such break-downs in collaborative "thicket management" may be occurring currently in the mobile telephony industry. The current dispute between the major players (most notably between Apple and Google) can be seen as a telling example of firms trying to find the right balance between confrontational and collaborative conflict resolution in an industry characterized by patent thickets. We suggest that research regarding the factors that trigger "patent wars" which can be socially and privately detrimental should receive particular attention in future work on patent management.

To summarize, our study suggests how challenging the management of innovation in complex technologies is. The dense interaction between holders of mutually blocking patents can render post-grant review rather ineffective in technological areas impacted by thickets. Mechanisms like opposition which are meant to ensure that strong patents survive on the register while weak patents are eliminated lose some of their appeal in this context. Our study cannot offer any strong results as to how the problem of weak patents in complex technologies can be addressed, but it shows that once firms have adopted the logic of patent portfolio races, the incentives to patent more and litigate less against holders of large patent portfolios spreads even to firms initially not caught up in the thicket but being active in the same technology. This tendency of patent thickets to self-perpetuate and grow is worrying. It remains to be seen whether the instruments soon to be available at the USPTO or post-grant mechanisms relying on independent parties other than the directly affected firms, such as an ombudsman who acts in the public interest, can alleviate this problem, or whether a much greater emphasis on examination quality is required. These are important questions for future work.

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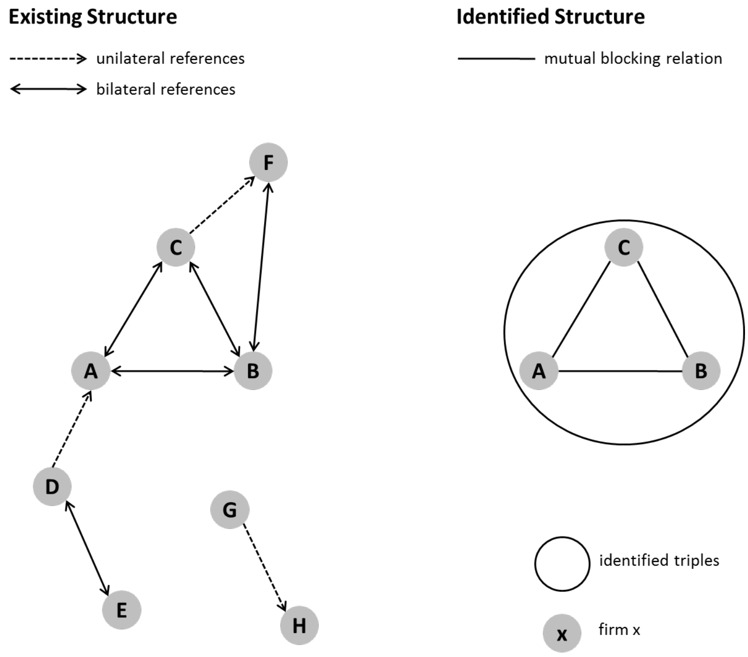
Figure 1 Schematic Presentation of Unilateral and Bilateral Blocking Relationships



Note: Adopted from von Graevenitz et al. (2011), Figure 1.

Figure 2 Opposition Rates by Main Technological Area – 1980-2007

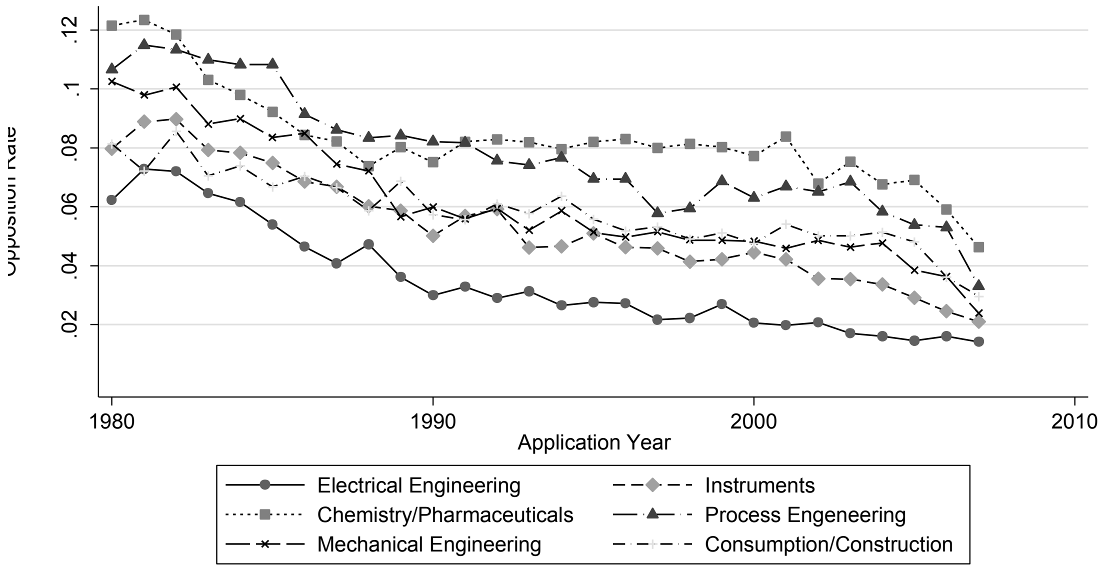
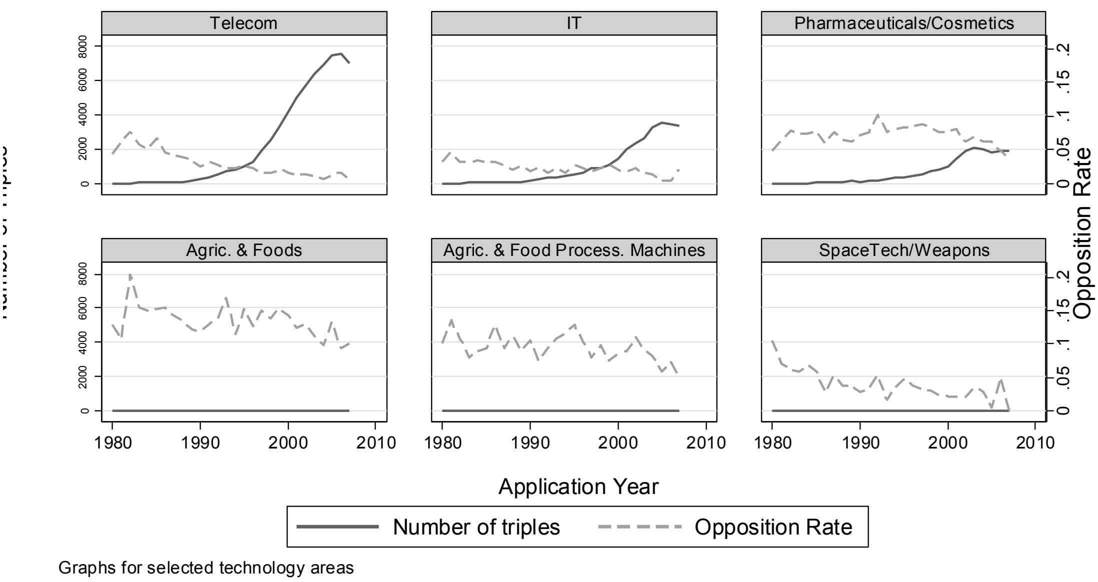


Figure 3 Triples (left ordinate) and Rate of Opposition (right ordinate) at the EPO (1980 to 2007) by Application Year and Technological Area



Note: Telecommunication, IT and Pharmaceuticals/Cosmetics have the highest average number of triples between 1980 and 2007. Agriculture/Food, Agriculture/Food Processing Machines and Space Technology/Weapons have the lowest average number of Triples between 1980 and 2007.

Figure 4 Structure of Patent Thickets Across Technology Areas for four different periods

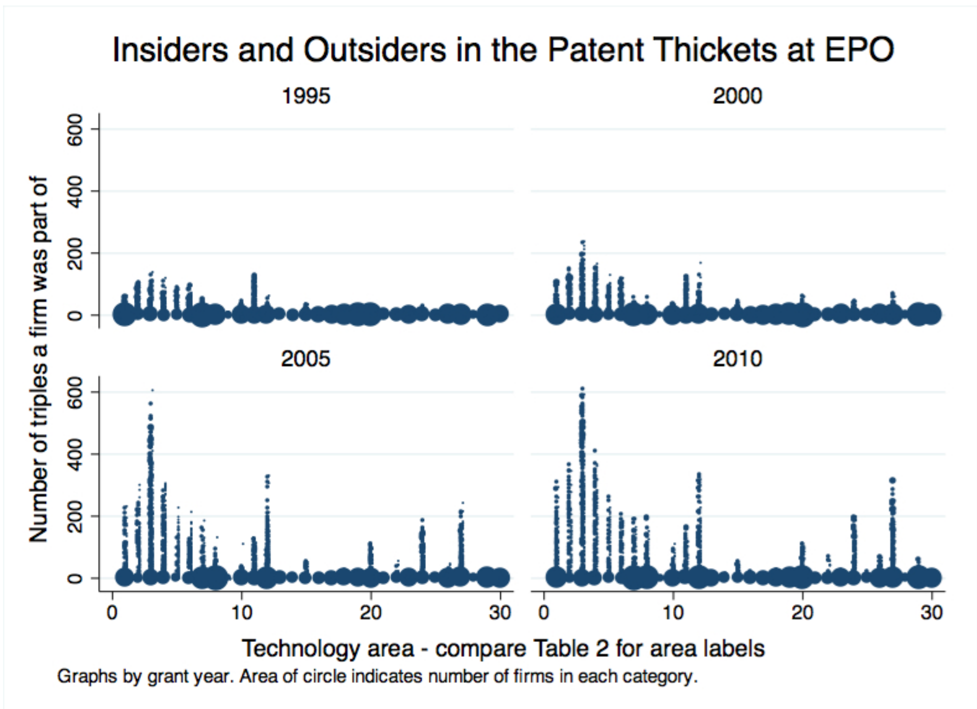


Figure 5 Average Marginal Effect of Additional Triples by Size of Patent Portfolio

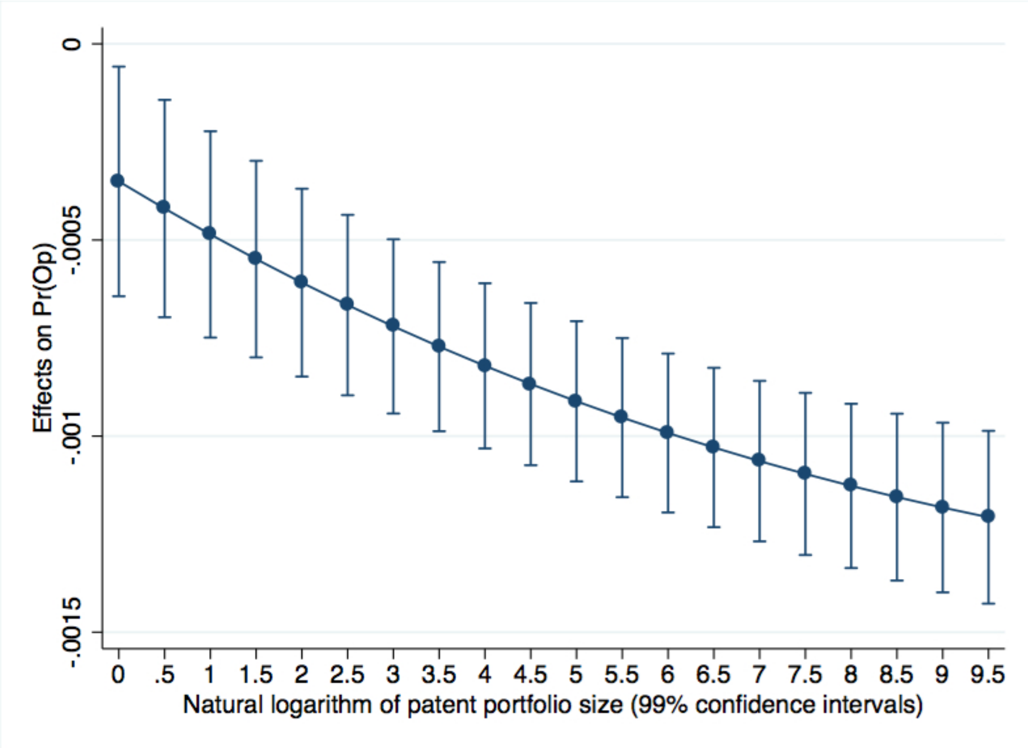


Figure 6 Average Marginal Effect of Additional Own Triples by Size of Patent Portfolio

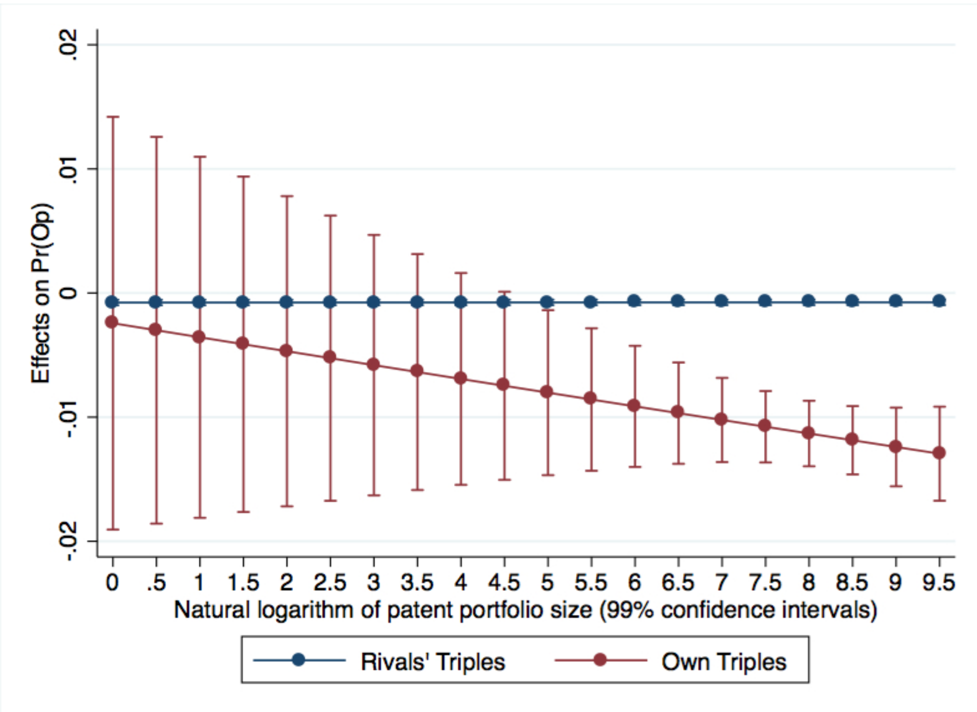


Table 1 Applications, Grants, Pending Cases and Oppositions by Application Year (1980-2007)

Application year	Applications	Grants	Grant rate	Pending cases	Share of pending cases	Oppositions	Oppostion rate*
1980	21,174	14,685	69.35%	18	0.09%	1,439	9.80%
1981	27,182	18,688	68.75%	24	0.09%	1,890	10.11%
1982	30,177	20,961	69.46%	40	0.13%	2,098	10.01%
1983	33,187	22,889	68.97%	72	0.22%	2,037	8.90%
1984	38,930	26,456	67.96%	82	0.21%	2,307	8.72%
1985	41,498	28,054	67.60%	41	0.10%	2,310	8.23%
1986	45,301	30,332	66.96%	48	0.11%	2,292	7.56%
1987	48,258	32,008	66.33%	137	0.28%	2,268	7.09%
1988	55,131	36,099	65.48%	288	0.52%	2,429	6.73%
1989	61,150	39,084	63.91%	497	0.81%	2,528	6.47%
1990	67,722	44,660	65.95%	236	0.35%	2,676	5.99%
1991	63,070	42,319	67.10%	52	0.08%	2,633	6.22%
1992	64,553	43,352	67.16%	332	0.51%	2,686	6.20%
1993	63,973	44,066	68.88%	171	0.27%	2,572	5.84%
1994	65,933	45,200	68.55%	367	0.56%	2,660	5.88%
1995	69,426	46,518	67.00%	660	0.95%	2,661	5.72%
1996	75,947	49,128	64.69%	1,195	1.57%	2,739	5.58%
1997	85,585	52,254	61.06%	2,072	2.42%	2,722	5.21%
1998	96,581	55,436	57.40%	3,543	3.67%	2,826	5.10%
1999	105,203	57,126	54.30%	6,093	5.79%	3,056	5.35%
2000	116,851	60,129	51.46%	9,226	7.90%	3,035	5.05%
2001	123,431	58,489	47.39%	15,061	12.20%	3,046	5.21%
2002	121,559	53,121	43.70%	22,032	18.12%	2,530	4.76%
2003	124,710	48,778	39.11%	32,813	26.31%	2,357	4.83%
2004	130,653	43,205	33.07%	46,487	35.58%	1,936	4.48%
2005	137,899	37,300	27.05%	62,795	45.54%	1,535	4.12%
2006	141,006	29,413	20.86%	80,634	57.18%	1,089	3.70%
2007	138,666	20,032	14.45%	97,225	70.11%	545	2.72%
Total	**2,194,756**	**1,099,782**	**50.11%**	**382,241**	**17.42%**	**64,902**	**5.90%**

Note: In case a patent has been filed by more than one applicant it is contained multiple times in the data**.**

* The opposition rate reported is the number of oppositions filed divided through patent grants by year of application. For patents granted less than 9 months before April 1st 2011 we do not observer whether opposition has been filed or not.

Table 2 Number of Patent Grants, Oppositions; mean values of Opposition Rate, Triples and Concentration of Rivals' Patent Grants by Technology Area (1980 - 2007)

Technology area	Area No.	Grants	Oppo-sitions	Oppostion rate	Triples	Concen-tration of rivals' patents
Electrical Engineering/Energy	1	62,002	2,780	4.48%	648.00	0.0118
Audiovisual	2	31,084	985	3.17%	987.33	0.0352
Telecom	3	66,629	1,496	2.25%	4,726.35	0.0237
IT	4	39,772	827	2.08%	1,867.94	0.0248
Semiconductors	5	19,998	442	2.21%	745.05	0.0308
Optical	6	36,737	1,054	2.87%	607.67	0.0214
Analysis / Measurement / Control Technology	7	67,968	3,461	5.09%	342.18	0.0045
Medical Technology	8	57,246	3,557	6.21%	352.03	0.0053
Nuclear Technology	9	4,505	247	5.48%	3.27	0.0486
Organic Chemistry	10	42,058	1,946	4.63%	138.02	0.0114
Polymers	11	46,859	4,413	9.42%	476.47	0.0155
Pharmaceuticals/Cosmetics	12	61,050	4,545	7.44%	1,164.40	0.0060
Biotechnology	13	16,884	1,109	6.57%	14.47	0.0061
Agriculture & Foods	14	11,938	1,608	13.47%	10.23	0.0134
Petrol Chem./Materials Chem.	15	27,966	2,621	9.37%	135.61	0.0171
Surface Technology	16	20,526	1,764	8.59%	20.04	0.0058
Materials	17	29,720	3,095	10.41%	22.56	0.0051
Chemical Engineering	18	40,251	2,899	7.20%	28.32	0.0039
Material processing / Textiles / Paper	19	47,778	4,521	9.46%	33.58	0.0038
Handling/Printing	20	63,690	3,644	5.72%	321.35	0.0073
Agriculture & Food Process-Machines	21	14,926	1,413	9.47%	4.36	0.0118
Environment	22	14,644	1,088	7.43%	49.91	0.0069
Machine Tools	23	35,069	2,663	7.59%	20.60	0.0034
Motors	24	33,682	1,560	4.63%	499.46	0.0189
Thermal Processes	25	13,571	991	7.30%	16.07	0.0078
Mechanical Elements	26	39,288	1,937	4.93%	82.55	0.0045
Transportation	27	65,168	3,369	5.17%	840.53	0.0072
Space Technology / Weapons	28	5,533	206	3.72%	0.41	0.0209
Consumer Goods	29	47,820	2,562	5.36%	61.15	0.0029
Construction Technology	30	35,420	2,099	5.93%	10.79	0.0023
Total		**1,099,782**	**64,902**	**5.90%**	**668.06**	**0.0110**

Note: In case a patent has been filed by more than one applicant it is contained multiple times in the data.

Table 3 Descriptive Statistics

Variables	Unit of observation	Mean	S.D.	Median	Min	Max
Opposition (0/1)	P	0.06	---	0.00	0.00	1.00
Number of area triples	YA	668.06	1343.45	147.00	0.00	7526.00
Number of own triples	FYA	27.89	76.90	0.00	0.00	610.00
Number of rivals' triples	FYA	640.17	1294.54	141.00	0.00	7526.00
Concentration of rivals' patents x100	FYA	1.05	0.97	0.68	0.15	11.66
Fragmentation x100	FYA	68.83	42.97	95.08	0.00	100.00
Patent applications per area and year	YA	3600.93	2448.24	3008.00	139.00	13608.00
Cum. number of patents /1000	FY	1.09	2.55	0.06	0.00	20.43
Company applicant (0/1)	F	0.89	---	1.00	0.00	1.00
Individual applicant (0/1)	F	0.07	---	0.00	0.00	1.00
University applicant (0/1)	F	0.01	---	0.00	0.00	1.00
Government applicant (0/1)	F	0.02	---	0.00	0.00	1.00
Generality	P	0.10	0.20	0.00	0.00	1.00
Originality	P	0.29	0.34	0.20	0.00	1.00
Duration of examination	P	4.79	1.96	4.39	0.23	24.16
Total references	P	3.89	2.83	4.00	0.00	123.00
Citations received within 5 years	P	0.82	1.61	0.00	0.00	100.00
Share of X relative to total references	P	0.19	0.30	0.00	0.00	1.00
Share of Y relative to total references	P	0.10	0.22	0.00	0.00	1.00
Share of other relative to total references	P	0.11	0.22	0.00	0.00	1.00
Number of equivalents	P	7.52	5.96	6.00	1.00	346.00
PCT filing (0/1)	P	0.35	---	0.00	0.00	1.00
Number of claims	P	13.49	10.45	11.00	0.00	476.00
EU applicant (0/1)	F	0.54	---	1.00	0.00	1.00
US applicant (0/1)	F	0.23	---	0.00	0.00	1.00
Japanese applicant (0/1)	F	0.19	---	0.00	0.00	1.00
Applicant ROW (0/1)	F	0.04	---	0.00	0.00	1.00

Note: A correlation table for all independent and the dependent variable is available from the authors upon request. Unit of observation is indicated in the second column: F- firm, Y - year, A - area, P – patent.

Table 4 **Results from Probit Regressions – Dependent Variable: Opposition (0/1)**

VARIABLES		(1) Coeff.	(2) dx/dy	(3) Coeff.	(4) dx/dy	(5) Coeff.	(6) dx/dy	(7) Coeff.	(8) dx/dy	(9) Coeff.	(10) dx/dy
Number of area triples	YA			-0.0096***	-0.0010***	-0.0027**	-0.0008***				
				[0.001]	[0.000]	[0.001]	[0.000]				
Number of rivals' triples /100	FYA							-0.0069***	-0.0007***	-0.0070***	-0.0008***
								[0.001]	[0.000]	[0.001]	[0.000]
Number of own triples/100	FYA							-0.1051***	-0.0113***	-0.0178	-0.0065
								[0.010]	[0.001]	[0.059]	[0.003]
Number of triples/100 x number of patents (log)						-0.0012***				-0.0107	
						[0.000]				[0.007]	
Concentration of rivals' patents	FYA			4.7258***	0.5082***	4.6593***	0.5008***	4.1634***	0.4474***	4.1175***	0.4425***
				[0.589]	[0.063]	[0.590]	[0.064]	[0.587]	[0.063]	[0.585]	[0.063]
Fragmentation	FYA			0.1368***	0.0147***	0.1342***	0.0144***	0.1327***	0.0143***	0.1310***	0.0141***
				[0.007]	[0.001]	[0.007]	[0.001]	[0.007]	[0.001]	[0.007]	[0.001]
Grant duration	P	0.1432***	0.0154***	0.1530***	0.0165***	0.1524***	0.0164***	0.1529***	0.0164***	0.1529***	0.0164***
		[0.002]	[0.000]	[0.002]	[0.000]	[0.002]	[0.000]	[0.002]	[0.000]	[0.002]	[0.000]
Applications in area	AY	0.0022	0.0002	0.0358***	0.0038***	0.0321***	0.0035***	0.0348***	0.0037***	0.0348***	0.0037***
		[0.004]	[0.000]	[0.004]	[0.000]	[0.004]	[0.000]	[0.004]	[0.000]	[0.004]	[0.000]
Cum. number of patents (log)	FY	-0.0173***	-0.0019***	-0.0310***	-0.0033***	-0.0243***	-0.0032***	-0.0236***	-0.0025***	-0.0233***	-0.0027***
		[0.001]	[0.000]	[0.002]	[0.000]	[0.002]	[0.000]	[0.002]	[0.000]	[0.002]	[0.000]
Individual applicant (0/1)	F	-0.2775***	-0.0299***	-0.2587***	-0.0278***	-0.2519***	-0.0271***	-0.2465***	-0.0265***	-0.2459***	-0.0264***
		[0.010]	[0.001]	[0.010]	[0.001]	[0.010]	[0.001]	[0.010]	[0.001]	[0.010]	[0.001]
University applicant (0/1)	F	-0.3629***	-0.0391***	-0.3567***	-0.0384***	-0.3575***	-0.0384***	-0.3649***	-0.0392***	-0.3636***	-0.0391***
		[0.022]	[0.002]	[0.022]	[0.002]	[0.022]	[0.002]	[0.022]	[0.002]	[0.022]	[0.002]
Government applicant (0/1)	F	-0.3473***	-0.0374***	-0.3386***	-0.0364***	-0.3399***	-0.0365***	-0.3489***	-0.0375***	-0.3486***	-0.0375***
		[0.017]	[0.002]	[0.018]	[0.002]	[0.018]	[0.002]	[0.018]	[0.002]	[0.018]	[0.002]
Generality	P	0.1304***	0.0141***	0.1350***	0.0145***	0.1332***	0.0143***	0.1294***	0.0139***	0.1299***	0.0140***

Table 4 **Results from Probit Regressions – Dependent Variable: Opposition (0/1)**

VARIABLES		(1) Coeff.	(2) dx/dy	(3) Coeff.	(4) dx/dy	(5) Coeff.	(6) dx/dy	(7) Coeff.	(8) dx/dy	(9) Coeff.	(10) dx/dy
ln(1+total references)	P	-0.0166***	-0.0018***	-0.0149***	-0.0016***	-0.0149***	-0.0016***	-0.0156***	-0.0017***	-0.0156***	-0.0017***
		[0.004]	[0.000]	[0.004]	[0.000]	[0.004]	[0.000]	[0.004]	[0.000]	[0.004]	[0.000]
Share of X relative to total references	P	0.1246***	0.0134***	0.1217***	0.0131***	0.1211***	0.0130***	0.1221***	0.0131***	0.1222***	0.0131***
		[0.008]	[0.001]	[0.008]	[0.001]	[0.008]	[0.001]	[0.008]	[0.001]	[0.008]	[0.001]
Share of Y relative to total references	P	0.0204	0.0022	0.0183	0.0020	0.0176	0.0019	0.0178	0.0019	0.0180	0.0019
		[0.011]	[0.001]	[0.011]	[0.001]	[0.011]	[0.001]	[0.011]	[0.001]	[0.011]	[0.001]
Share of other refs relative to total references	P	0.0240*	0.0026*	0.0222*	0.0024*	0.0192	0.0021	0.0198	0.0021	0.0198	0.0021
		[0.011]	[0.001]	[0.011]	[0.001]	[0.011]	[0.001]	[0.011]	[0.001]	[0.011]	[0.001]
Number of equivalents	P	0.0082***	0.0009***	0.0082***	0.0009***	0.0082***	0.0009***	0.0083***	0.0009***	0.0082***	0.0009***
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
PCT filing (0/1)	P	-0.0479***	-0.0052***	-0.0459***	-0.0049***	-0.0461***	-0.0050***	-0.0440***	-0.0047***	-0.0437***	-0.0047***
		[0.006]	[0.001]	[0.006]	[0.001]	[0.006]	[0.001]	[0.006]	[0.001]	[0.006]	[0.001]
Number of claims	P	-0.0006*	-0.0001*	-0.0006*	-0.0001*	-0.0006*	-0.0001*	-0.0006*	-0.0001*	-0.0006*	-0.0001*
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
US applicant (0/1)	F	-0.2749***	-0.0296***	-0.2821***	-0.0303***	-0.2859***	-0.0307***	-0.2861***	-0.0307***	-0.2875***	-0.0309***
		[0.008]	[0.001]	[0.008]	[0.001]	[0.008]	[0.001]	[0.008]	[0.001]	[0.008]	[0.001]
Japanese applicant (0/1)	F	-0.3919***	-0.0423***	-0.3973***	-0.0427***	-0.3982***	-0.0428***	-0.3964***	-0.0426***	-0.3970***	-0.0427***
		[0.009]	[0.001]	[0.009]	[0.001]	[0.009]	[0.001]	[0.008]	[0.001]	[0.008]	[0.001]
Applicant ROW (0/1)	F	-0.3381***	-0.0365***	-0.3377***	-0.0363***	-0.3413***	-0.0367***	-0.3360***	-0.0361***	-0.3374***	-0.0363***
		[0.021]	[0.002]	[0.021]	[0.002]	[0.022]	[0.002]	[0.021]	[0.002]	[0.021]	[0.002]
Time fixed effects (application years)	F	YES		YES		YES		YES		YES	
Area fixed effects		YES		YES		YES		YES		YES	
Log-likelihood	P	-196594		-196047		-195928		-195895		-195891	
Observations		966,974		966,974		966,974		966,974		966,974	

Note: Standard errors in parentheses. Standard errors have been clustered by firm, area and year and are reported in brackets.
*** p<0.001, ** p<0.01, * p<0.05. Source of variation is indicated in the second column: F- firm, Y - year, A - area, P – patent.
Marginal effects are average marginal effects calculated using Stata's margins command.

Appendix A - Theoretical Model

1.1 Introduction

Our empirical analysis focuses on the probability that a patent application is opposed. We adopt the perspective of the potential opponent's choosing whether or not to oppose. The solution to their decision problem yields characteristics of the patents that these firms are likely to oppose and of the technologies that the opposed patents belong to.

We model two effects that reduce a firm's incentives to oppose a patent application. The patent thicket effect derives from the behaviour of the applicant in a patent thicket. The public good effect derives from the presence of other potential opponents and may be effective in or outside a patent thicket.

1. The patent thicket effect is based on two aspects of patent thickets: patent owners hold large portfolios of patents covering related or similar technologies and patents are losely drafted leading to many potential conflicts between the patent owers. We identify two possible explanations for the patent thicket effect:

    - retaliation - the opponent may fear retaliatory oppositions or other forms of retaliation initiated by the patent applicant;
    - ineffectiveness of opposition - if the applicant makes multiple simultaneous applications, each one of which could reduce the opponent's profits, then opposing all of these applications may not be cost effective.

2. The public good effect - the opponent may perceive less need to oppose a patent that affects several other firms. If so, the aggregate effect on all opponents may be strong enough to reduce the overall probability of opposition.

We begin by analyzing the patent thicket effect, focusing on one applicant and one opponent. Once we have developed the logic of the opposition decision for this case, we add further potential opponents to the model to analyze the public good effect.

1.2 Literature Review

The literature on patent litigation, and by extension opposition, has largely focused on factors that determine when firms might settle disputes over a patent application cooperatively (Lanjouw and Lerner, 1998, Siegelman and Waldfogel, 1999, Harhoff and Reitzig, 2004). Our analysis focuses on a preceding decision which is made by a potential opponent, namely the decision whether or not to initiate opposition at all. We focus on variables that might lead the patent owner to conclude that opposition will be more expensive than simply living with the patent.

In undertaking this analysis we abstract from the costs of the opposition procedure for the applicant. This means we do not have to consider the possibility that firms settle their disputes, which keeps our analysis simple. The reason is that the applicant has no incentive to settle as they will still have some positive expectation that opposition might fail. In the resulting model potential opponents therefore choose between living with the patent or opposition and any resulting behavior on the part of the applicant.

1.3 Notation

Assume that a potential opponent's profits are initially π. With exogenously varying probability $1 \geq \sigma \geq 0$ the applicant firm's patent is significant enough to pose a threat to the potential opponent's future profits and the costs which it can create for the opponent are Γ. The probability that the applicant's patent will not survive opposition is given by $1 \geq \nu \geq 0$. The applicant's profits if the patent is granted are $\tilde{\pi} < \Gamma$, explaining why there is no cooperative solution.

The potential opponent's decision to oppose the applicant's patent depends on the degree of overlap between the two firms' patent portfolios. If overlap is high, then it is likely that the applicant firm will be able to retaliate, creating further costs Ψ for the focal firm. The probability that this happens and lowers own profits is $1 \geq \rho \geq 0$.

2 The Patent Thicket Effect

In a patent thicket opposition may prove to be costly, because it gives rise to retaliation by the opposed firm, or opposition may prove to be futile. We develop both cases below. First, consider retaliation.

2.1 Retaliation

The opponent will oppose the applicant's patent if this is more profitable than not opposing:

$$\sigma\Big[\nu\Big((1-\rho)\pi + \rho(\pi - \Psi)\Big) + (1-\nu)\Big((1-\rho)(\pi - \Gamma) + \rho(\pi - \Psi - \Gamma)\Big)\Big] + (1-\sigma)(\pi - \rho\Psi) > \sigma(\pi - \Gamma) + (1-\sigma)\pi$$
$$\Leftrightarrow \sigma\nu\Gamma > \rho\Psi \quad . \quad (1)$$

The opponent will choose to oppose the patent application whenever the expected value of the costs that opposition would remove ($\sigma\nu\Gamma$) exceed the expected cost of retaliation ($\rho\Psi$).

This simple trade-off explains why we expect opposition to be less likely between firms at the centre of a patent thicket: the probability of retaliation (ρ) is higher for such firms, because the applicant is more likely to hold a large portfolio of patents that allow such retaliation.

This explains Hypotheses 1 - 3. Insiders in the patent thicket have highly linked portfolios, making retaliation very easy, while outsiders have fewer links with a given insider's portfolio, which lowers ρ in any bilateral relationship between an insider and an outsider.

The model indicates that there could be a counteracting effect. Technology areas affected by a thicket are characterized by a high volume of patent applications. The quality of patents issued in areas with higher demands on the patent office's resources will not be higher than the quality of patents in other technology areas and most likely is significantly lower. Therefore ν is likely higher in a patent thicket increasing the expected profits from opposition.

In our empirical analysis we employ a number of variables that proxy the quality of patent examination. This allows us to identify the effects of retaliation on opposition using the triples measure.

2.2 Ineffective Opposition

Even if the opponent does not fear retaliation by the applicant, it may be that opposition is seen to be futile because the applicant has made multiple similar applications.

To capture this effect we introduce two further parameters:

C - the fixed cost of opposition for the opponent and

τ - the number of simultaneous applications that could affect the opponent's profits, where ($\tau \geq 1$).

To isolate the effects of multiple simultaneous applications we assume that the probability of retaliation is zero ($\rho = 0$). Then the tradeoff between opposing all τ patents submitted by the applicant and not opposing any is:

$$\begin{aligned} &[(1-\sigma)+\nu\sigma]^{\tau}\pi + (1-[(1-\sigma)+\nu\sigma]^{\tau})(\pi-\Gamma) - \tau C > \\ &\qquad (1-\sigma)^{\tau}\pi + (1-(1-\sigma)^{\tau})(\pi-\Gamma) \\ &\qquad\qquad \Leftrightarrow \Gamma\Big([(1-\sigma)+\nu\sigma]^{\tau} - (1-\sigma)^{\tau}\Big) > \tau C \qquad (2) \end{aligned}$$

Here $[(1-\sigma)+\nu\sigma]^{\tau}$ is the probability that none of the τ patent applications will reduce the opposing firm's profits. In setting up this expression, we assume that the outcome of opposition cases is independent and that the opposing firm does not know which of the τ patents are problematic, so that it must oppose all of them. Equation (2) shows that as the number of simultaneous patent applications by the applicant (τ) increases the cost of opposing all of these applications rises linearly, while the expected benefit of opposition falls in τ.

Therefore, as applicants submit increasing numbers of simultaneous patent applications relevant to a specific technology, opposition becomes proportionately less cost effective.

This mechanism can also support Hypotheses 1-3. Insiders in the thicket are identified as being linked by more critical references. This implies that simultaneous applications by an insider are likely to be more threatening for another insider than the same number of simultaneous applications by an outsider. Therefore insiders will evaluate opposition against insider patent applications as being futile sooner than against outsider patent applications.

The triples measure will capture this effect, but a better measure would consist of the number of simultaneous patent applications covering similar technology submitted by the applicant. To construct this measure requires information on similarity of technology covered by patent applications which would have to be derived using text mining techniques. Such measures are only just being tested and we do not yet have the necessary information to use such a measure.

3 Public Good Effect

In this section we extend the logic of the patent thicket effect to a setting with $\eta-1$ further firms all of whom are equally affected by the focal patent application. The η potential opponents are playing a coordination game amongst themselves. We solve for the mixed strategy equilibrium of this game in which each firm opposes the applicant's patent with probability ω. The public good effect can be derived for settings in which retaliation or ineffective opposition are at work.

3.1 The Public Good Effect and Retaliation

The main difference between opposing and not opposing the patent is that firms which do not oppose the patent are not in danger of retaliation from the patent's owner. Payoffs from opposing the patent application are:

$$\Big((\pi - \rho\Psi) - \sigma(1-\nu)\Gamma\Big) \tag{3}$$

Payoffs from not opposing the patent application are:

$$\Big(1-(1-\omega_{\not{i}})^{\eta-1}\Big)\left(\pi - \sigma(1-\nu)\Gamma\right) + (1-\omega_{\not{i}})^{\eta-1}\Big(\pi - \sigma\Gamma\Big) \tag{4}$$

Initially we investigate whether not opposing can be a dominant strategy for all firms. Comparing the payoffs obtainable from opposing to those obtainable from not opposing, it is obvious that $(\pi - \sigma(1-\nu)\Gamma) > ([\pi - \rho\Psi] - \sigma(1-\nu)\Gamma)$ and it can be shown that $(\pi - \sigma\Gamma) > ((\pi - \rho\Psi) - \sigma(1-\nu)\Gamma) \Leftrightarrow \rho\Psi > \sigma\nu\Gamma$. This implies that if an individual firm does not find it optimal to oppose, adding any number of further firms as additional potential opponents will not alter this firm's decision. However, if opposition is optimal for each firm alone, then choosing to oppose with positive probability ($1 > \omega > 0$) is optimal in the presence of multiple potential opponents. Expected payoffs are:

$$\begin{aligned}&\omega_i\Big((\pi - \rho\Psi) - \sigma(1-\nu)\Gamma\Big)\\ &\qquad + (1-\omega_i)\left[\Big(1-(1-\omega_{\not{i}})^{\eta-1}\Big)\left(\pi - \sigma(1-\nu)\Gamma\right) + (1-\omega_{\not{i}})^{\eta-1}\Big(\pi - \sigma\Gamma\Big)\right]\end{aligned} \tag{5}$$

As all firms are symmetrical this leads to the following expression for the probability with which firms oppose the patent application, whenever opposition is optimal for each firm:

$$(1-\hat{\omega})^{\eta-1} = \frac{\rho\Psi}{\sigma\nu\Gamma} \Leftrightarrow \hat{\omega} = 1 - \Big(\frac{\rho\Psi}{\sigma\nu\Gamma}\Big)^{\frac{1}{\eta-1}} \quad . \tag{6}$$

Comparative Statics

We now analyze the comparative statics of the public goods effect based on retaliation. First of all it is important to realize that we are interested in the overall probability that the applicant's patent is opposed by at least one firm:

$$\Omega = 1 - (1-\hat{\omega})^{\eta} \tag{7}$$

Analyzing how this probability changes with the number of potential opponents we identify two effects:

i) adding a potential opponent increases the overall probability of opposition if individual opposition probabilities are held constant and

ii) each potential opponent's probability of opposition may drop as an additional firm joins the group of potential opponents.

$$\begin{aligned}\frac{\partial\Omega}{\partial\eta} &= \underbrace{-(1-\hat{\omega})^{\eta}\ln(1-\hat{\omega})}_{i} + \underbrace{\eta(1-\hat{\omega})^{\eta-1}\frac{\partial\hat{\omega}}{\partial\eta}}_{ii} \\ &= (1-\hat{\omega})^{\eta-1}\Big(-(1-\hat{\omega})\ln(1-\hat{\omega}) + \eta\frac{\partial\hat{\omega}}{\partial\eta}\Big)\end{aligned} \tag{8}$$

If $\frac{\partial\hat{\omega}}{\partial\eta} < 0$, then it may be the case that the overall probability of opposition Ω falls with the number of potential opposing firms. The individual probability of opposition ($\hat{\omega}$) is affected by the number of potential opponents η as follows:

$$\frac{\partial\hat{\omega}}{\partial\eta} = \frac{1}{(\eta-1)^2}\Big(\frac{\rho\Psi}{\sigma\nu\Gamma}\Big)^{\frac{1}{\eta-1}}\ln\Big(\frac{\rho\Psi}{\sigma\nu\Gamma}\Big) < 0 \quad . \tag{9}$$

This shows that the individual probability of opposition falls as the number of potential opponents grows. The same is true for the overall probability of opposition:

$$\frac{\partial\Omega}{\partial\eta} = \Big(\frac{1}{\eta-1}\Big)^2(1-\hat{\omega})^{\eta-1}\ln\Big(\frac{\rho\Psi}{\sigma\nu\Gamma}\Big)\Big(\frac{\rho\Psi}{\sigma\nu\Gamma}\Big)^{\frac{1}{\eta-1}} < 0. \tag{10}$$

This shows that the public good effect is a separate effect from the retaliation effect, which arises when multiple firms can oppose an applicant and all are equally affected by the threat of retaliation.

3.2 The Public Good Effect and Ineffective Opposition

Here we analyze a setting in which each applicant submits multiple patents simultaneously and there is more than one firm that can oppose all of these applications. We assume that firms cannot coordinate on which patents to oppose, rather they pick the proportion of patents to oppose $\tilde{\omega}$ randomly.

Just as in the case of the public good effect derived from retaliation firms benefit from the presence of other opponents. Here it is because their cost of opposition falls. We now show that this leads each firm to reduce its opposition efforts by too much, leading to an overall reduction of opposition as the number of potential opponents increases.

Payoffs from opposing a fraction $\tilde{\omega}_i$ of the applicant's τ patent applications are:

$$\begin{aligned}&\left[(1-\sigma)+\sigma\tilde{\omega}_i\nu+\sigma(1-\tilde{\omega}_i)\nu(1-(1-\tilde{\omega}_{\not i})^{\eta-1})\right]^{\tau}\pi\\ &\qquad\left(1-\left[(1-\sigma)+\sigma\tilde{\omega}_i\nu+\sigma(1-\tilde{\omega}_i)\nu(1-(1-\tilde{\omega}_{\not i})^{\eta-1})\right]^{\tau}\right)(\pi-\Gamma)-\tilde{\omega}_i\tau C \qquad (11)\end{aligned}$$

The optimal proportion of applications which each firm will choose to oppose is given by:

$$\sigma\nu\left(1-\hat{\tilde{\omega}}\right)^{\eta-1}\left[(1-\sigma)+\sigma\nu(1-(1-\hat{\tilde{\omega}})^{\eta})\right]^{\tau-1}\Gamma-C=0 \qquad (12)$$

This is an implicit function which defines the proportion of the applicant's patents that is opposed by each one of the η opponents.

Comparative Statics

The total probability of opposition $(\tilde{\Omega})$ for each of the τ simultaneous patent applications is:

$$\tilde{\Omega}=1-(1-\hat{\tilde{\omega}})^{\eta} \quad . \qquad (13)$$

Just as previously the effect of increasing the number of potential opponents on the total probability of opposition per patent application is:

$$\frac{\partial\Omega}{\partial\eta}=(1-\hat{\omega})^{\eta-1}\left(-(1-\hat{\omega})\ln(1-\hat{\omega})+\eta\frac{\partial\hat{\omega}}{\partial\eta}\right) \quad . \qquad (14)$$

The derivative of the individual probability of opposition w.r.t. η is:

$$\frac{\partial\hat{\tilde{\omega}}}{\partial\eta}=-\left(1-\hat{\tilde{\omega}}\right)\ln(1-\omega)\frac{([(1-\sigma)+\sigma\nu-\tau\sigma\nu(1-\hat{\tilde{\omega}})^{\eta})}{\sigma\nu\left[-(\eta-1)\left[\frac{(1-\sigma)}{\sigma\nu}+1\right]+\left(1-\hat{\tilde{\omega}}\right)^{\eta}(\tau\eta-1)\right]} \qquad (15)$$

We can now show that the public goods effect exists in the context of futile opposition as well.

$$\frac{\partial\Omega}{\partial\eta} = -(1-\hat{\omega})^{\eta-1}(1-\hat{\omega})\ln(1-\hat{\omega})\left(1-\frac{\eta}{\eta-1}\frac{\left[\frac{(1-\sigma)}{\sigma\nu}+1\right]-\tau(1-\hat{\hat{\omega}})^{\eta}}{\left[\left[\frac{(1-\sigma)}{\sigma\nu}+1\right]-(1-\hat{\hat{\omega}})^{\eta}(\tau\frac{\eta}{(\eta-1)}-\frac{1}{(\eta-1)})\right]}\right)$$
$$= (1-\hat{\omega})^{\eta-1}(1-\hat{\omega})\ln(1-\hat{\omega})\left[\frac{\left[\frac{(1-\sigma)}{\sigma\nu}+1\right]-(1-\hat{\hat{\omega}})^{\eta}}{(\eta-1)\left[\left[\frac{(1-\sigma)}{\sigma\nu}+1\right]-(1-\hat{\hat{\omega}})^{\eta}(\tau\frac{\eta}{(\eta-1)}-\frac{1}{(\eta-1)})\right]}\right] \quad (16)$$

This expression can only have a positive sign if the denominator of the term in square brackets is negative. This requires that $\sigma \to 1$ and that the number of simultaneous applications (τ) be large while the number of potential other opponents (η) be small. As the number of other opponents rises, the sign of the expression will eventually turn negative.

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