Essays on the Economics of Patents

Post-Grant Review, Subsequent Innovation,
and Selection for Litigation

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and Selection for Litigation

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[N]obody would seriously dispute the proposition that living standards today are higher than in the eleventh century primarily because we know more than medieval peasants. [...] The central phenomenon of the modern age is that as an aggregate we know more.

Mokyr (2002, Chapter 1)

Preface

In developed economies, the exponential growth of productivity and of the standard of living is typically attributed to technological progress through innovation (Aghion and Howitt, 1992; Romer, 1986, 1990). Stimulating and facilitating innovative processes is thus a first-order concern for social welfare in the medium and long run.[1] In a competitive market, however, economic theory predicts an underprovision of ideas and inventions, which constitute a costly, intangible, and non-excludable good. For technologies that cannot be protected by trade secrets, inventors may lack incentives to develop socially beneficial products. Even when the social value exceeds an invention's development cost, private returns may not cover R&D expenditures if ideas can readily be copied or if the inventor is unable to capture a sufficient share of the invention's value for follow-on innovation (Nordhaus, 1969; Scotchmer, 1991). To alleviate such inefficiency, most countries resort to the provision of patents, granting a temporary exclusion right to the inventor of a novel technological product or process.[2]

Patent rights entail an inherent trade-off (Nordhaus, 1969). On the one hand, they provide ex-ante incentives to innovators, allowing them to appropriate a larger share of the social benefits they create, either through exclusive use of the invention, through licensing, or by sale. Besides, public disclosure of the invention, sufficient for reproduction by a person skilled in the art, is a requirement for patentability. Hence, patents in principle promote the diffusion of knowledge, technological transfer, and commercialization. On the other hand, strong patent protection may lead to monopolistic market structures and deadweight loss. In view of this trade-off, the optimal design of patent rights with respect to protection length and scope has been a traditional focus of the literature (Eckert and Langinier, 2013; Williams, 2017).

The efficiency and the effectiveness of the patent system, however, depend on systemic processes beyond the basic trade-off (cf. Hall and Harhoff, 2012; Eckert and Langinier, 2013):

(i) First, patents have economic implications which extend beyond their nature as an exclusion right for the focal invention. For instance, if each new invention builds on previous discoveries ("cumulative innovation"), existing patent rights may stifle inventive activ-

[1] "Innovation" is in this context defined as the union of invention and effective (commercial) diffusion among its users and consumers.

[2] The formal requirements for an invention to be patentable are fairly consistent across jurisdictions: novelty, involvement of an inventive step, i.e., non-obviousness to a person skilled in the art, and industrial applicability. Nonetheless, the scope of the "invention" definition varies, e.g., concerning software, business models or plant varieties.

ities if efficient agreements with the patent holder cannot be attained by all potential follow-on innovators.

(ii) Second, the use of the patent system depends on the administrative procedures inside the patent office, which govern the application process, the examination phase, and validity challenges by third parties. The institutional setup, the fee structure, and internal staff assessment schemes determine the incentives and the behavior of applicants, competitors, and examiners. In consequence, the design of patent office procedures impacts the quantity and the quality of applications and granted patents.

(iii) Third, the institutional setup and the usage of the legal system determine in how far patents facilitate the appropriability of returns to invention. Unless the exclusion right is enforceable in court, a patent does not benefit its holder, neither through exclusive use of the invention nor through an improved bargaining position as a licensor. Besides enforcement, litigation may serve as a means to revoke unduly granted patents that restrict other inventors' freedom to operate. To assess costs and benefits of patent litigation, it is important to understand the incentive structure for the involved parties and the selection mechanisms that regulate which disputes are litigated.

This dissertation sheds light on three such determinants of innovation outcomes beyond the basic patent trade-off, each in a self-contained chapter. The first chapter studies the causal effect of patent invalidation on follow-on invention by third parties. It thus examines how patents interact with cumulative innovation – a process ubiquitous in modern industrial innovation. Thereby, the chapter addresses a patent's repercussions beyond the protected invention (category i). The second chapter examines how the invalidation of marginally valid patents in opposition impacts affected inventors' subsequent patenting. Opposition proceedings allow for challenges to the validity of granted patents without the involvement of courts. Within the context of the institutional procedures at the patent office (category ii), the chapter thus adds to the understanding of social costs and benefits of post-grant review. Besides, in studying implications of marginal patents for the original innovator, it touches upon category (i). The third chapter develops and calibrates a model of the selection of patents for litigation. It characterizes the patent litigation system (category iii), and assesses the prevalence of latently invalid patents. To this end, it examines how patent heterogeneity interacts with incentives for dispute.

Chapter 1, which is based on joint work with Fabian Gaessler and Dietmar Harhoff (Gaessler, Harhoff, and Sorg, 2017), uses large-scale data on patent opposition at the European Patent Office (EPO) to investigate the effect of patent invalidation on follow-on invention. Building on previous inventions, or "cumulative innovation," is crucial to modern innovative processes and has therefore become the core of endogenous growth theories (e.g., Romer, 1990; Aghion and Howitt, 1992). Necessary knowledge spillovers can be facilitated by the disclosure of inventions in patent publications (Scotchmer and Green, 1990). However, as pointed out by Scotchmer (1991), if appropriate incentives need to be provided for both the original and follow-on inventors, designing optimal patent rights necessarily involves balancing a conflict of objectives, which can be resolved only partially. If bargaining between the parties is efficient, follow-on invention may not be blocked (Green and Scotchmer, 1995). In the presence of transaction costs, however, efficient coordination, e.g. through licensing agreements, may not be attained.

In how far and under which circumstances the existing patent design facilitates or impedes cumulative innovation is ultimately an empirical question. The extent may differ by technology area, the competitive environment, and the firm sizes of the original and the follow-on innovator. On the one hand, the invalidation effect could be more pronounced in technology areas where patent thickets, overlapping claims, and fragmented ownership could lead to bargaining failure. Efficient licensing agreements might be elusive, especially for small firms lacking a patent portfolio for cross-licensing deals (Lanjouw and Schankerman, 2004; Cockburn et al., 2010). On the other hand, the gain in freedom to operate following invalidation is largest in "discrete" technology areas, such as chemicals and pharmaceuticals, with a one-to-one correspondence between patents and products. In "complex" technologies, such as the ICT sector, where a multitude of patents protect the same product market, the invalidation of a single patent may not give competitors sufficient incentives to invest in follow-on innovation. In addition, the effect might be moderated by complementary assets held by the focal patent holder. Generally, invalidation should have a stronger impact where appropriability heavily relies on patent rights, such as in chemistry (cf. Hall et al., 2014).

Post-grant opposition at the EPO constitutes a unique setting for the purpose of our study. It is frequent and occurs early and only once in a patent's lifetime. In contrast to litigation settings, the vast majority of opposition outcomes is observable, since settlement rates are minimal. This allows us to construct a large, comprehensive dataset of around 33,000 opposed patents which are still far from expiration. The main empirical challenge is the endogeneity of the opposition outcome. For valuable patents, parties will employ larger financial resources and modify the probability of invalidation. At the same time, it is reasonable to expect more subsequent invention. For the purpose of causal inference, we therefore introduce a new instrumental variable for patent invalidation, which leverages the participation or absence of the patent's examiner in the opposition proceeding. We show that the instrument has a highly significant impact on the outcome of opposition and thus a strong first stage: Examiner participation decreases the probability of invalidation by around 6.6 percentage points. Exogenous to our estimating equation, participation is driven by the availability of other suitable examiners. To measure subsequent innovation, we use forward citations generated by EPO search examiners. European examiner citations are independent of strategic citation behavior of the applicant. Hence, they constitute a less biased proxy for measuring innovative activity than other approaches.

We find that patent invalidation leads to a highly significant and sizeable increase of forward citations. While this is in line with previous studies (e.g., Galasso and Schankerman, 2015), disentangling the effect leads us to results that stand in contrast to some of the literature. We find that the effects are most pronounced for patents in discrete technology areas, for areas where patent thickets are absent, and for patents which are not protected by "patent fences." Moreover, the effect is particularly strong for small patent holders facing small follow-on innovators. We are able to confirm our results within technology-specific subsamples and by a series of robustness tests, most prominently by a replication with US citation data.

We contribute to the growing literature assessing the effect of patent rights on cumulative innovation in several ways. First, we present causal estimates of the effect of patent invalidation on follow-on invention based on a new source of exogenous variation in patent rights. We conjecture and show that in our opposition sample, conclusions concerning the heterogeneity of the effect with respect to technology areas and firm sizes diverge from what has previously been found in litigation settings (Galasso and Schankerman, 2015). In addition, we explore heterogeneity with respect to the prevalence of patent thickets and fences, patent age, and indicators of patent value.

Second, our study stands out in the scope and scale of the underlying data. In comparison to the litigation settings studied in prior work, our study allows for causal inference on a much less selective sample of patents, for which we observe invalidation at a considerably earlier and less heterogeneous point in their lifetime. While a patent can be litigated multiple times, opposition occurs at most once. Concerning technological scope, large parts of the literature focus on specific product technologies, such as pharmaceuticals, biotechnology, or chemicals (Moser and Voena, 2012; Williams, 2013; Sampat and Williams, 2018), or the ICT sector (Watzinger et al., 2017). Our study comprises patents across all technology areas.

Third, we are the first to provide an instrumental variable for patent invalidation at the European Patent Office. Patenting outcomes at the EPO, which grants patents for 38 member states with a total population of more than 450 million, have substantial economic impact, and should be at least as important to the involved parties as the corresponding decisions at the USPTO. Nonetheless, the European context has so far been understudied.

Finally, we alleviate key concerns revolving around the use of forward citations as a proxy for cumulative innovation. The fine-grained EP citation data allow us to identify citations added by the patent examiner, which are not biased by the applicant's potentially strategic disclosure of prior art (cf. Alcacer et al., 2009; Sampat, 2010), as in the US system. Besides, their technological relevance appears to be higher (Breschi and Lissoni, 2004).

Chapter 2, which is based on joint work with Markus Nagler (Nagler and Sorg, 2018), studies patent invalidation from a different perspective. It is less concerned with hurdles for cumulative invention, but investigates how the invalidation of a marginally valid patent impacts the original innovator's subsequent patenting activities. As such, it illuminates social costs and benefits of post-grant review. Understanding the implications of invalidation is particularly relevant for marginal patent rights whose legal admissibility is disputable – and thus within the range of policy adjustments.[3] Prior empirical work has shown that post-grant opposition procedures may serve as substitutes for litigation: For patents litigated in the US, European equivalents are often invalidated or amended in post-grant opposition at the EPO (Graham and Harhoff, 2014). At the same time, opposition comes at substantially lower cost. Whereas US litigation can involve private costs above one million dollars per case (Bessen and Meurer, 2005; American Intellectual Property Law Association, 2017), costs for opposition cases in Europe are typically below 50,000 € (MacDougall and Hamer, 2009). It is hence natural to expect post-grant review to entail large welfare gains relative to litigation. Nonetheless, invalidation in opposition may be associated with social costs (Shane, 2009). In particular, the loss of patent protection may impact the original innovator, reduce her innovative activities and decrease her propensity to disclose inventions in patent applications (Galasso and Schankerman, 2015). Depending on the characteristics of subsequently undeveloped or undisclosed inventions, such outcomes can be socially undesirable and counteract the disclosure function of the patent system (cf. Williams, 2017).

This chapter examines how the invalidation of marginal patents during opposition influences affected inventors' subsequent supply of ideas to the patent system. Invalidation in opposition could impact subsequent patenting for several reasons. First, losing a patent has been shown to adversely affect firm success, especially for small ventures (Farre-Mensa et al., 2017; Gaulé, 2018; Galasso and Schankerman, 2018). Due to resulting capital restrictions, inventors may be forced to limit the scope and to change the direction of their inventive activity. Second, firms and patent attorneys may adjust their filing strategy. For instance, patenting could be shifted to substitute authorities or towards secrecy (Hall et al., 2014). Third, invalidation may serve as a negative signal at the inventor or the invention level (cf. Chan et al., 2014; Azoulay et al., 2015, 2017). If invalidation is informative about inventor or idea quality, firms may adjust the allocation of resources towards other inventors or technology areas. Finally, invalidation may impact inventor mobility (Melero et al., 2017), which may in turn affect subsequent productivity (Hoisl, 2007, 2009).

We build a panel dataset of more than 65,000 inventors, which covers the ten years before and after their first opposition outcome at the EPO. For causal identification, we leverage the examiner participation instrument of Chapter 1, while controlling for inventor fixed effects.

[3] Comparing the framing of the first two chapters, the marginal nature of complier patents – to which instrumental variable estimates correspond ("local average treatment effect") – is less emphasized in Chapter 1. We thereby adhere to the common terminology in the cumulative innovation literature. Moreover, marginality in terms of legal stability is not necessarily related to technological utility for follow-on work by third parties. In contrast, for the discussion in Chapter 2, examining the invalidation of opposed marginal patents to assess the impacts of post-grant review is of particular relevance. They constitute potent exclusion rights, with implications for social welfare, whose legal status can be shifted by the institutional setup of the opposition proceeding. Besides, signals and financial implications associated with the invalidation of a marginal patent might differ from those of an average patent – at least relative to the assignee's or the inventor's expectation.

The sample of opposed marginal patents, for which we estimate local average treatment effects, is particularly interesting. On the one hand, the legal admissibility of marginal patents is within the range of policy reform. On the other hand, Harhoff and Reitzig (2004) show that opposed patents are more valuable than the average patent. Patent rights of high value likely constitute efficient exclusion rights in economically interesting markets. As such, they are particularly prone to create economically relevant uncertainty for competitors and to impede follow-on innovation.

We find that following invalidation, inventors file significantly fewer patent applications. This result cannot be explained by a shift of patenting to the national patent offices or the World Intellectual Property Organization, where applicants might hope to avoid centralized opposition at the EPO. Instead, the effect is driven by a reduction of applications associated with novelty-threatening prior art. Invalidation thus deters filings of questionable novelty or inventive step.

The chapter's contribution to the literature is twofold. First, it adds to the nascent literature studying procedures of post-grant review. Despite substantial interest in such institutions, empirical evidence on their consequences remains scarce. Most of the literature has discussed potential costs and benefits conceptually (e.g., Hall and Harhoff, 2004; Shane, 2009). Empirical work has examined characteristics of opposed patents (Harhoff and Reitzig, 2004) and has compared opposition outcomes to litigation (Graham and Harhoff, 2014). Overall, the literature lacks empirical results on the impact of post-grant review on innovation.

Second, the chapter contributes to the growing literature studying the effect of patent invalidation on subsequent innovation and productivity. Prior work has so far mostly focused on firm outcomes (Farre-Mensa et al., 2017; Gaulé, 2018; Galasso and Schankerman, 2018). While it is informative to understand the implications of patent grants for firm success, further insights are needed on a more granular level. From an innovation perspective, it is important to know to what extent patent invalidation impacts inventors and their supply of ideas to the patent system. In view of recent results by Bhaskarabhatla et al. (2017), this gap is particularly evident. While inventor fixed effects explain 23-29% of patenting performance, firm heterogeneity only accounts for 3-5% of the variance. We are the first to show the impact of invalidation on subsequent patent applications of *individual* inventors.

In summary, the chapter contributes to a better understanding of the patent system's social costs and benefits. Within the framework of patent opposition at the EPO, our setup illuminates disciplinary effects of patent office decisions. In reaction to invalidation, affected inventors appear on fewer applications associated with novelty-threatening prior art. Post-grant review may therefore promote application quality in the long run.

Chapter 3 takes up the discussion on granted patents of questionable validity by studying the prevalence of low-quality patents and their dispersion throughout the litigation system. It thus addresses the *extent* of potential consequences, rather than their nature. It characterizes the patent litigation system and assesses the distribution of quality in the patent population.

There is an extensive literature discussing potential repercussions of unduly granted, low-quality patents.[4] Patents of insufficient inventive step or indeterminate scope may create uncertainty for competing innovators. In particular, substantial risk may arise from unjustified infringement suits. Furthermore, unnecessary costs associated with licensing, inventing around, or increased search efforts can become economically relevant. Despite substantial interest and controversial discussion, results on the extent of the issue remain scarce. This pertains in particular to the distribution of quality in the patent population. While invalidation rates are easily observable for patents litigated in annulment proceedings, rates of latent invalidity in the full population cannot be inferred in a trivial way: Only around 1% of all patents ever become subject of an annulment suit. Consequently, there is room for substantial selection. The high invalidation rates observed in court rulings may thus be a poor estimator for quality in the patent population.

To extract information from the characteristics of litigated patents, I develop a divergent expectations model for the selection of patents for litigation. In the model, patent heterogeneity is represented in a multi-dimensional fashion, through continuous notions of both legal stability and value. A patent holder, whose intellectual property grants him exclusion rights in a Cournot product market, is faced with a symmetric competitor. While monopoly and duopoly rents are known, the parties observe the focal patent's inventive step with error, leading to value-dependent divergent expectations concerning its validity. In a first stage, the potential infringer decides whether to enter the market protected by the focal patent. Disputes are thus endogenous. In a second stage, which is based on the divergent expectations framework developed by Priest and Klein (1984), the two parties either settle their dispute, or enter litigation if expectations diverge sufficiently given the commercial value of the patented invention. Courts then reveal the true inventive step and decide on the patent's validity. Depending on the outcome, the resulting market structure is either a monopoly or a duopoly.

To characterize the actual state of the patent litigation system, I leverage the structure imposed by the model. I calibrate its parameters such that it reproduces litigation and invalidation rates observed for German (DE) patents and the German components of European (EP) bundle patents. Of the around 1% of DE and EP patents which become subject to an annulment suit at the German Federal Patent Court, more than 75% are judged fully or partially invalid (Hess et al., 2014).

The key results are fourfold. First, latent invalidity is found to be considerably lower in the patent population than among settled and litigated patents (around 40% vs 90% and 75%). More specifically, the potential infringer's entry decision is identified as the driver of selection with respect to validity. In contrast, the selection of highly valued patents for litigation is

[4] See for example Federal Trade Commission (2003); Lemley and Shapiro (2005); Jaffe and Lerner (2007); Farrell and Shapiro (2008); Bessen and Meurer (2008); Hilty (2009); Mann and Underweiser (2012); Schankerman and Schuett (2016); Henkel and Zischka (2016)

regulated by negotiations between patent holder and infringer. Second, raising the courts' validity threshold is, ceteris paribus, effective in stimulating entry to otherwise monopolistic markets. Third, adverse effects of such reform can be mitigated by raising court fees in a feasible manner. Fourth, the calibrated model exhibits substantial selection with respect to patent value. Selection is most pronounced for litigated patents, which are around nine times as valuable as the average patent. This is in line with findings in the empirical literature, which has found similar orders of magnitude (cf. Harhoff et al., 2003a).

The chapter's contribution to the literature is twofold. First, it complements prior work on the economics of the patent litigation system (e.g., Crampes and Langinier, 2002; Bessen and Meurer, 2006) by characterizing the system's latent properties and the resulting selection mechanics. In contrast to previous studies, which have mostly focused on either theoretical modeling *or* descriptive empirics, this chapter develops a structural model that can reproduce empirical outcome rates of patent disputes. It provides new insights on how selection into litigation is driven by patent quality. At the same time, it confirms well-established empirical findings identifying patent value as a driver of litigation propensity (Lanjouw and Schankerman, 2001, 2003; Harhoff et al., 2003a). Moreover, the model allows to disentangle origins of selection. The calibration results suggest that different stages drive the selection with respect to validity and value.

Second, the chapter contributes to the literature investigating repercussions of low-quality patents. In prior work, consequences of exclusion rights with questionable legitimacy have primarily been discussed conceptually. In contrast, findings concerning the *extent* of the problem remain scarce (Schankerman and Schuett, 2016; Henkel and Zischka, 2016). To narrow this gap, the chapter suggests a novel approach to estimate the rate of latent invalidity in the patent population.

In summary, this dissertation sheds light on implications of the patent system that lie beyond the inherent trade-off between innovation incentives, deadweight losses, and disclosure. It investigates hurdles for cumulative invention, discusses the role of post-grant review in ensuring patent quality, and examines the prevalence of low-quality patents and their dispersion throughout the legal system. Providing new insights on the economics of intellectual property systems, this dissertation may contribute to refine their role as an important determinant of innovative activity, technological progress, and economic growth.

1

Patents and Cumulative Innovation

Evidence from Post-Grant Patent Opposition

1.1 Introduction

Patents are considered a key policy instrument to spur innovation and technological progress. With a patent grant, inventors receive temporary exclusion rights in return for the creation and disclosure of their inventions. Inventions are rarely stand-alone achievements, but build to a large extent on previous discoveries – "cumulative invention" has become a dominant characteristic of the modern industrial innovation apparatus. But the cumulative nature of technical progress may also cause major impediments for research and development. When inventions build on each other, exclusion rights on a preceding invention may limit the attractiveness of follow-on inventive steps. Whether such distortions of research incentives exist, is ultimately an empirical question. This paper contributes to the literature on cumulative invention by providing an econometric analysis of patent invalidation at the European Patent Office (EPO). If patent invalidation is followed by additional research and patenting activity, then this can be taken as evidence for the existence of such impediments. Our empirical results allow us to identify situations in which the effects of patents on cumulative innovation are particularly pronounced.

Cumulative innovation and the underlying knowledge spillovers form the nucleus of the recent macroeconomic literature on innovation and endogenous growth, e.g., Grossman and

Helpman (1991), Aghion and Howitt (1992), and Acemoglu and Akcigit (2012). However, a number of theoretical contributions have illustrated that the incentive created for one invention via a patent right may have a delaying or cost-increasing effect on follow-on inventions (see Hall and Harhoff (2012) for a literature survey). In general, the patent publication provides valuable information that allows follow-on inventors to build upon the protected invention. The disclosure and the resulting knowledge spillovers are commonly seen to facilitate cumulative invention (Scotchmer and Green, 1990). But intellectual property rights on existing technologies require coordination between original and follow-on inventors (Scotchmer, 1991), which often takes the form of licensing agreements. In the absence of transaction costs, the parties involved in a cumulative invention process could reach a licensing agreement such that cumulative innovation is not blocked. In the presence of transaction costs, however, such negotiations may not succeed. Even if the involved parties find an agreement, inefficiencies associated with the licensing outcome may limit the attractiveness of inventive efforts. In such cases, we would expect to see detrimental effects on technological progress and, ultimately, on economic growth.

Patent thickets and fragmented patent ownership have been identified as potential impediments to efficient licensing agreements and causes for bargaining failure (Heller and Eisenberg, 1998; Shapiro, 2001; Gallini and Scotchmer, 2002; Lemley and Shapiro, 2007; Bessen and Maskin, 2009). Follow-on innovation is particularly prone to patent blockage in industries with complex and modular technologies and among small firms and market entrants that lack leverage for cross-licensing deals (Lanjouw and Schankerman, 2004; Cockburn et al., 2010). Hence, one may expect a positive effect on follow-on innovation by others when patent invalidation occurs in industries characterized by complex products and in cases where follow-on inventions would come from small players (Galasso and Schankerman, 2015).

However, this argument does not take into account the possibility of strategic patenting and differences in the effectiveness of patent rights across technologies (Teece, 1986; Ziedonis, 2004; Harhoff et al., 2007). Moreover, as Cohen et al. (2000) have argued, cases in which one patent protects one product ("discrete" technologies) are rare. Inventions in "complex" technology areas are often protected by multiple patents, so that the reduction in protection from losing one patent could be relatively small compared to losing a patent in discrete technology areas. Furthermore, large patent portfolios with overlapping claims and dense patent thickets could marginalize the gain from the invalidation of a previous patent. Leaving aside the size of the patent portfolio, there are other complementary assets that may determine a firm's ability to exclude other parties. As the existence of complementary assets is likely correlated with the size of the patent holder, large patent holders should be more able to compensate for the loss of patent protection.

Hence, the gain in freedom to operate and to conduct R&D following patent invalidation could be larger in discrete technology areas and in cases where the focal patent holder cannot maintain protection with the help of overlapping patent claims or other complementary assets.

We thus argue that the effect of invalidation on follow-on research by third parties should then be strongest where appropriability heavily relies on patent rights.

Several empirical studies as to whether and where patents hinder follow-on innovation have been undertaken recently (see Table 1.1 for an overview). The identification strategies in these studies primarily exploit quasi-exogeneous variations in patent protection over time under the assumption that follow-on inventors would require a license from the upstream patent holder as long as the patent is enforceable. Since licensing agreements usually remain undisclosed, measures of follow-on innovation have had to rely on references to the focal invention in subsequent work. Commencing this stream of literature, Murray and Stern (2007), Huang and Murray (2009), and Williams (2013) focus on IP in biotechnology and analyze whether the protection of a particular genome sequence has any effect on follow-on activities, witnessed by either scientific studies, patents, or product development. Murray and Stern (2007) and Huang and Murray (2009) use difference-in-differences estimation models on a sample of patent-paper pairs, exploiting the grant of patent protection as variation over time and gene sequences. Yet only a subset the control sequences become the subject of a patent application in the first place. Both studies conclude that patent protection on genes impedes subsequent research. Huang and Murray (2009) find this blocking effect to correlate with patent scope, patent thickets, and fragmented patent ownership. The results of Williams (2013) suggest that (non-patent) IP rights on a specific set of genes led to a 20-30% decrease in subsequent scientific research and product development. Sampat and Williams (2018) further investigate the relationship of patent rights and follow-on innovation on human genes by comparing citations to successful and unsuccessful patent applications filed at the USPTO. To avoid issues arising from the presumable endogeneity of the patent grant event, they employ an instrumental variable based on the leniency of the respective patent examiner. The results of their analyses do not provide evidence for a blocking effect of human gene patents on follow-on innovation.

The exclusivity of patent protection is effectively limited in a compulsory licensing regime. Moser and Voena (2012) and Watzinger et al. (2017) each focus on cases where a set of patent rights became *de facto* ineffective in excluding others due to compulsory free licensing. Notably, Moser and Voena (2012) find an increase in innovation from compulsory free licensing in the chemical sector. Watzinger et al. (2017) study Bell Labs patents and find that compulsory free licensing particularly favored follow-on inventions by small and young firms. Both studies focus on specific technologies and use historical data. Given recent changes in patent systems and technology, not all of the results may apply to the current context.

Most similar to our study, Galasso and Schankerman (2015) investigate the effect of patent invalidations by the US Court of Appeals for the Federal Circuit (CAFC) on follow-on innovation. They address endogeneity of the patent invalidation event by exploiting the randomized allocation of judges at the CAFC to identify judge fixed effects. In a complementary study, Galasso and Schankerman (2018) use the same empirical setting to analyze the effect of patent

Table 1.1: Prior empirical studies on patent rights and cumulative innovation

Study	Dependent variable	Identification	Technology	Sample
Patent grant				
Murray and Stern (2007)	Scientific citations	DiD estimation	Biotech	169 patent-paper pairs
Huang and Murray (2009)	Scientific citations	DiD estimation	Biotech	1,279 patent-paper pairs
Sampat and Williams (2018)	Scientific citations	IV (examiner fe)	Biotech	292,655 patent-gene pairs
Patent invalidation				
Galasso and Schankerman (2015)	Patent citations	IV (judge fe)	All	1,357 patents
Galasso and Schankerman (2018)	Patents	IV (judge fe)	All	1,469 patents
Compulsory licensing				
Moser and Voena (2012)	Patent citations	DiD estimation	Chemistry	130,000 patents
Watzinger et al. (2017)	Patent citations	DiD estimation	IT	4,509 patents

Notes: DiD = difference-in-differences; fe = fixed effects (or similar).

invalidation on subsequent research activities of the focal patent holder.[1]

Results of the two approaches to identification are not fully comparable as the quasi-experimental settings differ in an important aspect. In the studies focusing on compulsory licensing events, many patents lose their function as an exclusion right simultaneously. Releasing a large set of patent rights into a compulsory licensing regime – and that at a price of zero – must have very different effects than the invalidation of a single patent right. One would expect that interactions between patent rights – as caused by thickets and fences – do not play a major role in the former scenario, but limit the effect of invalidation of individual patents in the second case, where the contextual restrictions from overlapping claims would largely be maintained.

With the present study, we contribute to this emerging stream of literature and investigate the causal effect of a patent's invalidation on follow-on innovation, using a relatively large dataset on opposition to patents granted by the European Patent Office. The EPO provides a harmonized application procedure for patent protection in one or more member states of the European Patent Convention (EPC). By now, the EPO grants patents for 38 countries, covering a population of more than 450 million. Hence, patenting decisions by the EPO are economically at least as important to patent-owners and their rivals as corresponding decisions made by the USPTO. In the first nine months after grant, third parties can challenge the validity of a European patent at the EPO by filing an opposition against the granting decision.[2] The

[1]The focal patent holder's activities are at the center of attention in several other studies (e.g., Baten et al., 2015; Farre-Mensa et al., 2017; Gaulé, 2018).

[2]The opposition procedure at the EPO can be compared to the *Post Grant Review* (PGR) at the US Patent and Trademark Office (USPTO). PGR represents an option to challenge validity administratively at the USPTO (hyperlink) during the first 9 months after grant without involvement of the judiciary.

opposition procedure represents the last opportunity to centrally invalidate an EPO-granted patent before it is disassembled into national patent rights. With total costs between 6,000 € and 50,000 €, the opposition procedure is relatively cheap compared to – sometimes inevitably duplicative – patent revocation proceedings at the national level (Mejer and van Pottelsberghe de la Potterie, 2012). As a result, opposition is a relatively frequent event with a historical opposition rate of about 6% which well exceeds litigation rates in Europe (Cremers et al., 2017) and the US (Lanjouw and Schankerman, 2004; Bessen and Meurer, 2013). Oppositions should also be less prone to settlements given the short time horizon available for negotiations and given the possibility of the EPO pursuing an invalidation even after the parties have withdrawn the case. For these reasons, our data should be less selective than data for decisions at the CAFC as used by Galasso and Schankerman (2015).

In line with previous studies we use post-opposition forward citations as a proxy for follow-on innovation. To address endogeneity issues concerning the outcome of opposition, we introduce a new instrumental variable. We exploit exogenous variation in the participation of the patent's granting examiner in the opposition division, which decides on the grounds for opposition against the patent's validity. Although the rules and regulations of the EPO allow some personnel overlap in the examination and opposition procedure, they do not require the involvement of the examiner. In fact, the examiner participates in about 68% of all opposition proceedings covered by our dataset, with variation over time and technology field. This variation appears to primarily be a function of the non-availability of other examiners with expertise in the particular technology area.

According to our baseline specification, patent invalidation leads to a highly significant increase of other party and total forward citations, whereas the effect is insignificant for self citations. While this is in line with previous studies, disentangling the effect leads us to results that stand in stark contrast to the literature. We find that the effect is most pronounced for discrete technology areas such as chemistry, for areas where patent thickets are absent, and for patents which are not protected by similar applications by the same applicant (patent fences). Besides, the effect is relevant mostly for small- and medium-sized patent holders and, to a lesser extent, for large patent holders facing large follow-on innovators. We do not find a significant effect on follow-on invention by small- and medium-sized applicants if the focal patent holder is large. In summary, our results challenge the view that bargaining failure and its typical determinants constitute a sufficient explanation for the effect of patent invalidation on follow-on innovation. In our robustness tests, we can show that the impact of relative size, thickets, and fencing is visible even when we perform estimation for separate technologies. Hence, cumulative research is impacted through multiple channels in the aftermath of invalidation.

Galasso and Schankerman (2015) focus on the causes for bargaining failure and their implications, but give less consideration to factors that determine the effectiveness of patent rights in excluding others. Furthermore, the findings for the highly selective sample of litigation cases at the appellate court for patent disputes cannot be extrapolated to the patent population in a straightforward fashion, because the selection mechanisms may substantially influence the composition with respect to a variety of both observable and unobservable characteristics beyond the commercial value of the patent.[3] In fact, cases reaching a decision by the CAFC represent only a small share of litigation cases – the settlement rate of first instance patent litigation in the US is in excess of 90% (Lanjouw and Schankerman, 2004) –, which in turn represent only a small share of all granted patents. Moreover, it is unclear to which extent first instance rulings impact expectations of market participants.

Our study contributes to the growing literature on the effect of intellectual property rights on cumulative innovation in several ways. First, compared to previous work, our study stands out in the scope and scale of the underlying data. Variation in patent rights that can be used to study causal effects is scarce. So far, variation comes primarily from cases where patents are invalidated in court – as illustrated, a highly selective and small sample of patents that can be very heterogeneous in age. Looking at post-grant opposition at the EPO, we exploit an institutional device to challenge validity that is more frequently used than patent litigation before ordinary courts. With more than 33,000 observations at the patent level, we capture a sample of patent invalidations that exceeds prior studies by more than an order of magnitude, although we restrict ourselves to a relatively short and recent time frame. Furthermore, with a narrow time window of 9 months right after grant, oppositions occur relatively early in patent life and are far less spread out across a patent's lifetime than patent litigation. As each patent can be subject to only one opposition proceeding, we have no observations where the same patent is litigated more than once. We also focus on the first decision on validity for the granted patent, for which, in contrast to cases heard by appeals courts, there is no prior decision that may blur the causal link between invalidation and follow-on innovation. Since the outcome of opposition proceedings can be appealed, we perform related robustness tests, but given the low reversal rate we expect the first outcome to give follow-on inventors a trustworthy indication whether or not to re-engage in research on the subject matter. An additional aspect worth highlighting concerns technological scope. While large parts of the literature are limited to patents in discrete product technologies such as pharmaceuticals, biotechnology, or chemicals (Moser and Voena, 2012; Williams, 2013; Sampat and Williams, 2018), or the IT sector (Watzinger et al., 2017), our dataset comprises patents across all technologies – an advantage we share with the study by Galasso and Schankerman (2015).

Second, the fine-grained EP citation data used in this study alleviate a key point of criticism concerning the analysis of cumulative innovation proxied by forward citations. On the one hand, potential bias in citations may emerge if applicants can strategically disclose or withhold relevant prior art (cf. Alcacer et al., 2009; Sampat, 2010). In contrast to the US patent system,

[3]For instance for complex technologies, selection may single out patents which are *not* embedded in a dense thicket that could compensate for the loss of one exclusion right. In consequence, the invalidation effect for complex technology patents would be overstated.

in Europe citations are made by EPO personnel during the search and examination phase and not by the applicant (Criscuolo and Verspagen, 2008). Furthermore, our dataset includes information on the origin of the citation, which allows us to exclude citations stemming from patents belonging to the applicant herself. On the other hand, it is unclear whether the subject-matter of the citing patent falls within the scope of the cited patent in the first place. The fact that a license may not be required to use the cited technology, independent of the cited patent's invalidation, may blur the estimated effect of the focal patent right on follow-on innovation (cf. Sampat and Williams, 2018). With no obligation of the applicant to disclose prior art, the average number of EPO patent citations is lower, whereas their technological relevance appears to be higher (Breschi and Lissoni, 2004).

Third, we employ an instrumental variable which is new in that it represents the first instrument for patent invalidation in the context of the European patent system, which lacks the randomized administrative processes that allow for a proper identification of fixed effects as used by Galasso and Schankerman (2015). Instead, we focus on the event of administrative personnel overlap in the examination and opposition procedure. Although well established, the literature on oppositions at the EPO focuses primarily on the determinants of opposition (Harhoff and Reitzig, 2004; Schneider, 2011; Harhoff et al., 2016) and opposition as an error correction mechanism (Burke and Reitzig, 2007; Graham and Harhoff, 2014). We complement this literature, for the first time providing causal evidence for the effect of oppositions on subsequent innovative behavior.

The remainder of this study is structured as follows: Section 1.2 describes the institutional framework of patent opposition at the EPO. Section 1.3 provides details on the dataset, the dependent and independent variables, and shows descriptive statistics. Section 1.4 then presents the econometric analysis and a discussion of the results. Section 1.5 concludes.

1.2 Empirical Setting

The European Patent Office provides a harmonized application procedure for patent protection in one or more member states of the European Patent Convention (EPC). As of now, a patent application granted by the EPO does not lead to a single "European patent." Instead, it is split into a bundle of national patent rights, each entering the patent system of the respective member states. As these rights exist independently of each other, the invalidation of a national patent in one country has no effect on its counterparts in other countries.

However, in the first nine months after grant, third parties can challenge the validity of a European patent at the EPO by filing an opposition against the granting decision. Since its outcome is binding for all designated states, the centralized opposition procedure represents the only option to invalidate a patent right with coverage of multiple European countries in a single, relatively inexpensive step.[4]

[4]See Figure A.1 in the appendix for a timeline of events for the average patent in our sample.

1.2.1 Examination Procedure

The majority of patent applications at the EPO are based on national first filings or international PCT filings (see Harhoff and Wagner (2009) for a detailed description). Only a small share of filings takes the EPO as its priority office. Publication of patent applications occurs at the EPO (as in many other patent authorities) exactly 18 months after the priority date; the publication of the patent document is acccompanied by the EPO Search Report. In the case of PCT filings, which are published by the World Intellectual Property Organization (WIPO), an International Search Report is generated by an International Search Authority (ISA). Most International Search Reports are actually generated by the EPO. While the original patent application may contain many references to prior art inserted by the applicant, only the prior art listed in the search report is relevant for the examination process. The examiner has full control over the selection of prior art references already listed by the applicant for inclusion into the search report, while also generating references via own search efforts.

Within six months after the publication of the search report compiled by the patent office, the patent applicant has to request the examination of the patent application. If the applicant fails to do so, the application is deemed to be withdrawn. With the end of the search procedure, the responsibility for examining the application passes internally from the receiving section to an appointed examination division, which consists of a primary examiner, a secondary examiner, and the chairman. The primary examiner assesses whether the application and the invention meet the requirements of the European Patent Convention and whether the invention is patentable based on the search report. The primary examiner then either grants the patent directly, contingent on the approval by the other two members of the division, or requests a reply from the applicant within a certain time period that addresses the objections raised in the search report. If the objections are successfully overcome by the applicant, the primary examiner sends the version in which he intends to grant the patent, including his own amendments, to the applicant. After the applicant's approval and the completion of formalities, such as the payment of fees, the provision of translations, etc., the grant of the patent is published. The publication date of the EPO B1 document is the official grant date of the patent.

Currently, it takes on average more than four years from the filing of the application to the final decision on the grant of the patent (Harhoff and Wagner, 2009). Since the grant comes along with validation fees and costly translations into national languages, some applicants deliberately delay the examination process. However, in order to make complementary investment decisions or to claim injunctive relief before court, some applicants are interested in fast resolution of the patent examination and file a request for accelerated examination (Harhoff and Stoll, 2015).

1.2.2 Opposition Procedure

The grant decision of the examination division is subject to a post-grant review mechanism, which is initiated by filing a notice of opposition within nine months after the publication of the mention of the patent grant. Oppositions can be filed by any party except the patent holder herself.[5] Receiving the notice of opposition, the primary examiner informs the patent holder and checks whether the grounds for opposition are admissible. Oppositions may be filed on the grounds that the subject-matter is not new or inventive, the invention is not sufficiently disclosed, or the granted patent extends beyond the content of the application as filed.

Consisting of three technically qualified examiners, the appointed opposition division has to decide whether the raised objections compromise the maintenance of the patent. If necessary, the opposition division invites patent holder and opponent to file observations on the other party's communications. During this exchange of communications, the patent holder can amend the description, claims and drawings of the patent. An oral proceeding is summoned if requested by one of the parties, including the opposition division itself. Despite being optional, the oral proceeding before the opposition division is a rarely omitted part of the opposition procedure.

The opposition division usually states its decision verbally at the end of the oral proceeding. The conclusion of the oral proceedings is either the invalidation of the patent in its entirety, the maintenance of the patent as is, or the maintenance of the patent in amended form. A written decision, including the opposition division's reasoning, typically follows one to six months afterwards. If no oral proceeding was requested, the opposition division simply issues its decision in writing. Patent applicant and/or opponent may appeal against the decision of the opposition division. The involvement of the opposition division ends after the opposition phase. Appeal proceedings are heard by judges forming the Boards of Appeal, a separate and independent decision-making body within the EPO.

Withdrawals of oppositions may occur at any stage prior to the decision, but do not necessarily terminate the opposition proceedings. The opposition division has the option to continue the proceeding on its own motion (EPC Rule 84) and make a decision on the patent's validity based on the grounds of opposition previously stated. Since the opposed patent may still end up being invalidated, settlements between opponent and patent holder are relatively rare events. More than 85% of all oppositions conclude in a decision by the opposition division.[6]

1.2.3 Appointment of Examination and Opposition Division

Technically qualified examiners are assigned to technical art units, so-called directorates. Patent applications are allocated to technical art units according to the application's underlying

[5] In case of multiple independently filed oppositions, all objections are dealt with in one combined proceeding.

[6] According to our data (see Figure A.1 in the Appendix), the patent holder surrenders the opposed patent in about 5.1% of all oppositions, whereas opponents withdraw their notice without continuation in about 7.7% of all oppositions.

technology.[7] The examination division regularly consists of the previous search examiner as first member and two examiners appointed by the director as second member and chairman.[8]

The opposition division consists of a first examiner, a minute writer and a chairman. The director appoints the members of the opposition division under consideration of the technical qualifications relevant to the patent. The opposition division may be enlarged to a fourth member with a legal background, if there are complex legal questions to be resolved.

As substantive examiners with the necessary technical qualification, the members of the examination division are natural candidates for the opposition division. Concerning the participation of the grant examiners in the opposition proceeding, Article 19(2) of the European Patent Convention states the following:

> *"An Opposition Division shall consist 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. An examiner who has taken part in the proceedings for the grant of the European patent may not be the Chairman."*

Statements of interviewed EPO officials and our empirical findings show that the primary examiner of the examination division frequently participates in the opposition proceeding of the same patent. Case law has established that the patent holder and the opponent cannot object the director's decision regarding the appointment of a particular examiner in the opposition division. The opposition division's decision can in principle be appealed on the ground of suspected lack of impartiality among the division members. However, there are only very few cases where this has occurred; the precedent cases that we are aware of refer to different allegations than the involvement in the previous grant decision.[9]

1.3 Data and Descriptive Analysis

We use data on opposed patents granted at the EPO between 1993 and 2011 to empirically analyze the causal effect of patent invalidation on follow-on invention. 1993 is taken as the starting point of our data collection as this is the year when the members of the opposition division were – for the first time – explicitly listed in the rulings of the opposition divisions. In order to allow for a sufficiently large time span of 5 years for citations to occur, 2011 marks the last opposition decision year of our data set. This section provides detailed information on our data sources, a discussion of the variables we derive, and a selection of descriptive statistics.

[7] The technical art units are based in Berlin, Den Haag and Munich.

[8] The primary examiner used to be different from the search examiner. This has changed due to the "BEST" ("Bringing Search and Examination Together") initiative, with the goal to have search report as well as examination decision made by the same examiner.

[9] For instance in the case G 0005/91 with a decision from May 5, 1992, a patent holder's objection originated from a former employment relationship between examiner and opponent.

1.3.1 Data Sources

We construct a sample of all patents granted between 1993 and 2011 that became subject to an opposition by drawing on several distinct patent data sources. For each granted patent at the EPO we first observe in the EPO PATSTAT Register whether an opposition was filed within the statutory period of nine months after the grant date.[10] Via the patent application number, we gather all relevant document files concerning the examination and the opposition procedure from the online file inspection system of the European Patent Register.[11] We read out documents on the grant decision, the oral proceedings and the opposition decisions in order to extract the names of the examination and the opposition division members, since this information is not available from patent data providers.[12] We elaborate on our read-out and parsing efforts in Appendix A.6.

We rely on the procedural steps data in the EPO PATSTAT Register to determine the result and date of the first instance as well as the final decision of the opposition proceeding.[13] Furthermore, the EPO PATSTAT Register provides us with information on the name and address of the opponents. For bibliographic data on the opposed patents, the patent holders, and forward citations, we again use the EPO Worldwide Patent Statistical Database. A few important aspects of the examination process, such as the assigned technical art unit and the examination location, are not covered by any of the above patent databases. We obtain those details from the EPO's administrative database EPASYS (April 2015).

1.3.2 Dependent Variable

A common way to capture a technology's dependence on a past technology is to use citation data. This approach assumes that a cited patent represents the exclusion right that is important when determining the scope of patent protection of the citing patent application. To measure follow-on invention to a focal patent, we therefore look at its number of forward citations in a fixed time window after the opposition outcome. We discuss potential weaknesses of this approach below. As we are most interested in analyzing the effect of the patent's invalidation on follow-on invention, we distinguish citing patents by their filing date relative to the date of invalidation. In order to link the effect to inventive activity and not to application behavior, we use the earliest application date within the DOCDB family of the citing patent. This is also

[10]Unless otherwise noted below, we use the EPO PATSTAT Statistical Database – 2016 Spring Edition for the selection of patent filings and for extracting citation information.

[11]See https://register.epo.org/regviewer?lng=en. The European Patent Register provides access to digital documents in the public part of a patent file (also known as online file inspection or "file wrapper"). The documents are grouped by procedural stage and include the full written correspondence between the EPO, the applicant, and the opponent. Outgoing communications become available online the day after the dispatch date; incoming communications become available once the EPO has coded the filed document.

[12]For PCT patent applications with a filing date from 2011 onwards, the WIPO patent database contains information on the examiner.

[13]The EPO Worldwide Patent Statistical Database represents an alternative data source. However, it contains only final opposition outcomes with limited means to reconstruct the result of reversed first instance decisions.

the priority date of subsequent filings, and thus closest to the actual date of invention of the presumed follow-on invention.

We further categorize forward citations by the citing party. Comparing names of the citing applicant with the focal patent holder and the opponent, we distinguish between citations from patents by the patent holder itself ("self citations"), and citations by third parties ("other citations"). In contrast to the US patent system, most citations of European patent applications are generated by the examiners during the search and examination phase and not by the applicant (Criscuolo and Verspagen, 2008). We restrict the citations to those included in the EPO Search Report or the International Search Report generated by the EPO as International Search Authority. These citations are fully under the control of the examiner. Thus, by design of our dependent variable, we avoid the use of measures impacted by (strategic) citation patterns which may occur when using US citation data (cf. Alcacer et al., 2009; Sampat, 2010).[14]

While we maintain that EPO citations should be more suited to our analysis, it would be comforting to obtain qualitatively similar results when using USPTO data. Therefore, we replicate our empirical analysis on the basis of USPTO citations and present the results in the appendix. As information on the origin of citations is only available for citations made from 2001 onwards, we include both examiner and applicant citations published by the USPTO. Moreover, even the distinction available after 2001 may not be fully satisfactory, since US examiners add missing references, but do not mark applicant-generated references as relevant or not. The European-type search report provides that information.

1.3.3 Independent Variables

The independent variables used in the main empirical analysis capture characteristics of the opposition proceeding, the involved parties, and the focal patent.

Opposition variables

The decision of the opposition division may have three mutually exclusive results for the opposed patent: "valid" (opposition rejected), "valid in amended form", and "invalid". We operationalize the decision in line with Galasso and Schankerman (2015). Our "invalidated" indicator variable equals 1 for the outcomes "invalid" and "valid in amended form" and 0 for the outcome "valid". The decision of the opposition division can be subject to appeal. In fact, almost half of all decisions in our sample are appealed. However, the reversal rate of the Boards of Appeal is very low and skewed; that is, pro-patent holder outcomes are more likely

[14]A prominently raised limitation of citation analyses is the lack of distinction between citations where the citing patent is within the scope of protection of the cited patent, and citations where the citing patent is beyond the scope of protection (cf. Sampat and Williams, 2018). In the latter case, a license to use the technology is not required, independent of the cited patent's invalidation – blurring the causal effect of patent rights on follow-on invention. With no obligation of the applicant to disclose prior art relevant for the examination at the EPO, the average number of patent citations is lower in comparison with US patent citations, while the technological relevance appears to be higher (Breschi and Lissoni, 2004).

to be overruled in favor of the opponent than vice versa.[15] As appeals considerably delay the final outcomes of opposition proceedings to the effect of substantial truncation in our sample, we focus on the first decision of the opposition division. We expect that potential bias from disregarding appeals – if at all – understates the effect of invalidation.[16]

Patent holder, opponent and third party variables

Prior literature has found that the risk of bargaining failure between patent holder and potential licensees varies by the vertical position and the size of the parties. Furthermore, the country of residence may influence patenting and appropriation strategies. Hence, the selection of patents into opposition, as well as the effect of the opposition outcome on follow-on invention, is likely a function of patent holder, opponent, and third party characteristics.[17] In line with previous work (Harhoff and Reitzig, 2004), we include the sector (corporate entity or not), the country of residence, and the patent portfolio size of each entity as independent dummy variables. See the explanations below for details on coding.

Patent and procedural variables

We include patent value indicators and technology controls to reduce asymptotic variances and to mitigate bias. To preempt endogeneity issues, we focus on patent value indicators that are set at a very early stage of the patent application and are thus independent of the examination and opposition proceedings. We include a dummy variable for international patent applications (PCT) and count variables for DOCDB patent family size, IPC subclasses, claims, applicants, inventors, and patent as well as non-patent backward citations. We include pre-opposition self and other citations restricted to the first three years after filing as further proxy variables for patent value.

We assign each patent to a technology area by mapping the IPC classes according to the concordance table developed by the Fraunhofer ISI and the Observatoire des Sciences et des Technologies in cooperation with the French patent office (cf. Schmoch, 2008). The IPC codes are grouped into 34 technology areas,[18] each belonging to one of five main technological areas: (a) electrical engineering, (b) instruments, (c) chemistry, (d) mechanical engineering, and (e) other fields.

In our empirical analysis, we further aim to account for contextual factors of the focal patent. We employ a time-variant variable that measures the density of patent thickets in the focal patent's technology area (cf. von Graevenitz et al., 2011). The focal patent may also be

[15] Which is in line with the established view that arguing against already identified novelty destroying prior art is considerably more challenging than presenting new subject matter.

[16] A further reason to focus on the opposition outcome is the fact that our instrumental variable has a direct effect on first instance outcomes, but merely an indirect effect on appeal outcomes.

[17] Harhoff et al. (2016) argue that non-corporate applicants hold on average patents of lower commercial value and higher novelty, with implications for the selection into opposition.

[18] The original classification's areas '21 Surface technology' and '22 Nanotechnology' are merged into one area.

part of a "patent fence" consisting of several similar patents held by the patent holder. With the help of a novel approach that calculates a measure of similarity using a sophisticated semantic comparison of patents' full texts (abstract, description, claims, and title) (cf. Harhoff, 2014), we count the number of patents that are highly similar to the focal patent and belong to the patent holder's portfolio.

In order to show randomness of our instrumental variable, we test correlations with a set of further variables specific to the patent examination process. These variables include the duration of examination, the language of the proceeding, and the granted request for accelerated examination.

1.3.4 Instrumental Variable

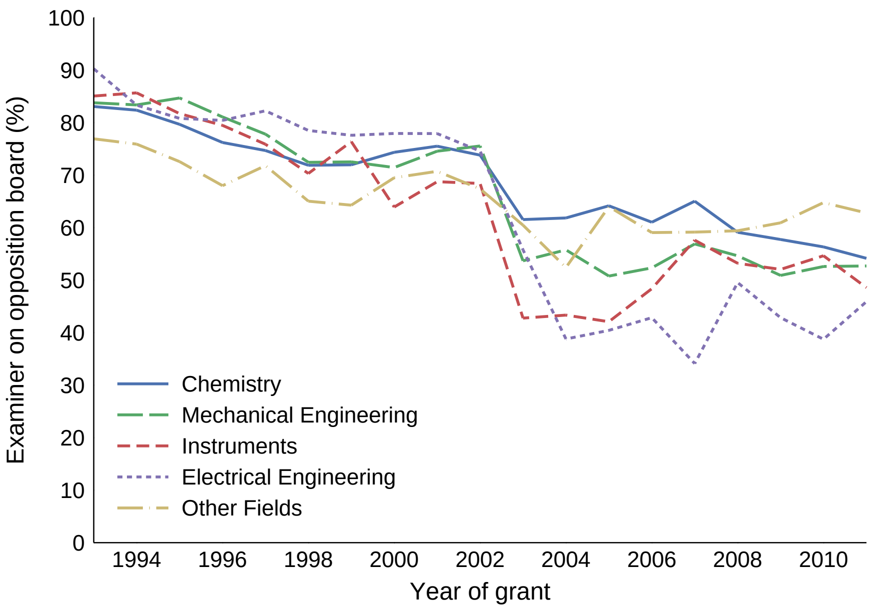
The opposition division consists of three technically qualified substantive examiners, of which at least two must not have taken part in the examination of the opposed patent. Opposition cases are decided by a vote of all three members of the opposition division.[19] It seems like a natural assumption that the examiner who granted the patent is generally more inclined to be in favor of the patent holder than of the opponent, who dissents with the examiner's prior decision. Given that this pro-patent holder effect exists, two requirements must be fulfilled so that we can exploit the participation of the examiner in the opposition proceeding as an instrumental variable. First, we need perpetual variation in examiner participation across time and within cohorts. Second, we must be able to exclude any endogeneity in the determination whether the patent examiner participates in the opposition division or not.

We conducted interviews with EPO officials to explore the process by which opposition divisions are formed. These discussions revealed that the reasons for the participation of the examiner are primarily found in the non-availability of other examiners with expertise in the particular technology area. If the number of substantive examiners relative to oppositions is large, the granting examiner is less likely to take part in the opposition proceeding as the third member of the division. The supply of substantive examiners depends *inter alia* on the labor market – staff shortage induces the granting examiner to become indispensable for the opposition proceeding. Figure 1.1 shows that the average participation rate is well above 60% before 2003, but then declines to an average rate of about 55% with increasing variations between technology main areas. This drop is caused by a sharp increase in the number of substantive examiners eligible to participate in opposition proceedings in the course of the "BEST" initiative.[20] We conclude that the event "examiner participation in opposition proceeding" is exogenous and frequent, yet does by far not always occur – with perpetual variation within cohorts and technology areas.

[19] Voting follows a simple majority. In case of parity (when a fourth legal member is present), the vote of the chairman is decisive.

[20] The "BEST" ("Bringing Search and Examination Together") initiative had the goal to have the search report and examination decision made by the same examiner. For this purpose, search examiners were – on a large scale – trained and promoted to substantive examiners.

Figure 1.1: Annual rate of examiner participation in opposition proceeding



Notes: This graph shows the annual rate of examiner participation in opposition proceedings by technology main area. The sample includes oppositions with first outcome after 2011.

To further argue against potential endogeneity, we discuss the instrument's randomness and its adherence to the exclusion restriction. In Table A.6, we show that common patent value indicators as well as characteristics of the patent holder and opponent do not show any significant effect on the likelihood of the examiner's participation in the opposition proceeding. This supports the view of EPO officials and patent attorneys that the participation or absence of the examiner is independent of the opposed patent and beyond the influence of the patent holder or the opponent. However, one legitimate concern is that the duration of examination may affect the likelihood of examiner participation as well as follow-on citations. An applicant with a considerable pipeline of follow-on inventions may be interested in having the patent granted as quickly as possible. As prior empirical analyses (e.g., Harhoff and Wagner, 2009) have shown, the duration of examination is not perfectly exogenous, because the applicant can speed up or delay the examination process. This may present a problem to the instrumental variable if the duration of the proceeding affects the examiner's availability to participate in the opposition proceeding. For instance, the granting examiner may become unavailable due to retirement, promotion, or transfer to a different technical art unit. However, our sample does not show any effect of examination length on the likelihood of the examiner's participation in the opposition proceeding. Accelerated examination constitutes an additional issue. Even when controlling for length of examination, the request of accelerated examination positively affects the participation dummy. We assume this is due to the fact that the accelerated examination request releases the examiner from further duties and provides him with a free schedule to participate in the opposition proceeding. To underline the robustness of our instrument, we remove cases with accelerated examination (about 11% of the sample) in a robustness test, yet we find no significant changes throughout our results.

A random instrument could still violate the exclusion restriction if the outcome is affected through different ways than just the first stage.[21] This would be the case if the applicant foresaw whether the examiner is part of the opposition proceeding before the decision on the patent's validity, providing her with enough time to adjust her behavior accordingly. However, this seems very unlikely. While the composition of the division is set at the beginning of the opposition proceeding, all correspondence between the applicant or the opponent and the EPO is channeled through the formalities officer. Only at the time of the oral proceeding, which usually ends in a decision on the case, the opposition division members become known to the parties.[22] The applicant may also be able to foresee whether the examiner is part of the opposition proceeding if examiner-specific participation rates are concentrated at zero or at one. As can be seen from Figure A.3, this concern is unfounded.

1.3.5 Descriptive Statistics

We count 49,938 patents granted between 1993 and 2011 with opposition at the EPO. Since the composition of the examination and opposition board is essential to construct our instrumental variable, our sample is limited to those patents where we are able to gather the names of the examiners involved in the grant and opposition decisions. For several reasons outlined in Table A.1, we are forced to exclude about 17% of patents, leading to a sample size of 41,358 patents. We assume that this selection has little relevance to our subsequent analysis. The fact that the excluded patents are equally distributed over time (cf. Figure 1.2) supports this view.

A second sample restriction comes into play when constructing the follow-on citation variables. To mitigate truncation effects for more recently invalidated patents, we exclude patents with a first instance opposition decision after 2011. This reduces our main sample of analysis to 33,075 observations at the patent level.

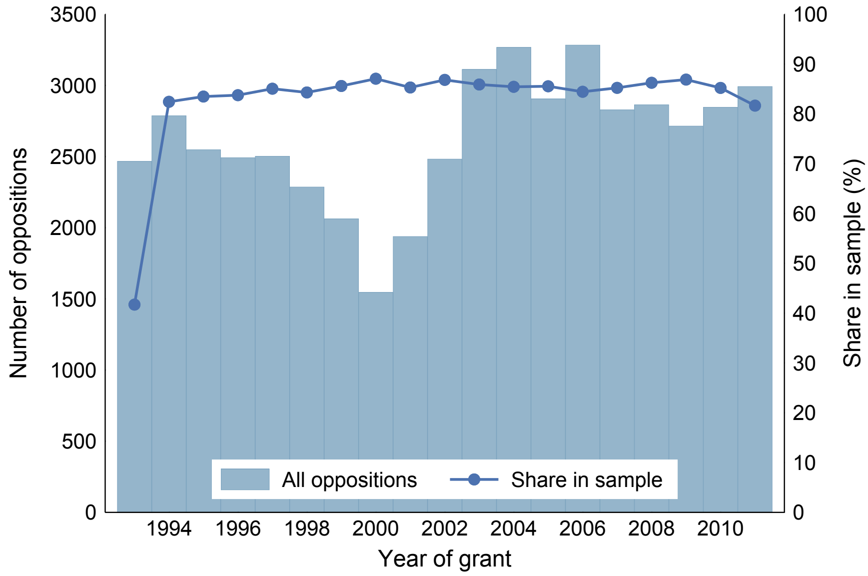
Opposition proceedings usually result in one of three distinct outcomes for the opposed patent: valid, amended, or invalid. In line with prior analyses of oppositions at the EPO, we find fairly equal shares across the three outcomes. Yet, time trends appear to exist in our sample (see Figure 1.3a): invalidations have seen a moderate increase over the last 20 years, whereas fewer patents survive opposition perfectly unscathed.

The opposition rates across technology fields differ substantially (Harhoff et al., 2016). These rates hardly correspond to recent technology-specific estimates of weak patents granted by the EPO (de Rassenfosse et al., 2016). Since patent invalidation is ex ante uncertain and its benefits often difficult to internalize, potential opponents may be reluctant to invest in a post-

[21]This concern follows a similar argument raised and discussed in Farre-Mensa et al. (2017).

[22]In those cases where applicant and opponent waive the oral proceeding, the parties learn about the identity of the opposition division members only through the published decision.

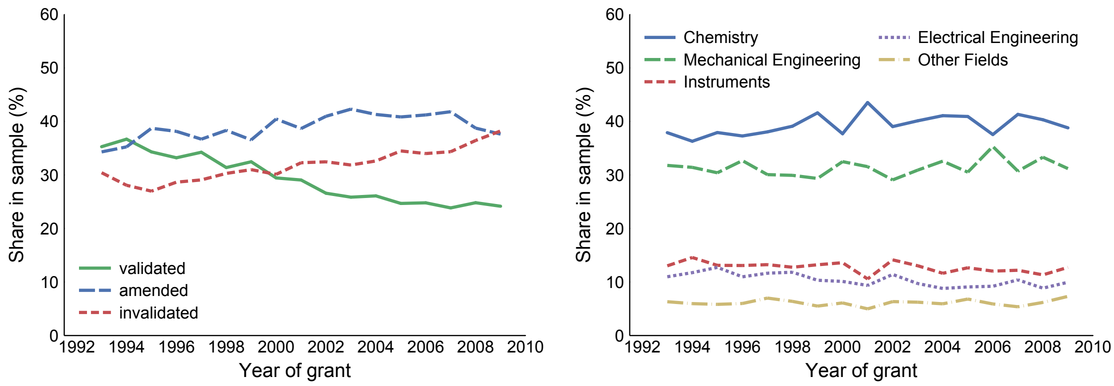
Figure 1.2: Annual number of opposed patents and sample rate



Notes: This graph includes all opposition proceedings (at the patent level) with grant date between 1993 and 2011. The low sample rate in the first year is due to the fact that the EPO introduced the grant document type that contains examiner names only in mid of 1993. The used sample includes oppositions with first outcome after 2011.

Figure 1.3: Time trends in oppositions

(a) Opposition outcomes over time **(b)** Oppositions over time by technology area



Notes: Both graphs include all opposition proceedings (at the patent level) which are part of our main sample of analysis. Grant year 2010 includes only 21 opposition proceedings and is not displayed.

grant validity challenge. This public good problem weakening the error correction mechanism is most prevalent in complex technology areas with a low concentration of patent ownership and a high density of patent thickets (Harhoff et al., 2016). In line with this, Figure 1.3b shows that with negligible variation over time the predominant share of oppositions in our sample are filed against patents in the technology areas “Chemistry” and “Mechanical Engineering.”

We present the summary statistics of patent and procedural characteristics in Table 1.2. Among the patent characteristics, we distinguish between self/other forward citations within three years after filing and self/other forward citations within five years after the opposition decision. While the latter represent our dependent variables of interest, we include the former, which are independent of the subsequent opposition proceeding, as control variables. As further exogenous patent value indicators we draw on the DOCDB family size and counts of applicants, inventors, claims, IPC subclasses, and backward references. With application filing years between 1981 and 2008, the average patent has spent about 4 years in examination and is close to 9 years old when the opposition division decides on its validity. That is, opposition outcomes occur relatively early in patent life and are far less spread across a patent’s lifespan than the outcome in patent litigation (see Figures A.1 and A.2).

Concerning the opposition proceeding, the average participation rate of an examiner in the opposition division is about 68%, with considerable variation over time and technology areas as already elaborated in Section 1.3.4. Almost half of all opposition decisions are appealed before the EPO’s board of appeals. However, the reversal rate (computed as the share of all cases where the appeal outcome is different from the opposition outcome) stands at mere 7%. Moreover, appeals initiated by the patent holder, for which the decision in first instance was rather in favor of the opponent, are even less commonly reversed than vice versa (see Table A.2).

Oppositions are mostly filed by corporations and directed at corporate patent holders. Table 1.3 shows that 94% of patent holders and 98% of opponents are companies with practically no involvement of parties from the academic or the non-profit sector.[23] The opposition proceeding may consolidate multiple notices of opposition that were filed during the nine months window after grant. On average, about 1.3 parties represent the validity challenging side. We account for cases with more than one opponent in our subsequent empirical analysis.

The distribution of the patent holders’ countries of residence is very similar to the overall distribution among all granted patents. Naturally, as the grant of EP patents affects primarily companies active in EPC countries, the share of opponents with residence in one of these countries is considerably higher in comparison. To capture effects varying with the patent holder’s size, we classify the patent holder as either small, medium or large according to his patent portfolio. This measure seems less appropriate to proxy the opponent’s size. For instance, oppositions against pharmaceutical patents are frequently filed by generic drug companies

[23]EPO caselaw has rendered the use of a “straw man” representing the real party interested in the opposition eligible. In those rare occasions, our data reference a law firm or a single patent attorney as opponent.

Table 1.2: Patent and procedural characteristics

Variable	Mean	SD	Min	Max
Patent characteristics				
Self forward citations (3 years after filing)	0.39	0.99	0	20
Other forward citations (3 years after filing)	0.87	1.85	0	84
Self forward citations (5 years after decision)	0.14	0.52	0	10
Other forward citations (5 years after decision)	0.80	1.47	0	34
Age of patent (yr)	8.84	2.47	3	26
DOCDB family size	10.75	10.56	1	263
No of patent holders	1.07	0.32	1	13
No of inventors	2.61	1.76	1	21
No of claims	13.12	10.05	0	329
No of IPC subclasses	2.74	2.45	1	56
No of patent backward references	6.31	4.82	0	128
No of non-patent backward references	1.15	3.39	0	110
PCT application (d)	0.44	0.50	0	1
Year of application filing	1996.22	4.71	1981	2008
Year of grant decision	2001.01	4.62	1993	2010
Patent technology main area				
Electrical Engineering (d)	0.10	0.31	0	1
Chemistry (d)	0.39	0.49	0	1
Instruments (d)	0.13	0.33	0	1
Mechanical Engineering (d)	0.31	0.46	0	1
Other Fields (d)	0.06	0.24	0	1
Examination proceeding				
Duration filing to examination (yr)	1.72	1.22	0	18
Duration of examination (yr)	3.98	1.80	0	16
Accelerated examination (d)	0.11	0.31	0	1
Opposition proceeding				
Examiner participation (d)	0.68	0.47	0	1
Outcome: valid (d)	0.29	0.45	0	1
Outcome: invalid (d)	0.71	0.45	0	1
Appeal (d)	0.46	0.50	0	1
Outcome reversal (d)	0.07	0.26	0	1
Observations		33,075		

Notes: This table presents characteristics of the patent and examination as well as opposition proceeding at the level of opposition cases.

Table 1.3: Characteristics of patent holder and opponent

	Patent holder				Opponent			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Number of parties	1.07	0.31	1	11	1.28	0.76	1	19
Sector								
Company (d)	0.94	0.25	0	1	0.98	0.15	0	1
Country of residence								
EPC (excl. GB) (d)	0.58	0.49	0	1	0.83	0.37	0	1
GB (d)	0.04	0.20	0	1	0.04	0.20	0	1
US (d)	0.23	0.42	0	1	0.10	0.29	0	1
JP (d)	0.12	0.32	0	1	0.02	0.14	0	1
Other (d)	0.03	0.16	0	1	0.01	0.10	0	1
Size								
Large (d)	0.38	0.49	0	1		–		
Medium (d)	0.28	0.45	0	1		–		
Small (d)	0.34	0.47	0	1		–		
Observations		33,075				33,075		

Notes: This table presents characteristics of the patent holder(s) and the opponent(s) at the level of opposition cases. In case of multiple patent holders / opponents, we give preference according to the ordering of sector, country of residence, and size. Size categories are proxied by the number of patents (incl. applications) filed during the last five years prior to the opposition decision (large: 200 and more patents, medium: 20 and more patents, small: fewer than 20 patents).

that hold few if any patents. As we are more interested in the size of firms with innovative follow-on activities, we disregard this aspect of the opponent.

We capture follow-on inventions by the number of forward citations the focal patent receives within the first five years after the opposition outcome. In line with prior empirical analyses, we distinguish between "self citations", where the citing applicant and the focal patent holder are the same entity, and "other citations", where the citing applicant and the focal patent holder are different entities. We focus on forward citations linking two patent families on the basis of patent applications published by the EPO or the WIPO. The EPO/WIPO citation data are unusually rich, letting us distinguish between citations by the applicant and the examiner and providing information on the technological relevance of the cited patent. As can be seen from Table 1.4, citation characteristics differ between self citation and other citations. If the citing applicant is also the holder of the cited patent, the citation is more likely to originate from herself than from an examiner.[24]

[24] This suggests that citation data based on applicant information only may be prone to substantial bias.

Table 1.4: Characteristics of EP/WO forward citations by relationship to cited patent

	Self citations				Other citations			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Publication authority								
EPO	0.45	0.50	0	1	0.45	0.50	0	1
WIPO	0.55	0.50	0	1	0.55	0.50	0	1
Citation characteristics								
Citation lag (yr)	10.18	2.71	1	22	10.44	2.88	1	25
DOCDB family size	6.79	5.64	1	85	5.92	5.50	1	254
Sector (citing applicant)								
Company (d)	0.98	0.15	0	1	0.92	0.28	0	1
Country (citing applicant)								
EPC (excl. GB) (d)	0.64	0.48	0	1	0.57	0.49	0	1
GB (d)	0.02	0.15	0	1	0.04	0.19	0	1
US (d)	0.23	0.42	0	1	0.23	0.42	0	1
JP (d)	0.09	0.29	0	1	0.09	0.29	0	1
Other (d)	0.01	0.11	0	1	0.06	0.24	0	1
Size (citing applicant)								
Large (d)	0.52	0.50	0	1	0.32	0.47	0	1
Medium (d)	0.28	0.45	0	1	0.25	0.43	0	1
Small (d)	0.21	0.40	0	1	0.43	0.50	0	1
Observations	4,139				25,413			

Notes: This table includes examiner forward citations for patents subject to opposition proceedings in our main sample of analysis. The unit of observation is the citation. We only consider citation links established in search reports issued by the EPO. In case of multiple citations coming from the same patent family, we keep the earliest citation. In case of multiple citing applicants, we give preference according to the ordering of sector, country, and size. "Country" refers to the country of residence. Size categories are proxied by the number of patents (incl. applications) filed during the last five years prior to the opposition decision (large: 200 and more patents, medium: 20 and more patents, small: fewer than 20 patents).

1.4 Empirical Analysis

1.4.1 Baseline Specification and Identification Strategy

Our data on oppositions is a cross section where the unit of observation is the opposition proceeding involving the unique patent p. Our main empirical specification is

$$\log(\textit{Forward citations}_p) = \beta_1\ \textit{Invalidated}_p + \beta_2\ \boldsymbol{Patent}_p\ +\ \beta_3\ \boldsymbol{Patent\ holder}_p\ + \\ +\ \beta_4\ \boldsymbol{Opponent}_p\ +\ \beta_5\ \boldsymbol{Age}_p\ +\ \beta_6\ \boldsymbol{Year}_p\ +\ \beta_7\ \boldsymbol{Tech}_p\ +\ \epsilon_p.$$

The coefficient β_1 captures the effect of invalidation on subsequent forward citations the opposed patent receives. If patent rights have a positive or no impact on follow-on innovation, we would expect $\beta_1 \leq 0$. Vice versa, a finding of $\beta_1 > 0$ would suggest that patents block follow-on innovation.

Our dependent variable captures the number of forward citations within the first five years after the opposition outcome. We distinguish between forward citations in total, those from patents held by the focal patent holder herself ("self citations") and those from patents held by others ("other citations"). To control for heterogeneity in the value that the patent has for the patent holder and follow-on inventors, we include patent value indicators, such as the number of claims and the number of self citations and other citations received within the first three years after filing as covariates in the regression. We also include age, grant year, decision year, and technology field dummies to control for additional heterogeneity that may correlate with the court decision and subsequent citations.

As previous studies have amply illustrated, our main empirical challenge is the endogeneity of the opposition division's decision to invalidate the patent. More valuable inventions may lead to more forward citations, but may also induce the patent holder to heavily defend the patent. This negative correlation, biasing the OLS estimate of β_1, renders this specification inappropriate to estimate causal effects. To address this endogeneity, we need an instrument that affects the likelihood of patent invalidation, but does not belong directly in the citations equation, hence creating exogenous variation in patent invalidation.

We construct our instrument around the participation of the primary examiner in the opposition proceeding – an approach new to the literature, which has focused on the use of decision maker fixed effects (Galasso and Schankerman, 2015; Sampat and Williams, 2018). Following the basic intuition that the primary examiner is more likely to come to the same conclusion concerning the validity of the patent as in the examination proceeding than an arbitrary examiner, namely a confirmation of the patentability of the subject matter, we expect his participation to negatively affect the probability of invalidation. To verify this, we use probit estimation models to regress the binary opposition outcome variable "Invalidated" on the "Examiner participation" dummy and all other exogenous variables $\boldsymbol{x}$,

$$\begin{aligned} \text{Prob}\,(\textit{Invalidated}_p) &= \Phi\,(\gamma_1 \textit{Examiner participation}_p + \boldsymbol{\gamma x}_p) \\ &\rightarrow \textit{Predicted probability of invalidation}_p\,. \end{aligned} \tag{1.1}$$

We find strong evidence that examiner participation indeed has an effect on the opposition outcome (p-value < 0.001). More importantly, we use the probit regression to obtain a fitted probability (propensity score) of invalidation for each observation, which we use as our instrument throughout the paper. We then apply standard Two-Stage Least Squares (2SLS) regression analysis, instrumenting the dummy of the opposition outcome with the predicted probability,[25]

$$\begin{aligned} \textit{Invalidated}_p &= \alpha_1\ \textit{Predicted probability}_p + \boldsymbol{\alpha x}_p\ + u_p \\ \log\,(\textit{Forward citations}_p) &= \beta_1\ \widehat{\textit{Invalidated}}_p\ + \boldsymbol{\beta x}_p\ +\ \epsilon_p\,. \end{aligned} \tag{1.2}$$

In Table 1.5, Columns (1) and (2), we report detailed results of the probit regression models of the invalidation dummy on the examiner participation dummy. The estimated effect in Column (1) indicates that examiner participation is associated with a decrease of about 6.6 percentage points in the likelihood of invalidation. The results are similar when we add the full set of control variables (cf. Column (2)) – examiner participation is associated with a highly significant decrease of about 4 percentage points in the probability of invalidation. We also find that patents with a larger number of claims are more likely to be invalidated, whereas variables concerning the time until grant have no significant effect.

Column (3) explores the interrelation of the observable control variables with examiner participation to provide some additional perspective concerning the exogeneity assumption. Variables with the potential to raise concerns have statistically insignificant coefficients close to zero. For a more detailed overview, especially concerning patent characteristics, see Table A.6 in the appendix.

For a regression-based comparison of patent characteristics (analogous to simple t-tests) with respect to the opposition outcome and with respect to the examiner participation instrument, see Tables A.4 and A.5 in the appendix, respectively. Invalidated opposed patents are found to have significantly larger DOCDB family sizes, a larger share of PCT applications, more inventors, more claims, more patent literature references and more forward citations than non-invalidated opposed patents, underlining the necessity of an instrumental variables approach. In contrast, patents with and without examiner participation do not differ in a significant way.

Note that weak identification is never an issue in the 2SLS regressions in the following, with heteroskedasticity-robust first-stage F-statistics ranging from >70 for one of the considered subsamples to 500 for the full sample.

[25]The resulting estimator is asymptotically efficient in the class of estimators where the instrumental variables are functions of all exogenous variables (Wooldridge, 2010, p. 939, Procedure 21.1).

Table 1.5: Examiner participation and opposition outcome (EP/WO citations)

	(1)	(2)	(3)
Estimation method	Probit	Probit	Probit
Dependent variable	Invalidated (d)	Invalidated (d)	Examiner participation (d)
Exam. participation (d)	−0.066***	−0.038***	
	(0.005)	(0.006)	
log(No of claims)		0.039***	−0.005
		(0.004)	(0.004)
log(CitEPExaPre3Other)		0.006	0.001
		(0.005)	(0.005)
log(CitEPExaPre3Self)		−0.006	0.007
		(0.007)	(0.007)
Duration of examination (yr)		−0.003	0.004
		(0.006)	(0.007)
Duration of wait (yr)		0.009	0.007
		(0.007)	(0.007)
Year effects	No	Yes***	Yes***
Age effects	No	Yes*	Yes*
Technology effects	No	Yes***	Yes***
Patent characteristics	No	Yes***	Yes†
Patent holder characteristics	No	Yes***	Yes*
Opponent characteristics	No	Yes***	Yes
Model degrees of freedom	1	111	110
χ^2-statistic	154.3	1,812.5	2,772.1
Pseudo-R^2	0.004	0.061	0.073
Observations	33,075	33,075	33,075

Marginal effects; Robust standard errors in parentheses

(d) for discrete change of dummy variable from 0 to 1

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: The probit regressions in Columns (1) and (2) illuminate the relevance of the "Examiner participation" dummy for the outcome of the opposition proceeding. The invalidation predictions of the probit regression in Column (2)—or equivalent predictions for subsamples and other citation measures—are used as the instrument in the 2SLS instrumental variables regressions throughout the paper. Column (3) shows the probit regression of the "Examiner participation" dummy on the other exogenous variables. One is added to all citation variables before taking the logarithm to include patents with no forward citations. A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

1.4.2 Results and Discussion

In Table 1.6 we examine how patent invalidation or partial invalidation in an opposition proceeding affects the number of subsequent EP/WO forward examiner citations. Column (1) shows the baseline OLS regression of the logarithmized number of forward citations of parties other than the focal patent holder within five years after the opposition decision on the invalidity dummy and an extensive set of control variables. The correlation between patent invalidation and future citations is insignificant and close to zero. In contrast, turning to the 2SLS instrumental variables regression in Column (2), we find a highly significant positive coefficient. The obvious discrepancy from the OLS estimate is in line with the expected endogeneity of invalidation, a suspicion confirmed on the 5% level by a test of endogeneity. The estimated coefficient implies that patent invalidation causes a significant increase in citations by other parties in the five years following the opposition outcome. Note that the instrument explains a sizable part of the variation in patent invalidation, which is underlined by the first stage heteroskedasticity-robust F-statistic of 500 – a value that easily exceeds the Stock and Yogo (2005) (i.i.d. error) critical values for weak identification tests. Column (3) presents the results of the same baseline specification, however, with the dependent variable restricted to citations from patents held by the focal patent holder herself. We find a weakly significant, positive effect of invalidation on the focal patent holder's follow-on inventive activity.[26] Column (4) presents the results of the baseline specification on the total number of citations. While these positive average effects over the whole sample for "other" as well as "total" citations are in line with the findings of Galasso and Schankerman (2015), the results concerning the origin of the effect stand in stark contrast.

The following four tables disentangle the average effect on other citations by technology area, complexity of the technology, and size of both the focal and the citing patent holder.

First, Table 1.7 lists the estimation results on subsamples defined by technology main area. While the coefficients for "Electrical Engineering", "Instruments", and "Chemistry" are all positive, the latter is the only one with statistical significance. It appears that the effect of invalidation on citations by others is most coherent in "Chemistry" – an area which is commonly associated with discrete technologies, while "Electrical Engineering" and "Instruments" predominantly encompass complex technologies.

Second, given that the fairly large standard errors for "Electrical Engineering" and "Instruments" hint at potential heterogeneity in the effect of invalidation on citations, in Table 1.8 we split the sample based on the nature of the underlying technology and based on the size of the focal patent holder. In Column (1) we restrict our sample to complex technology areas, resulting in no significant effect of invalidation on forward citations by others. In contrast, the subsample of patents in "discrete" technologies in Column (2) shows a highly significant

[26]Note that the measure used here is distinct from those used in Chapter 2. Forward "self" citations measure follow-on (or cumulative) invention of the opposed patent's holder and hence are not representative of her overall patenting activity.

Table 1.6: Impact of invalidation on EP/WO citations

	(1)	(2)	(3)	(4)
Estimation method	OLS	IV	IV	IV
Dep var: log(CitEPExaPost5...)	Other	Other	Self	Total
Invalidated (d)	−0.008	0.292***	0.074*	0.329***
	(0.006)	(0.074)	(0.033)	(0.077)
log(No of claims)	0.062***	0.051***	0.014***	0.059***
	(0.005)	(0.006)	(0.003)	(0.006)
log(CitEPExaPre3Other)	0.130***	0.128***	0.005†	0.127***
	(0.006)	(0.006)	(0.003)	(0.006)
log(CitEPExaPre3Self)	0.019*	0.020*	0.047***	0.050***
	(0.008)	(0.008)	(0.005)	(0.009)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes**	Yes*	Yes	Yes**
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes***	Yes**	Yes	Yes**
Patent holder characteristics	Yes**	Yes**	Yes***	Yes
Opponent characteristics	Yes***	Yes***	Yes	Yes***
Underidentification test		221.8	221.8	221.8
Weak identification test		504.8	504.8	504.8
Observations	33,075	33,075	33,075	33,075

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Columns (1) and (2) provide a comparison between the OLS and the 2SLS regressions for the impact of invalidation on EP/WO examiner citations to patents held by other parties than the focal patent owner, as measured by EP/WO examiner forward citations in a 5-year window following the decision of the opposition proceeding. Columns (2)–(4) show 2SLS regressions for the impact of invalidation on the number of follow-on patents held by other parties than the focal patent owner, on the number of follow-on patents held by the focal patent owner herself and on the total number of follow-on patents, respectively. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table 1.7: Impact of invalidation on EP/WO citations – technology main areas

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExaPost5...)	Other	Other	Other	Other
Technology area	Electr Eng	Instruments	Chemistry	Mech Eng
Invalidated (d)	0.183	0.308	0.299**	0.055
	(0.194)	(0.248)	(0.102)	(0.166)
log(No of claims)	0.060***	0.060***	0.041***	0.070***
	(0.015)	(0.016)	(0.009)	(0.010)
log(CitEPExaPre3Other)	0.140***	0.166***	0.097***	0.144***
	(0.017)	(0.017)	(0.009)	(0.012)
log(CitEPExaPre3Self)	0.085**	0.023	0.005	0.034*
	(0.031)	(0.024)	(0.011)	(0.016)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes	Yes***	Yes	Yes†
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes	Yes	Yes	Yes***
Patent holder characteristics	Yes**	Yes	Yes**	Yes
Opponent characteristics	Yes	Yes*	Yes	Yes*
Underidentification test	32.5	50.8	122.3	43.0
Weak identification test	75.5	64.0	256.4	77.0
Observations	3,432	4,220	13,011	10,384

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Columns (1)–(4) show the impact of invalidation on EP/WO examiner forward citations to patents held by parties other than the focal patent holder for the technology main area subsamples Electrical Engineering, Instruments, Chemistry and Mechanical Engineering, respectively. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table 1.8: Impact of invalidation on EP/WO citations – technology and size

	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	IV	IV	IV	IV	IV	IV
Dep var: log(CitEPExaPost5…)	Other	Other	Other	Other	Other	Other
Subsample	Complex	Discrete	Large	Non-large	Complex or large	Discrete, non-large
Invalidated (d)	0.097	0.369***	0.086	0.378***	0.131	0.414***
	(0.134)	(0.092)	(0.140)	(0.088)	(0.105)	(0.107)
log(No of claims)	0.067***	0.039***	0.045***	0.054***	0.061***	0.038***
	(0.008)	(0.008)	(0.010)	(0.007)	(0.007)	(0.009)
log(CitEPExaPre3Other)	0.153***	0.105***	0.111***	0.135***	0.133***	0.113***
	(0.009)	(0.008)	(0.010)	(0.008)	(0.008)	(0.010)
log(CitEPExaPre3Self)	0.031*	0.017†	0.019†	0.032**	0.018†	0.031*
	(0.014)	(0.010)	(0.012)	(0.012)	(0.010)	(0.014)
Year effects	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Age effects	Yes*	Yes	Yes	Yes**	Yes†	Yes†
Technology effects	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes*	Yes*	Yes	Yes**	Yes	Yes**
Patent holder characteristics	Yes*	Yes*	Yes	Yes	Yes†	Yes
Opponent characteristics	Yes*	Yes*	Yes*	Yes†	Yes**	Yes
Underidentification test	78.0	135.5	63.9	171.0	103.5	118.7
Weak identification test	191.1	313.3	147.1	350.9	268.9	238.1
Observations	14,946	18,129	11,038	22,037	20,923	12,152

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table shows the impact of invalidation on EP/WO examiner forward citations to patents held by parties other than the focal patent holder for different sample splits. Columns (1) and (2) compare the effect in complex technologies to that in discrete technologies, Columns (3) and (4) compare the effect for patents held by large patent holders to that for patents held by non-large patent holders and Columns (5) and (6) compare the effect for patents which are in complex technologies or held by a large patent holder to that for patents which are in discrete technologies and held by a non-large patent holder. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

positive invalidation effect. These results go hand in hand with the common perception of the difference between complex and discrete technologies. While the protection of an invention in discrete technologies is concentrated in a single patent, resulting in profound consequences for the IP landscape in the case of an invalidation, inventions in complex technologies are typically spread across two or more patents, rendering the implications of an invalidation less severe and more heterogeneous. We further explore this channel in Table 1.10. Column (3) and Column (4) concern the size of the focal patent holder. We find a much stronger and highly significant effect of invalidation on citations by others if the focal patent holder is small or medium-sized. This result is difficult to align with the findings of Galasso and Schankerman (2015), who find that the effect of invalidation on forward citations is larger if the holder of the invalidated patent is large. According to our results, bargaining failure, which presumably blocks follow-on innovation as long as the patent remains in force, is considerably less likely in negotiations with large patent holders. We investigate this channel in more detail in Table 1.9.

We include both aspects, complexity and size, in the subsample definitions used in Column (5) and Column (6). While there is a positive, insignificant coefficient for the subsample that includes all complex patents and/or large focal patent holders, we find estimates more than twice as large in magnitude and highly significant for the subsample based on patents in discrete technology areas which are held by non-large patent holders.

Third, motivated by our findings on patent holder size, in Table 1.9 we further explore the heterogeneity of the invalidation effect with respect to the differences in size between the owner of the citing (dependent variable) and the owner of the focal patent (subsample). Columns (1) and (2) show the effects of invalidation of a large holder's patent on forward inventive activity by large and non-large patent holders, respectively. While the coefficient for large follow-on holders is marginally significant and positive, the coefficient for small- and medium sized owners facing a large focal patent holder is insignificant. In contrast, for Columns (3) and (4), which display the corresponding effects for the invalidation of a patent held by a non-large owner, we find highly significant coefficients. More specifically, the effect on non-large other parties appears stronger than the one for large other parties. These results imply an ordering with regard to bargaining failure in the presence of a patent right. Frictions are most pronounced for non-large focal patent holders and non-large follow-on innovators (4), significant for non-large original applicants and large subsequent innovators (3), marginally significant for large focal patent holders and large follow-on innovators (1) and close to zero for large original applicants and non-large subsequent applicants (2). This is consistent with intuition: While small firms struggle to efficiently negotiate a path for follow-on innovation building on a second small firm's patented invention, they are free to operate after an invalidation (4). However, small firms are unable to profit from the invalidation of a patent held by a large company which is able to retain protection of its invention by further patents or by other means (2). Although this logic may apply to large focal patent holders

Table 1.9: Impact of invalidation on EP/WO citations – sizes of focal and citing patent holders

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExa. . . Post5Other)	Large	Non-large	Large	Non-large
Patent holder subsample	Large	Large	Non-large	Non-large
Invalidated (d)	0.159†	−0.067	0.190***	0.245**
	(0.085)	(0.127)	(0.050)	(0.078)
log(No of claims)	0.013†	0.039***	0.010**	0.050***
	(0.007)	(0.008)	(0.004)	(0.006)
log(CitEPExaPre3Other)	0.058***	0.073***	0.060***	0.100***
	(0.008)	(0.008)	(0.005)	(0.007)
log(CitEPExaPre3Self)	0.023*	0.002	0.023**	0.017†
	(0.009)	(0.009)	(0.007)	(0.010)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes	Yes	Yes**	Yes
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes	Yes	Yes	Yes**
Patent holder characteristics	Yes	Yes	Yes**	Yes***
Opponent characteristics	Yes	Yes*	Yes*	Yes*
Underidentification test	63.9	63.9	171.0	171.0
Weak identification test	147.1	147.1	350.9	350.9
Observations	11,038	11,038	22,037	22,037

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table explores the impact of invalidation on EP/WO examiner citations with respect to the differences in size between the holder of the citing patent (dependent variable) and the holder of the focal patent (subsample). Columns (1) and (2) show the effect of invalidation on citations to patents held by large and non-large patent owners, respectively, for the subsample of patents held by large patent owners, Columns (3) and (4) analogously for the subsample of patents held by non-large patent owners. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

facing small follow-on innovators, it seems to be less applicable for those faced with a large competitor, where the invalidation does not have a coherent effect (1). Finally, although non-large original applicants enjoy some protection against large follow-on innovators as long as the patent right is in place (3), it is not as effective as against small subsequent innovators. It seems that large follow-on innovators can more confidently rely on being capable of building on an invalidated patent when the original applicant is small (1 vs 3).

Fourth, to further inquire into the findings for complex technologies (Table 1.8), we discuss the invalidation effect in the presence of patent thickets and patent fences in Table 1.10. In Columns (1) and (2) the sample is split into technology areas with and without patent thickets, respectively. Consistent with intuition we do not find a significant effect of invalidation in areas with thickets, but a positive and significant effect for those without. Similarly, there is no significant effect for patents protected by a fence, i.e., those protected by the presence of one or more similar patents filed by the focal patent holder before the opposition proceeding of the focal patent. In contrast, there is a strong and highly significant effect in the case of the absence of a protecting fence.

Fifth, in order to examine potential differences in the invalidation effect with respect to patent age and value, Table 1.11 shows the results for sample splits at the age median of 8 years and the DOCDB family size median of 8. The effect seems to be primarily driven by younger and more valuable patents.

1.4.3 Robustness Tests

Robustness across main technology area subsamples

To verify that the results reported in Tables 1.9 and 1.10 are not exclusively driven by a single technology area, we report analogous regressions for the chemistry and the electrical engineering / instruments subsamples in Tables A.9 to A.12, finding qualitatively very similar coefficients.

Exclusion of particular cases

Table A.13 shows that our results are not merely artifacts of very particular patents or final outcomes. In Column (1) we exclude "dead" patents, i.e., patents solidified in the opposition proceeding which lapse prior to the end of the citation window 5 years after the opposition decision. Column (2) presents the results with patents with accelerated examinations excluded, to rule out the possibility that the effect is solely driven by patents of special interest to the applicant. To mitigate concerns addressing the use of the opposition decision instead of the final outcome of a potential appeal, in Columns (3) and (4) we exclude all cases in which an appeal leads to a reversal of the opposition decision and in which any appeal is filed, respectively.

Table 1.10: Impact of invalidation on EP/WO citations – patent thickets and patent fences

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExaPost5...)	Other	Other	Other	Other
Subsample	Thicket	No thicket	Fence	No fence
Invalidated (d)	−0.031	0.229**	0.195	0.369***
	(0.154)	(0.082)	(0.135)	(0.086)
log(No of claims)	0.056***	0.056***	0.043***	0.051***
	(0.015)	(0.006)	(0.011)	(0.007)
log(CitEPExaPre3Other)	0.129***	0.130***	0.109***	0.134***
	(0.016)	(0.007)	(0.011)	(0.007)
log(CitEPExaPre3Self)	0.028	0.011	0.013	0.038***
	(0.022)	(0.009)	(0.012)	(0.011)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes	Yes*	Yes	Yes*
Technology effects	Yes**	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes	Yes**	Yes†	Yes*
Patent holder characteristics	Yes	Yes*	Yes*	Yes†
Opponent characteristics	Yes	Yes***	Yes	Yes***
Underidentification test	64.4	179.7	68.8	171.7
Weak identification test	81.0	425.5	116.7	392.0
Observations	3,239	28,494	8,826	24,233

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table explores the different effects of invalidation on EP/WO examiner citations in the presence or absence of patent thickets and patent fences. Columns (1) and (2) represent a sample split with respect to the presence of a patent thicket in the focal patent's technology area. We consider a thicket to be present if the area triples variable derived by von Graevenitz et al. (2011) lies at or above the 90th percentile in the full sample. Columns (3) and (4) show the effect of invalidation for a sample split with respect to the presence of a patent fence erected by the holder of the focal patent. We consider a fence to be present if we find at least one similar patent by the focal patent owner prior to opposition. The similarity measure we use is sensitive to the title, the claims, the technology area and the full text of the patent. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table 1.11: Impact of invalidation on EP/WO citations – patent age and value

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExaPost5...)	Other	Other	Other	Other
Subsample	Younger	Older	Smaller family	Larger family
Invalidated (d)	0.242*	0.144	0.129	0.330**
	(0.119)	(0.103)	(0.100)	(0.106)
log(No of claims)	0.070***	0.039***	0.048***	0.057***
	(0.008)	(0.008)	(0.007)	(0.008)
log(CitEPExaPre3Other)	0.172***	0.097***	0.149***	0.110***
	(0.010)	(0.008)	(0.009)	(0.008)
log(CitEPExaPre3Self)	0.033**	0.005	0.030*	0.015
	(0.012)	(0.010)	(0.013)	(0.010)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes*	Yes	Yes	Yes*
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes	Yes**	Yes	Yes*
Patent holder characteristics	Yes	Yes**	Yes	Yes***
Opponent characteristics	Yes	Yes*	Yes**	Yes†
Underidentification test	93.1	129.3	38.7	155.7
Weak identification test	182.4	255.9	205.9	249.8
Observations	16,981	16,094	17,188	15,880

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: In this table we explore the differences of the invalidation effect with respect to the age of the focal patent at the time of the opposition division's decision and with respect to the size of its DOCDB family, a common patent value indicator. In Columns (1) and (2) we split the sample at the age median (8 years), where "Younger" refers to patents of age ≤ 8 years and "Older" refers to patents of age > 8 years. In Columns (3) and (4) the sample is split at the median DOCDB family size (8 members), "Smaller family" referring to patents with a family size ≤ 8, "Larger family" referring to patents with a family size > 8. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Focus on the extensive margin

Additionally, we limit our count of forward citations to the first of each unique follow-on innovator within the respective time frame. This operationalization allows us to estimate the effect of invalidation on the extensive margin of follow-on innovation. The results are very similar to the ones in our main section (see Table A.15).

Bootstrapped standard errors

In analogy to Table 1.6, Table A.14 shows bootstrapped instead of robust standard errors. The bootstrapping procedure includes both the probit invalidity probability prediction stage and the subsequent 2SLS instrumental variable estimation. Bootstrapped and robust standard errors are quantitatively very similar, leading to identical conclusions concerning the significance levels of the invalidation coefficient.

Dummy citation variables

The regressions of Table A.16 follow our baseline specification with all citation variables replaced with the corresponding dummy variables indicating that at least one citation has been made. The results closely reproduce the findings of Table 1.6.

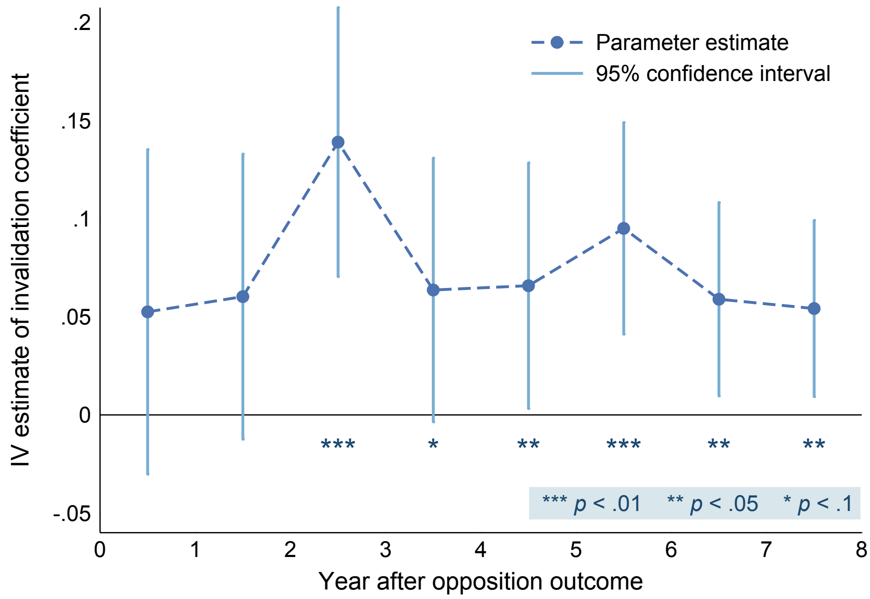
Alternative definition of opposition outcome

We further test whether the results are robust to an alternative operationalization of our independent variable of interest, "invalidation." Instead of treating all patents subject to an amendment as invalidated, we choose a demarcation based on the relative loss of patent scope due to opposition. Patents that lose a smaller number of claims relative to the median of all amendment cases ($N = 5,415$) are treated as remaining valid. The coefficients are quite similar to the ones when using the standard operationalization but less precisely estimated (see Table A.17 and A.18).

Exclusion of citations by focal patent's examiner

To rule out potential concerns that the involvement of the focal examiner in the opposition proceeding may modify his powers of recall, we include only those citations, for which we can exclude that they were made by the focal patent's examiner (Table A.19). Due to resulting data restrictions we have to limit the sample to patents with an application filing year ≥ 2001. Despite a substantial reduction in the number of observations and in the citation count, the results closely resemble those of Table 1.7. We can hereby rule out potentially modified powers of recall (when a focal examiner involved in the opposition proceeding is compiling subsequent search reports) as a main driver of the observed effect.

Figure 1.4: Timing of the invalidation effect



Notes: Blue points depict the coefficients of invalidation resulting from IV regressions for each year after opposition outcome. The dependent dummy citation variable indicates whether or not a patent has been cited in the respective time span. The usual independent citation control variables (Pre3Self and Pre3Other) are also replaced by dummies. Error bars show the corresponding lower and upper 95% confidence limits. The significance levels are indicated by stars below each parameter estimate.

US citations

Tables A.21 to A.26 demonstrate that all findings are qualitatively similar when using US citations. This alternative measure of follow-on innovation results in a dependent variable with much higher variation and more non-zero observations (see Figure A.4 in the appendix). Besides, we are able to rule out the citation behavior of EP/WO examiners as the key driver of the effect.

Timing of the invalidation effect

Figure 1.4 provides some insights into the timing of the invalidation effect. For each year after the opposition outcome, we run IV regressions with a dummy dependent citation variable indicating whether or not a patent has been cited in the respective time span. Significant coefficients of invalidation are only found starting from the third year after opposition, with the third and the sixth year showing particularly large effects. This supports the interpretation that a true change in inventive behavior underlies the increase in the citation likelihood. Conversely, it further attenuates the potential concern that the effect is mainly driven by the examiners' increased attention and memory for invalidated patents when searching prior art for subsequent inventions, which one would expect to set in immediately. Figures A.5 and A.6

show the corresponding results for the chemistry and the electrical engineering / instruments subsamples.

Local average treatment effect

In a potential-outcomes framework, IV estimates of the invalidation coefficient can be interpreted as the local average treatment effect on "complier" patents, i.e., patents whose invalidation status can be changed by the instrument (Imbens and Angrist, 1994). Tables A.7 and A.8 explore the size and the characteristics of the complier patent subpopulation. Depending on the (binary) instrument, complier patents are estimated to constitute a share of around 6% to 20% of the patent population. The composition of the complier subpopulation is found to be very similar to the composition of the entire sample with respect to a diverse range of characteristics.

1.5 Conclusion

In this study, we investigate the causal effect of a patent's invalidation on follow-on inventions. Our empirical setting is the opposition procedure at the European Patent Office. Opposition allows rivals and other third parties to invalidate patents centrally, before they are converted to a bundle of national patent grants in up to 38 signatory states of the European Patent Convention. In order to take the presumably endogenous nature of opposition outcomes into account, we introduce a new instrument that exploits the presence or absence of the focal patent's examiner, who granted the patent in the first place, in the opposition proceeding. Participation of the examiner in the opposition division is associated with a significant reduction of invalidation outcomes. Since opposition is relatively frequent with around 6% of granted patents being attacked, we are able to compile a dataset of more than 33,000 opposed patents to study the impact of invalidation on post-opposition citations. In line with the results presented by Galasso and Schankerman (2015), our baseline model shows that patent invalidation overall leads to a highly significant increase of other party and total forward citations. Forward citations by others increase by about 23% following an invalidation. At the same time, we do not find evidence that follow-on inventive activity by the holder of the focal patent is negatively affected.

However, concerning the origin of the invalidation effect, our results strongly contradict previous findings. First, the positive effect of invalidation on subsequent citations is confined to discrete technology industries. Second, it is most pronounced for small and medium-sized patent holders and, to a lesser extent, for large patent holders facing large follow-on innovators. Finally, the effect is limited to areas where patent thickets are absent and to patents which are not protected by "patent fences", i.e., similar applications of the same applicant. We probe the robustness of our results in various ways. In the relatively large subsamples of chemistry and electrical engineering / instruments patents, we confirm that invalidation does not lead to a coherent or significant increase in citations when thickets or fences are present. In a second round of robustness tests we use USPTO citations and confirm for most cases the results obtained with EP/WO citations.

Our results for chemistry are in line with those of Murray and Stern (2007), Huang and Murray (2009), and Williams (2013), who focus on IP protection in genome analysis. Moreover, Moser and Voena (2012) find an increase in innovation from compulsory free licensing in the chemical sector. We do not obtain a strong result for electrical engineering and instruments patents per se, but identify a positive effect of invalidation on subsequent citations for small and medium-sized patent-holders and same-size follow-on inventors. These results are broadly in line with findings by Watzinger et al. (2017).

In the study most similar to ours, Galasso and Schankerman (2015) obtain very different results. In their regressions, the invalidation of chemistry patents by the CAFC does not result in an increase of forward citations, while they do find such an effect for computers, electronics, and medical instruments (pooled with biotechnology). They also find that the strongest effect emerges when patents of large firms are invalidated. In contrast, in our EPO opposition sample the invalidation of patents of small- and medium-sized firms leads to a particularly strong increase in subsequent forward citations, especially for citations coming from other small- and medium-sized applicants. Our results are in line with the view that bargaining problems are particularly pronounced between small players, while having a large player on either or both sides of the negotiation table helps to alleviate the bargaining problems. We find this view more appealing than one in which the presence of large players causes bargaining problems.

Nonetheless, the differences are intriguing. They may suggest new avenues for exploring the nature of cumulative effects in invention processes. We speculate that the samples used here differ in more ways than we initially anticipated. Opposition is far less selective than selection into cases heard at the CAFC. This allows us to work with a much larger number of observations, but the nature of the cases may differ as well. Presumably, the CAFC cases are both particularly valuable and particularly uncertain, to an extent that prevented the parties to achieve some form of settlement. In the case of oppositions, settlements are discouraged by institutional means, reducing ex ante selection effects, but increasing the heterogeneity of cases in the sample. The comparatively low costs of opposition work in the same direction. To fully explain the differences, further insights illuminating the context-specific selection mechanisms are needed. One way of resolving the issue might be to extend studies of US litigation data to cases that reached a final conclusion (invalidation or rejection thereof) at a litigation stage prior to the CAFC. A second approach would be to restrict the European opposition sample of this study in a way that mimics US selection to the CAFC. Leaving the differences in recent results aside, our estimates clearly support the view that the invalidation of patents does – in the aggregate – lead to a rekindling of inventive processes.

2

Marginal Patents and the Supply of Ideas

The Impact of Post-Grant Review

2.1 Introduction

Marginally valid patents are a prime concern for the social value of the patent system, causing, inter alia, tremendous litigation costs that run in the billions of dollars every year (e.g., Hall and Harhoff, 2004, 2012; Bessen and Meurer, 2012). To alleviate these negative consequences of marginal patents, many patent systems rely on centralized opposition procedures. In contrast to litigation, which easily generates costs above one million dollars per case in the US (Bessen and Meurer, 2005; American Intellectual Property Law Association, 2017), opposition procedure costs in Europe range between 6,000 and 50,000 euros (MacDougall and Hamer, 2009; Mejer and van Pottelsberghe de la Potterie, 2012). Therefore, post-grant review is thought to generate large welfare gains and to ensure patent quality (Hall et al., 2004). In the United States, the America Invents Act of 2011 has established a post-grant review process following the calls of various scholars (e.g. Lemley et al., 2005; Farrell and Shapiro, 2008). In Europe, the European Patent Office (EPO) has long been using a centralized opposition procedure. Empirical evidence on the social costs and benefits of post-grant review still remains scarce, however.

In this paper, we analyze how the invalidation of marginal patents during opposition influences affected inventors' subsequent patenting. We study post-grant opposition at the European Patent Office, which constitutes a unique setting for our analysis. In the first nine months after a patent grant, any third party can challenge the validity of an EPO patent by filing opposition against the decision. Opposition thus occurs early in the patent's lifetime, in contrast to court proceedings previously used for identification (e.g., Galasso and Schankerman, 2015, 2018). The opposition procedure is relatively inexpensive and is the only centralized possibility to invalidate EPO patents on a transnational level.[1] As a result, with a rate of around 6-7%, opposition is a relatively frequent event: Our sample contains around 65,000 inventors first involved in around 30,000 oppositions filed between 1994 and 2010. In comparison to prior work, this should make our sample less selective regarding patent quality and, in particular, patent value.[2] An "opposition division" comprising three qualified patent examiners decides on the outcome of the opposition proceeding. According to Art. 19(2) EPC, the examiner who granted the patent initially may be part of this committee.

The identification of causal effects of patent invalidation poses an empirical challenge. For example, an inventor who increasingly targets incremental rather than radical innovation will on average file patent applications of lower quality or of a reduced inventive step, thus increasing the probability of invalidation. At the same time, it is coherent to expect her to apply for a larger number of patents in any given time period in the future. Thus, any correlation between the loss of patent protection and the propensity to file patent applications does not have a causal interpretation.

We exploit the random allocation of the original examiner to the opposition division as an instrumental variable for the invalidation of opposed patents, as first suggested in Chapter 1 (Gaessler, Harhoff, and Sorg, 2017). We therefore estimate local average treatment effects: The invalidation coefficients reflect differences in subsequent patenting for inventors whose opposition outcome is shifted by the instrumental variable. The corresponding patents are marginal in patentability because the participation of the original examiner in the opposition division alone determines whether they are invalidated.[3] The instrument provides a strong first stage: When the granting examiner is part of the opposition division, the likelihood of invalidation decreases by around 6 percentage points. Importantly, the allocation of examiners to opposition divisions is as good as random. Participation of the original examiner is primarily driven by the availability of *other* suitable examiners.[4] Besides, neither the patent holder nor

[1] Once an EP application has split into national patent rights, invalidation requires separate proceedings at the national courts, which is a substantially more costly avenue to pursue. Besides, differences in outcomes across countries can be substantial (Cremers et al., 2017)

[2] In comparison to the litigation setting studied by Galasso and Schankerman (2015, 2018), the opposition procedure is also less prone to unobserved settlement for two reasons: (i) because of the short time frame for filing an opposition and (ii) because the EPO can continue the proceeding on its own motion, independent of the party that initially filed opposition.

[3] This does not imply that these patents are not valuable. In fact, if marginal patents were not valuable, they would not pose a problem for cumulative innovation or the patent system. Marginal patents are valuable because they still deter competitors from innovating (cf. Chapter 1).

[4] This is corroborated by the substantial decrease in the rate of granting examiner participation after an EPO initiative promoted search-only examiners to substantive examiners (see Figure 1.1). Only the latter are eligible as members of the opposition division.

the opponent can influence the composition of the opposition division.

Invalidation in opposition could impact subsequent patenting for several reasons. First, losing a patent has been shown to adversely affect firm success, especially for small ventures (Wagner and Cockburn, 2010; Farre-Mensa et al., 2017; Gaulé, 2018; Galasso and Schankerman, 2018). Due to resulting capital restrictions, inventors may be forced to limit the scope and to change the direction of their inventive activity. Second, inventors or their firms and patent attorneys may adjust their filing strategy. For instance, patenting could be shifted to substitute authorities such as the national patent offices or the World Intellectual Property Organization (WIPO) to avoid centralized opposition at the EPO. More importantly, inventions could be kept secret instead of being disclosed in a patent application. However, secrecy is differently viable across technology areas (Hall et al., 2014) and may only be a worthwhile alternative to patenting for substantial technological advances, where competitors would learn much from disclosure (Anton and Yao, 2004; Zaby, 2010). Third, invalidation may serve as a signal at the inventor or the invention level (cf. Chan et al., 2014; Azoulay et al., 2015, 2017). If invalidation is informative about inventor or idea quality, firms may adjust the allocation of resources towards other inventors or technology areas. Finally, invalidation may impact inventor mobility. Melero et al. (2017) show that inventors respond to patent grants by becoming less mobile, especially between firms in the same technology area. Mobility decisions may in turn affect subsequent productivity (Hoisl, 2007, 2009).[5]

We find that in the ten years after patent invalidation, inventors file on average 0.5 or around 20% fewer applications annually than comparable inventors whose patents were also opposed, but not invalidated. The effect starts to materialize around three years after the decision to invalidate the patent. Inventors are 15 percentage points less likely to file for a patent in the ten years after invalidation. These effects also appear when using citation-weighted patent applications. We do not observe increases in national patenting or substitution towards the transnational WIPO procedure. We can thus rule out that our findings only reflect shifts to alternative patent application authorities. The overall effect is primarily driven by a decrease in patent filings which search examiners associate with "novelty-threatening" prior art. In EPO search reports, examiner categorize references by whether they challenge the application's novelty or the existence of an inventive step (Harhoff and Wagner, 2009). In our data, patent filings *without* such novelty-threatening references, if anything, even slightly increase. In reaction to an invalidation in opposition, inventors hence file fewer applications that are at the margin of being patentable.

We further explore these effects by constructing alternative dependent variables and by analyzing the heterogeneity of effects along inventor and applicant characteristics. First, the effects on patent filings in the same technology area as the invalidated patent are similar to those in other areas. Second, inventors who experience an invalidation in their expert area

[5]Similar effects may arise from changes to the inventors' stream of income (Harhoff and Hoisl, 2007; Toivanen and Väänänen, 2012) following invalidation.

show comparable effects to those who experience an invalidation outside their central field of expertise. Third, using median splits along several *applicant* characteristics such as the size of the patent portfolio, revenue, and profitability, we do not find significant differences in effect sizes. Fourth, using median splits along several *inventor* characteristics such as tenure, the number of prior applications, and the prior number of technology areas in which applications were filed, we also do not find strong heterogeneities. If anything, the effects seem to be less pronounced for inventors with fewer prior applications and applications in fewer technology areas.

While we cannot disentangle the underlying mechanisms directly, these results do not support some of the explanations proposed in the literature as potential drivers behind our effects. First, if the effect was a consequence of firm success or exit, heterogeneity across applicant characteristics would be likely. However, we do not find substantial differences in coefficients. Second, if the effect was driven by inventor mobility, a reduced stream of income, or learning about inventor or idea quality, experienced inventors should be less impacted. Yet, if anything, we find that the effect is less pronounced for inventors with few prior applications. Third, if a general shift to secrecy was the driver, the effect would not be concentrated in applications that constitute a minor departure from prior art. While such patents might be valuable as exclusion rights, they should reveal little information to competitors. However, we mainly find a reduction of applications with novelty-threatening references after invalidation.[6]

This paper contributes to the nascent literature analyzing the impacts of post-grant review. Although these procedures have gained substantial interest, there is little empirical evidence about the consequences of establishing such institutions. Most of the literature has outlined potential costs and benefits theoretically (e.g., Hall and Harhoff, 2004). Empirically, Harhoff and Reitzig (2004) show that patents in the EPO's post-grant review system are associated with higher measures of patent value, such as forward citations.[7] Graham and Harhoff (2014) show that for patents which are litigated in the US, the European counterparts are often revoked or amended in the EPO's post-grant process. This suggests high social welfare gains from an opposition system, relative to litigation. Nonetheless, such procedures might be associated with social costs (Shane, 2009). Overall, there is a lack of empirical evidence as to how post-grant reviews affect innovation.

This paper also contributes to an emerging literature investigating the impact of patent invalidation on subsequent innovation and productivity, which has so far mostly focused on firm outcomes. Galasso and Schankerman (2018) use the random allocation of judges to committees deciding on the invalidation of litigated patents to find that small firms decrease their inventive activity in response to an invalidation. Gaulé (2018) and Farre-Mensa et al. (2017) use prior examiner leniency and find that venture-capital backed start-ups fare substantially

[6]More generally, a decrease in patent filings is not necessarily equivalent to a decrease in inventive activity. However, given that one of the main goals of the patent system is to encourage the disclosure of ideas (Williams, 2017), we believe that our results are interesting even if the effects were merely reflecting shifts into secrecy.

[7]Love et al. (2018) analyze the determinants of invalidation in the US post-grant review system.

better when being granted a patent.[8] Implications of patent grants for firms' follow-on innovation, firm behavior, and firm success have thus been studied to some extent. From an innovation viewpoint, it is however important to know whether *inventors* stop patenting altogether or whether they just continue inventing for other companies. The relevance of inventor-level output is corroborated by the recent finding that firm heterogeneity only explains around 3-5% of the variance in inventors' patenting performance. In contrast, inventor fixed effects explain 23-29% of innovative performance, with inventor productivity being highly correlated over time (Bhaskarabhatla et al., 2017). In light of this result, it is surprising just how little is known about whether and how patents affect the performance of individual inventors. To the best of our knowledge, we are the first to show that patent invalidation affects the subsequent patent filings of *individual* inventors.

In summary, this paper thus contributes to a better understanding of the social costs and benefits of the patent system. In the context of post-grant review, our setup allows us to examine how decisions of the patent office affect the supply and disclosure of ideas: Inventors stop filing applications that are at risk of not being patentable, as indicated by potentially novelty-destroying search report references. Invalidation in post-grant review may therefore help to ensure the quality of patent applications in the long run.

The remainder of this paper proceeds as follows. In Section 2.2, we describe our setup, our data, and our empirical specification. In Section 2.3, we present and discuss our results. Section 2.4 concludes.

2.2 Setup, Data, and Empirical Strategy

In this section, we describe the empirical setting of our study, the patent opposition procedure at the EPO. We then describe our panel data set of inventors, which comprises the ten years before and after an inventor's first opposition procedure. Finally, we outline our instrumental variables strategy.

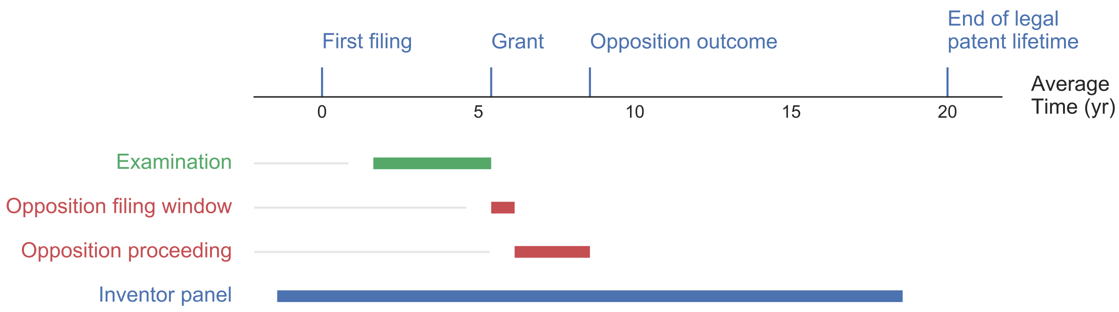
2.2.1 Patent Opposition at the EPO

The EPO provides a harmonized application procedure for patent protection in one or more member states of the European Patent Convention (EPC).[9] Patent applications granted by the EPO disperse into a bundle of national patent rights, each entering the patent system of the respective member state. Thus, the invalidation of a national patent through litigation in one country's courts has no effect on its counterparts in other countries. However, in the first nine months after grant, third parties can challenge the validity of a European patent issued by the EPO by filing an opposition against the granting decision. The centralized opposition

[8] There is an ongoing discussion about the identifying assumption behind using patent examiner leniency for identification (cf. Sampat and Williams, 2018; Righi and Simcoe, 2017).

[9] See Chapter 1, Section 1.2, for a more extensive description.

Figure 2.1: Timeline for the average opposed patent in our sample



Notes: The inventor panel is constructed using applications filed within ± 10 years around the first outcome of the respective inventor's first opposition proceeding.

procedure, the outcome of which is binding for all designated states, represents the only option to invalidate a patent right covering multiple European jurisdictions in a single, relatively inexpensive step.[10] Because it is a centralized, low-cost procedure, it is a frequent event. In total, around 6-7% of all granted patents are opposed before the EPO. Constructing a sample based on oppositions thus compares favorably with similar, more selective litigation setups such as the one by Galasso and Schankerman (2015, 2018). Figure 2.1 displays the timeline for the average opposed patent in our sample.

Oppositions may be filed by any party (except the patent holder herself) on the grounds that the subject matter is not new or inventive, that the invention is not sufficiently disclosed, or that the granted patent extends beyond the content of the application as filed. Consisting of three technically qualified examiners, the appointed "opposition division" has to decide whether the raised objections compromise the maintenance of the patent.[11] Typically, an oral proceeding before the opposition division is an integral part of opposition procedures, although being optional and dependent on a request. The opposition division usually states its decision verbally at the end of the oral proceeding.[12] Thus, the decision of the opposition division is not known to the parties until the day of the oral hearing. The conclusion of an opposition procedure is either the rejection of the opposition and hence the maintenance of the patent as is, the maintenance of the patent in amended form, or the invalidation of the patent in its entirety. Patent applicants and/or opponents may appeal against the decision of the opposition

[10]Currently, it takes on average more than four years from the filing of the application to the final decision on the grant of the patent (Harhoff and Wagner, 2009). However, in order to make complementary investment decisions or to claim injunctive relief before court, some applicants are interested in fast resolution of the patent examination and file a request for accelerated examination (Harhoff and Stoll, 2015).

[11]If necessary, the opposition division invites patent holder and opponent to file observations on the other party's communications. During this exchange of communications, the patent holder can amend the description, claims, and drawings of the patent.

[12]If no oral proceeding was requested, the opposition division simply issues its decision in writing. A written decision, including the opposition division's reasoning, typically follows one to six months later.

division.[13] Withdrawal statements can be made at any stage prior to the decision, but do not necessarily terminate the opposition proceedings. The opposition division has the option to continue the proceeding on its own motion (EPC Rule 84) and to make a decision on the patent's validity based on the grounds of opposition previously stated. Since the opposed patent may still end up being invalidated, settlements between opponent and patent holder are relatively rare events. More than 85% of all oppositions conclude with a decision by the opposition division. Since there are few settlements, almost all outcomes can be observed.[14]

The opposition division consists of a first examiner, a minute writer, and a chairman. The director of the patent's technical art unit appoints the members of the opposition division under consideration of the technical qualifications relevant to the patent.[15] As substantive examiners with the necessary technical qualification, the members of the examination division are natural candidates for the opposition division.[16] Concerning the participation of the grant examiners in the opposition proceeding, Article 19(2) of the European Patent Convention states that at least two of the members of the opposition division must not have taken part in the original examination and that the original examiner may not be the chairman of the opposition division. As shown in Chapter 1, the primary examiner frequently participates in the opposition proceeding of the same patent. Case law has established that patent holder and opponent cannot object to the director's decision regarding the appointment of a particular examiner to the opposition division.[17]

2.2.2 Data and Summary Statistics

We build a panel data set of opposed inventors' patenting activity using the European Patent Office's 2018 spring release of PATSTAT. Our panel of individual inventors covers 10 years before and after their first opposition decision at the EPO. Because we observe the universe of patent applications, we assign a value of zero patents to years in which inventors do not appear in the data. We identify inventors in two separate ways: (a) by their *doc_std_name*, correcting obvious errors using string similarity metrics, and (b) using the disambiguation provided by Morrison et al. (2017) for robustness. For our primary dataset, we obtain information on 65,415 inventors associated with 29,009 first oppositions filed between 1994 and 2010. Our data on oppositions is largely based on Chapter 1. As described in Section 1.3, the sample comprises (almost) all patents granted between 1993 and 2011 that became subject to an

[13]The involvement of the opposition division ends after the opposition phase. Appeal proceedings are heard by judges forming the Boards of Appeal, a separate and independent decision-making body within the EPO.

[14]The remainder consists predominantly of cases where the patent holder abandons the patent prior to the decision.

[15]The opposition division may be enlarged to a fourth member with a legal background, if there are complex legal questions to be resolved.

[16]The entire examination division regularly consists of the previous search examiner as first member and two examiners appointed by the director as second member and chairman.

[17]In principle, the opposition division's decision can be appealed on the ground of suspected lack of impartiality among the division members. However, there are only very few cases where this has occurred (see Chapter 1, Section 1.2.3).

opposition. For each patent granted by the EPO, the PATSTAT Register database allowed to extract information on whether an opposition was filed within the statutory period of nine months after grant and to identify the corresponding decision of the opposition division. For full information on the data construction process of the instrumental variable, especially the extraction of the examination and the opposition division members, see Section A.6 in the appendix.

Our main dependent variable is the number of patent applications that inventors file.[18] We further construct a dummy variable indicating whether inventors patent in a given year and compute the log of the number of patent applications in our main analysis to account for outliers. In addition, we distinguish subsequent applications by their technology area (same vs. different area than the invalidated patent) and split the sample by whether the invalidation occurred in the inventor's field of expertise (defined as the area in which she has filed most patents prior to her first opposition outcome). Besides, we analyze whether there has been a shift to national patenting or to WIPO applications. We also provide evidence on the impact of patent invalidation on the quality of subsequent applications. To this end, we use citation-weighted patent applications.

We additionally distinguish patents with and without novelty-threatening prior art, as indicated by so-called X-, Y-, and E-references in the EPO search reports. The reports classify prior art by their relevance for the patentability of the focal application. According to the EPO's examination guidelines (EPO, 2017), X-references indicate prior documents that are "such that when taken alone, a claimed invention cannot be considered novel or cannot be considered to involve an inventive step". Analogously, category Y indicates threats to patentability due to a combination of prior documents. Finally, category E labels prior patent documents that may conflict with the application, but were not disclosed at the time of filing.[19] This detailed information about the content of patent applications is an important advantage of using EPO data over data from other jurisdictions that do not contain reference types: We have an additional and interesting measure for patent quality.

The decision of the opposition division may have three mutually exclusive results for the opposed patent: "opposition rejected" (patent valid as is), "valid in amended form", and "invalid". Following the prior literature (Galasso and Schankerman, 2015, 2018) and Chapter 1, we classify the outcomes "invalid" and "valid in amended form" as an invalidation.[20] Following Chapter 1, we construct our analysis around the first decision of the opposition division,

[18]Throughout the paper, we construct all variables on the patent family level instead of using single patent applications.

[19]While the latter category is different in that the applicant could not have known this prior art from patent documents, in practice there are very few such references. We include this category because we believe this still reflects patents that are marginal in the sense that their patentability is threatened.

[20]Our results are robust to only coding "invalid" as an invalidation.

Table 2.1: Summary statistics

	N	Mean	SD	p10	p50	p90
Inventor level						
Inventor tenure at opp outcome date (yr)	65,415	10.675	5.050	5.892	9.046	18.204
No of app (pre av, per year)	65,415	0.577	0.892	0.100	0.300	1.300
No of app with XYE ref (pre av, per year)	65,415	0.418	0.685	0.000	0.200	1.000
No of app without XYE ref (pre av, per year)	65,415	0.159	0.294	0.000	0.100	0.400
No of cit5 weighted app (pre av, per year)	42,390	1.800	3.731	0.000	0.600	4.400
No of co-inventors (pre av, per year)	65,415	1.601	3.459	0.100	0.600	3.800
No of technology areas (pre av, per year)	65,415	0.378	0.417	0.100	0.200	0.800
1(Opposition in expert area)	65,415	0.770				
Opposition level						
1(Invalidated in opposition)	29,009	0.705				
1(Examiner on opposition board)	29,009	0.681				
DOCDB family size	29,009	10.258	9.101	4	8	18
App filing year	29,009	1996.5	4.897	1990	1997	2003
First outcome year	29,009	2004.2	4.961	1997	2005	2011

Notes: p10, p50 and p90 denote the 10th, 50th and 90th percentile, respectively. For indicator variables only the mean is shown. For the number of applications, (non-) XYE-referenced applications, citation weighted applications, co-inventors, and technology areas, inventor means are calculated over relative years prior to opposition outcome. The number of citation weighted applications counts the forward citations in a 5-year window after application filing, accumulated over all applications of the inventor in the given year relative to opposition outcome. It is shown for fewer inventors, since inventor-years are excluded for which the full 5-year citation window is not observable and inventors are only included in the panel regressions if they appear in at least five post periods. 1(Invalidated in opposition) denotes the endogenous variable of interest, 1(Examiner on opposition board) is the corresponding instrumental variable for examiner participation. Applications are counted on the DOCDB family level.

not the final outcome of a potential appeal.[21]

Table 2.1 shows the summary statistics of our sample. The upper panel shows descriptive statistics on the inventor level. At the date of the opposition outcome, the mean inventor in our data has been patenting at the EPO for more than ten years, filing a yearly average of 0.6 applications in 0.4 technology areas and working with 1.6 co-inventors per year. Inventors in opposition are therefore among the more productive. For over three quarters of inventors we observe the first opposition in the technology area they are most active in, which we refer to as the inventor's "expert area." The bottom panel contains descriptive statistics on the level of the opposed application. In over two thirds of oppositions, the original examiner is in the opposition division. Around two thirds of opposed patents are fully or partially invalidated

[21]The decision of the opposition division may be subject to appeal. In fact, almost half of all decisions in the sample are appealed. However, the reversal rate of the Board of Appeals is very low and skewed; i.e., pro-patent holder outcomes are more likely to be overruled in favor of the opponent than vice versa.

during the proceeding. The average DOCDB patent family comprises around 10 applications, the mean application filing year is 1997. The year of the first outcome of the opposition is 2004 on average, reflecting an average time period of around 7-8 years between application and opposition outcomes.

We additionally retrieve data on financial characteristics and on the size of applicant firms from Bureau van Dijk's Orbis database by matching to the assignees of the opposed patents in our sample. We use leverage, profitability, and R&D intensity to explore effect heterogeneity along applicant financial characteristics in Figure 2.5 and Table B.15. They are defined as total liabilities per total assets, EBITDA per total assets, and R&D expenses per total assets, respectively. As proxies for firm size, we extract the number of employees and revenues. Revenues are deflated by the US GDP deflator provided in the World Bank's World Development Indicators database.

2.2.3 Econometric Specification

It is difficult to empirically assess the effects of patent invalidation on affected inventors' subsequent patent filings. On the one hand, if some inventors' work becomes more "incremental" over time, then this will both increase the likelihood of invalidation and the number of subsequent applications. In this case, the coefficient reflecting the impact of invalidation on future patenting would be positively biased, even when accounting for inventor fixed effects. On the other hand, if patent quality decreases over time because inventors become less creative (e.g., due to fishing out of ideas or inventor age; see Jones, 2010), then a higher likelihood of invalidation may be correlated with a lower level of future patenting. In this case, the estimated impact would be negatively biased. Thus, any correlation between patent invalidation and the inventor's application propensity does not have a causal interpretation, with unclear direction of bias.

Our econometric setup therefore leverages the presence of the original examiner in the opposition division as an instrumental variable. The presence of the original examiner in the opposition division is a suitable instrument if it predicts the invalidation of the opposed patent (i.e., if it is relevant) and if it is orthogonal to future patenting of the opposed patent's inventors (i.e., if it is exogenous). The relevance condition is directly testable in our data. In the instrument's first stage, we estimate the following equation:

$$\text{Invalidated}_{i,t} = \alpha\,\text{Examiner participation}_{i,t} + a_t + b_{t-t_{\text{af}}} + c_i + \epsilon_{i,t}$$

where i denotes the inventor index, t the index for the year relative to the opposition outcome, and a_t the corresponding year effects. t_{af} is the year of application filing relative to opposition outcome and $b_{t-t_{\text{af}}}$ are the corresponding year effects.[22] Table 2.2 demonstrates that the

[22]The notation $\text{Invalidated}_{i,t}$ is short for $1(\text{Invalidated}_i)\,1(\text{Post}_t)$, the notation $\text{Examiner participation}_{i,t}$ is short for $1(\text{Examiner participation}_i)\,1(\text{Post}_t)$.

Table 2.2: First stage

	(1)	(2)	(3)	(4)
Estimation method	OLS	OLS	OLS	FE
Dependent variable	1(Invalidated)	1(Invalidated)	1(Invalidated)	1(Inv) × 1(Post)
Level of observation	Opposition	Opposition	Inventor	Inv panel
1(Examiner participation)	-0.071^{***}	-0.043^{***}	-0.044^{***}	
	(0.006)	(0.006)	(0.007)	
1(Exam part) × 1(Post)				-0.059^{***}
				(0.007)
App filing year effects	No	Yes***	Yes***	Implicit
Opp outcome year effects	No	Yes***	Yes***	Implicit
Year effects (rel to oppo)	No	No	No	Yes***
Year effects (rel to appl)	No	No	No	Yes***
Number of oppositions			29,009	29,009
Number of inventors				65,415
Observations	29,009	29,009	65,415	1,276,729

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Columns (1) and (2) show OLS-regressions on the opposition level of the indicator for invalidation on the examiner participation instrumental variable. Column (3) displays the results of an analogous OLS-regression on the inventor level. In Columns (2) and (3), year effects for the filing of the opposed application and for the first outcome of the opposition proceeding are included as controls. Column (4) shows a fixed-effects regression on the first-opposition inventor-panel. Due to inventor fixed effects, application filing year and opposition outcome year effects need not explicitly be controlled for. The post period is defined as the time window from 0 to 10 years after opposition. The standard errors reported in columns (1) and (2) are robust to heteroskedasticity, the standard errors in columns (3) and (4) are clustered at the opposition level.

original examiner's participation in the opposition division significantly decreases the opposed patent's likelihood of invalidation by around 4-7 percentage points. This corresponds to decrease of about 10% relative to the average rate of invalidation. Heteroskedasticity-robust first stage F-statistics are substantially above the common thresholds for weak instruments (Kleibergen and Paap (2006) Wald $F = 77.5$). Thus, the instrument meets the relevance condition.

The exogeneity condition is by definition untestable. However, there are a number of reasons why we believe that it holds. First and most importantly, the presence of the original examiner in the opposition division is mostly driven by the availability of *other* potential members with expertise in the particular technology. Thus, staffing at the EPO seems to be the primary driver of the original examiners' participation in the opposition division. This is confirmed by interviews conducted with EPO officials (see Chapter 1, Section 1.3.4). Figure 1.1

in the appendix presents further evidence, showing the likelihood of examiner participation over time: After the EPO introduced the "BEST" initiative to increase the number of available patent examiners, the likelihood of having the original examiner in the opposition division decreased substantially.[23] Second, the associated parties do not know the composition of the opposition division until the oral proceedings, i.e., the day of the decision on the opposition outcome. Therefore, lobbying in some direction is difficult. Third, attributes of the opposed application or the inventor have no explanatory power for examiner participation in our data: Table B.1 in the appendix shows that conditional on grant year, outcome year, and technology fixed effects, examiner participation in the opposition division is unrelated to a number of important application and inventor characteristics. In summary, the participation of the original examiner in the opposition division is likely exogenous to the future patenting activity of inventors.

We are interested in the impacts of patent invalidation on affected inventors' subsequent supply of ideas to the patent system. To assess these, we estimate the following main specification.

$$y_{i,t} = \beta\, \widehat{\text{Invalidated}}_{i,t} + a'_t + b'_{t-t_{\text{af}}} + c'_i + \epsilon'_{i,t}\,,$$

where $y_{i,t}$ is the outcome under consideration of inventor i in year t relative to opposition outcome. $\widehat{\text{Invalidated}}_{i,t}$ is the instrumented dummy variable indicating that the inventor's patent has been invalidated prior to year t relative to the opposition outcome, a'_t is a time period fixed effect and $b'_{t-t_{\text{af}}}$ are fixed effects which indicate years relative to the application filing. These account for life-cycle patterns in inventors' patenting. Finally, we add inventor fixed effects c'_i which remove any variation that is constant within inventors over time, such as innate ability. The standard errors are adjusted for clustering at the opposition level throughout the paper.

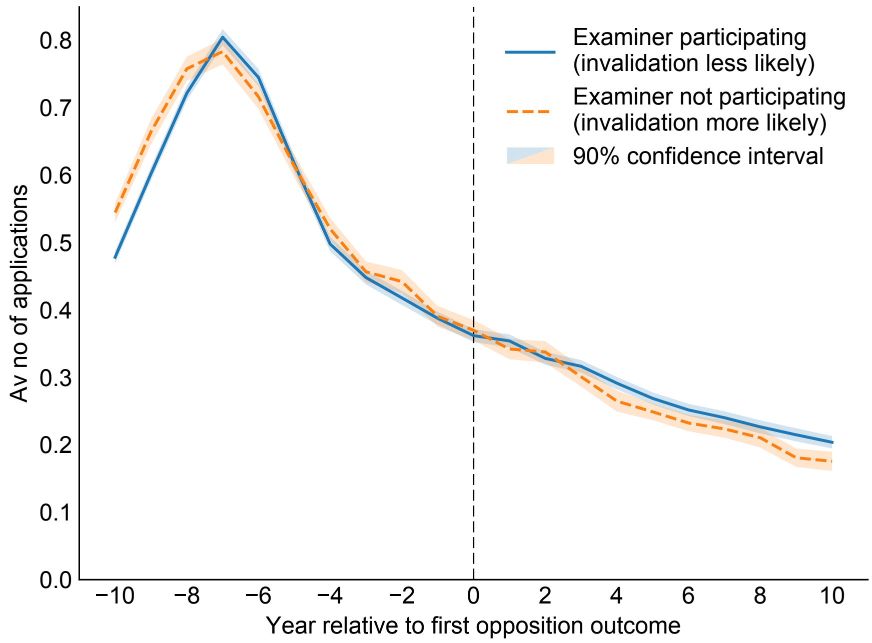
Our estimates can be interpreted as causal if conditional on inventor fixed effects and time period specific effects, the allocation of original patent examiners to the opposition division is exogenous to the future productivity of inventors. For the reasons outlined above, we believe this assumption is plausible.

2.3 Results and Discussion

In this section, we present and discuss our results. We start by providing evidence on the impact of patent invalidation on future patent applications of affected inventors. In this context, we also test for substitution of patenting to other authorities. We then assess the impact of invalidation on the quality of these applications. Subsequently, we investigate changes in the direction of patenting activities by using alternative dependent variables. Finally, we assess the

[23]The "BEST" ("Bringing Search and Examination Together") initiative aimed at having the search report and examination decision made by the same examiner. For this purpose, search examiners were trained and promoted to substantive examiners.

Figure 2.2: Inventor patenting around the outcome of opposition, by examiner participation



Notes: The figure shows the average number of patent applications in the years around the outcome of an inventor's first opposition. The blue solid line indicates inventors with opposition divisions that include the original examiner, the orange dashed line represents examiners with divisions that do not. Absence of the original examiner in the opposition division makes an invalidation more likely (see Table 2.2). Shaded areas indicate 90% confidence intervals around the mean.

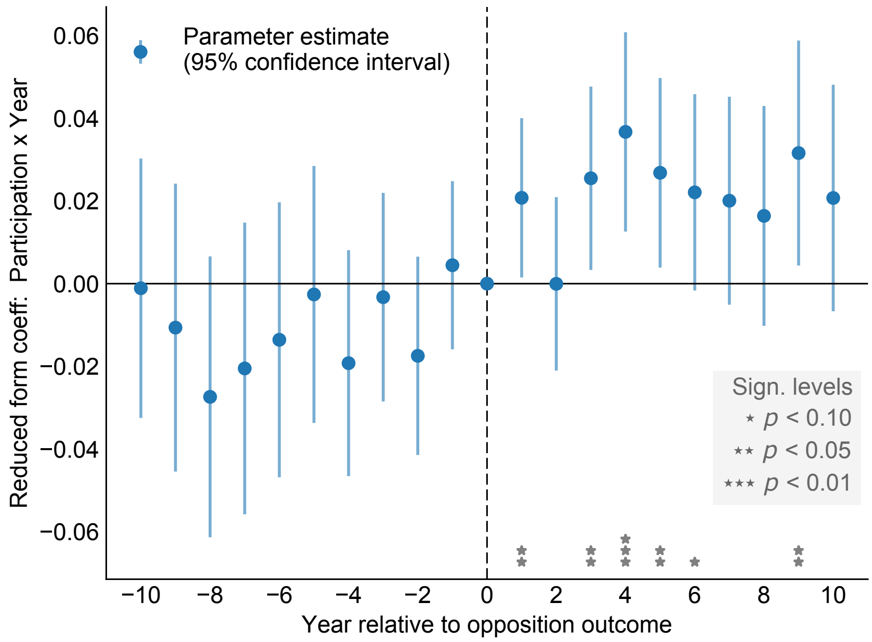
heterogeneity of our results through splits by applicant and inventor characteristics. In each case, we discuss in how far our results are compatible with potential underlying mechanisms.

2.3.1 Patent Counts

Figure 2.2 shows the time series of inventor productivity, split by whether the original examiner of the patent participates in the opposition division. Absence of the examiner is associated with a higher likelihood of invalidation. In line with our identification assumption, in the years leading up to the outcome of opposition, we find no visible differences in the average number of patent applications. After the outcome, however, inventors with participating examiners are relatively more productive. This effect starts around three years after the opposition outcome.

To assess whether these reduced-form effects are statistically significantly different from zero and whether they are robust to the inclusion of control variables and fixed effects, we repeat this analysis in an event-study framework. Figure 2.3 shows the time-varying reduced form impact of examiner participation on subsequent patent filings. In line with the prior graph, "lucky" inventors whose original examiner takes part in the opposition division subsequently file more patent applications. The effect materializes after around three years, as before. In line with the identification assumption, there are no statistically significant differ-

Figure 2.3: Reduced form effect of examiner participation on the number of applications



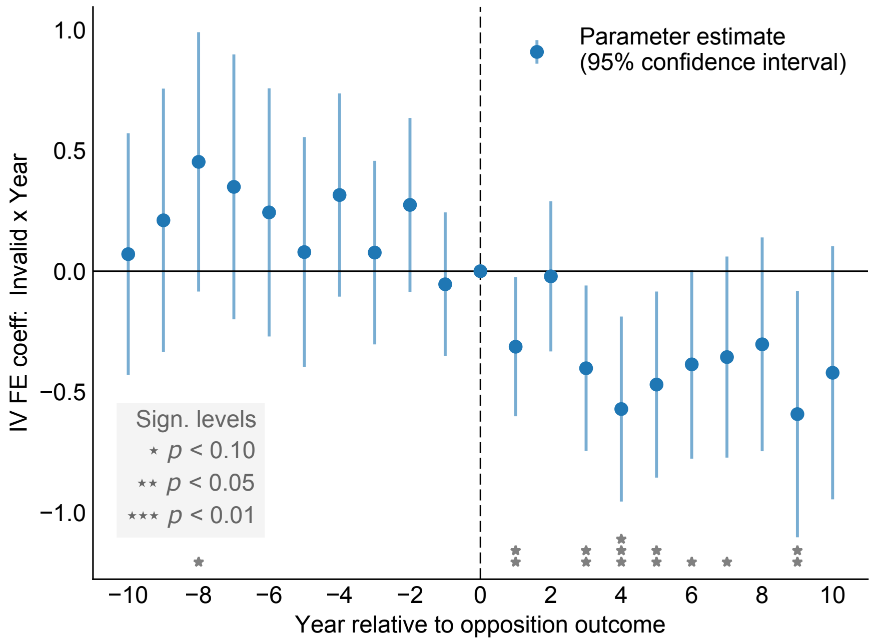
Notes: Coefficient estimates for years relative to the opposition outcome from a reduced form regression on (inventor, year relative to opposition outcome)-level of the number of applications on the examiner participation instrumental variable. The dependent variable $y_{it} = N_{\text{app},it}$ counts the number of applications on DOCDB family level which inventor i has filed in period t. The corresponding specification is given by $y_{it} = \sum_{\tau=-10}^{10} \beta_\tau \mathbf{1}(\text{Exam part}_i)\,\mathbf{1}(t = \tau) + a_t + b_{t-t_{af}} + c_i + \epsilon_{it}$. i and t are the indices for the inventor and the year relative to opposition outcome, respectively; fixed effects are described in the main text. $\tau = -10, \ldots, 10$ denotes years relative to opposition outcome. Error bars indicate the respective coefficient's 95% confidence interval. Stars at the bottom of the figure indicate the significance levels of the coefficients.

ences in patent filings before the decision of the opposition division.

Figure 2.4 shows the instrumented yearly effect of patent invalidation on the number of applications that inventors file. Again, there is no statistically significant difference between inventors in the treatment and in the control group before the opposition outcome. In response to the outcome, inventors whose patent was invalidated due to the absence of the original examiner in the opposition division file significantly fewer patent applications. The effect starts around three years after the opposition outcome and is statistically significantly different from zero in most years. In the appendix, Figure B.1 shows the instrumented impact of patent invalidation on the likelihood of filing for a patent. In line with our identification assumption, there is no differential application propensity in the years prior to the outcome of opposition. Yet, after an invalidation, inventors are significantly less inclined to file for a patent, with the effects being most pronounced around four years after the opposition outcome.

Table 2.3 displays the regression results of our preferred specification. Without instrumenting the invalidation decision, Column (1) shows the partial correlation of patent invalidation and the number of subsequent patent applications. The inventor fixed effects regression re-

Figure 2.4: Effect of invalidation on the number of applications



Notes: Coefficient estimates of invalidation for years relative to opposition outcome from an instrumental variable (2SLS) fixed effects regression on (inventor, year relative to opposition outcome)-level using Schaffer (2010). The dependent variable $y_{it} = N_{\text{app},it}$ counts the number of applications on DOCDB family level which inventor i has filed in period t. The corresponding specification is given by $y_{it} = \sum_{\tau=-10}^{10} \beta_\tau \mathbf{1}(\text{Invalidated}_i)\mathbf{1}(t=\tau) + a_t + b_{t-t_{af}} + c_i + \epsilon_{it}$. i and t are the indices for the inventor and the year relative to opposition outcome, respectively; fixed effects are described in the main text. The interactions are instrumented with $z_{i,t}^{\tau} = \mathbf{1}(\text{Examiner participation}_i)\mathbf{1}(t=\tau)$, where $\tau = -10, \ldots, 10$ denotes years relative to opposition outcome. Error bars indicate the respective coefficient's 95% confidence interval. Stars at the bottom of the figure indicate the significance levels of the coefficients. We find similar results for a dummy dependent variable $y_{it} = 1(N_{\text{App},it} > 0)$, indicating whether inventor i has filed a patent application in period t (see Figure B.1 in the appendix).

turns a negative, significant coefficient of patent invalidation. Because of the potential endogeneity of the invalidation decision, we use the examiner participation instrumental variable in all subsequent columns. In a first step, Column (2) shows the reduced form coefficient. The presence the original examiner (lower likelihood of invalidation) increases subsequent patent applications. Column (3) presents the instrumented coefficient of invalidation. It shows that the magnitude of the effect is substantial: On average, the local average treatment effect implies that inventors file half a patent less per year. The sizeable difference to the coefficient in Column (1) indicates that an important source of endogeneity is time-varying and cannot be controlled for by individual fixed effects. This is in line with the findings of Galasso and Schankerman (2015, 2018). Column (4) shows that our results are robust to using the log number of applications to account for the skewness of the dependent variable. Following invalidation due to examiner (non-)participation, inventors file around 20% fewer patents. To get a sense of whether the productivity effects are driven by the extensive or the intensive margin, Column (5) shows the effect on the probability of filing a patent application at all in

Table 2.3: Effect of invalidation: Number of applications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Estimation method	FE	FE	IV FE	IV FE	IV FE	IV FE	IV FE
Dependent variable	N_{app}	N_{app}	N_{app}	$\log(1+N_{\text{app}})$	1_{app}	$N_{\text{app}}^{\text{nat}}$	$N_{\text{app}}^{\text{WO}}$
Application authority	EP	EP	EP	EP	EP	National	WIPO
1(Invalidated) × 1(Post)	−0.042***		−0.515***	−0.204***	−0.151***	−0.001	0.082
	(0.008)		(0.150)	(0.049)	(0.038)	(0.103)	(0.104)
1(Exam part) × 1(Post)		0.031***					
		(0.008)					
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Underidentification test			76.9	76.9	76.9	76.9	76.9
Weak identification test			77.5	77.5	77.5	77.5	77.5
Number of oppositions	29,009	29,009	29,009	29,009	29,009	29,009	29,009
Number of inventors	65,415	65,415	65,415	65,415	65,415	65,415	65,415
Observations	1,276,729	1,276,729	1,276,729	1,276,729	1,276,729	1,276,729	1,276,729

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Fixed Effects (Column 1), reduced form fixed effects (Column 2) and instrumental variable (2SLS) fixed effects (Columns 3–7) regressions on (inventor, year relative to opposition outcome)-level. Columns (1)–(3) use different specifications for the same dependent variable, the number of applications. Columns (3)–(5) use the same IV FE estimator for different functional forms of the dependent variable: a linear-, a log- and an indicator variable specification. To test whether the reduction is driven by a shift to national or transnational patenting, Columns (6) and (7) display the effect on the number of patent families, which do not contain an EP application. First, in Column (6), only patent families are counted, which contain a national application in a European country, but do not contain EP or WIPO applications. Second, in Column (7), only patent families are counted, which contain at least one WIPO application, but no EP application. For Columns (6) and (7), we have used the same set of inventors as in the preceding columns. If we restrict the sample to inventors who have at least one "national" or at least one "WIPO" patent family in our sampling period, we find qualitatively similar results. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010). For an analogous table using the Morrison et al. (2017) inventor disambiguation, see Table B.6 in the appendix. For analogous tables on the subsamples of European and foreign inventors, see Tables B.7 and B.8.

a given year. Having a patent invalidated in opposition reduces the likelihood of subsequently filing a patent by 15 percentage points.

In principle, the decrease in patent applications after invalidation could be independent of innovative activities and merely reflect a change in filing strategies. First, inventors, their firms, or their patent attorneys could steer patenting away from the EPO and instead patent directly at the desired national patent offices, avoiding a potential centralized opposition procedure. To investigate this channel, Column (6) uses the number of patent families with (European) national patent applications as the dependent variable (not counting patent families that contain EP or WIPO applications). We find no change in national patenting. Alternatively, innovators could substitute EP patenting with WIPO's centralized application procedure. To investigate this possibility, the dependent variable in Column (7) counts patent families containing a WIPO, but no EP application. While the point estimate is positive, it is not significantly different from zero. Besides, its magnitude is substantially smaller than our main effects. Our results therefore reflect an actual decrease in patent filings rather than a shift to substitute patent authorities. Second, inventors or their firms could be more selective in choosing inventions for patenting and could be more reluctant to split connected inventions into several applications. In either case, one would expect an immediate change in filing behavior. However, Figure 2.4 shows that the invalidation effect is most pronounced 3-5 years after the opposition outcome. This could reflect the delayed effect of a real change in innovative activities.

In the appendix, we show that our main productivity results are robust to excluding outliers (such as the top 5% of inventors with respect to prior filings and technology areas) and to restricting the sample to inventors who patent both before and after the opposition outcome (Table B.5). In Table B.6, we also show that our results are unaffected by using the alternative inventor disambiguation by Morrison et al. (2017). Finally, in Tables B.7 and B.8 we show that findings are very similar for European and non-European inventors.

Given that we instrument invalidation by the presence of the original examiner in the opposition division, our estimates reflect local average treatment effects. To explore whether compliers differ from the overall population of patents in opposition, in Appendix B.2 we follow Angrist and Pischke (2009) and document the relative incidence of certain applicant and inventor characteristics among compliers. Note that in our context, compliers are inventors whose application was invalidated *because* the original patent examiner did not participate in the opposition division. Table B.2 shows the complier share, which lies at around 7% on average. Table B.3 examines the characteristics of complier applications relative to the general population of patents in opposition. On average, applications whose opposition outcome changes with the examiner's presence in the opposition division are less likely to have more than two inventors and to receive above median citations. Their family size is larger, but this is at the margin of statistical significance. Table B.4 conducts an analogous comparison for inventor characteristics. Inventors of complier patents are more likely to have below median tenure and to have filed patents in a lower number of technology areas before the invalidation.

They have also filed fewer patents before the opposition, but the difference is insignificant. In summary, however, complier patents do not differ substantially from the average patent in opposition.

2.3.2 Patent Quality

While the effects on the number of patent applications are interesting in their own regard, a goal of post-grant review systems is to increase the *quality* of applications to the patent system. An assessment of the consequences of invalidations in opposition therefore critically depends on the impact on patent quality. To this end, we explore the effect on different proxies for patent quality in Table 2.4. We first split the dependent variable by whether subsequent applications are linked to novelty-threatening prior art through an X-, Y-, or E-reference in the EPO examiner's search report. The first column shows that the number of patent applications containing such references decreases significantly and that the effect is even stronger than the baseline estimate. In contrast, Column (2) shows that the number of patent applications which do not contain such references even slightly increases. Column (3) uses a standard measure of patent quality by weighting applications with forward citations received in a five-year window after filing. The effect is significantly negative. Column (4) repeats this exercise counting citations only for those subsequent applications that do not contain X-, Y-, or E-references. Here, we do not find a statistically significant effect, and the point estimate is negative.

Overall, this table shows that while invalidation in opposition decreases subsequent patent filings, this effect is driven by a decrease in applications with novelty-threatening prior art. This sheds a favorable light on the opposition procedure at the EPO: Following an invalidation, inventors decrease applications that are at risk of being invalidated because of a lack of novelty or the absence of an inventive step. This finding is in line with a positive impact of invalidation in opposition on the average quality of subsequent filings. The effects for non-XYE-referenced applications are ambiguous, given that the number of such applications increases significantly while we do not find a positive impact on their forward-citations.[24]

In principle, shifts from patenting to secrecy[25] could be driving our results, since private incentives for nondisclosure may differ for applications at the margin of patentability. Generally, firms and inventors will prefer to keep inventions secret if the expected benefit from filing compares unfavorably with disclosure and the risk of invalidation. Applications with X, Y, or E search report references are likely less novel and insightful than the average patent (Harhoff and Wagner, 2009). On the one hand, they will thus be subject to a higher risk of invalidation. On the other hand, filing such applications will reveal little technological information to competitors. Besides, as a signal about future firm strategy they should not be more informative

[24]In the appendix, we show in Table B.9 that our results are very similar when using the disambiguation by Morrison et al. (2017). In Tables B.10 and B.11 we further show that our findings are similar for European and non-European inventors.

[25]For an extensive review of motives to choose between patenting and secrecy, see Hall et al. (2014), who discuss results of firm-level surveys, the theoretical literature, and empirical analyses.

Table 2.4: Effect of invalidation: Quality of applications

	(1)	(2)	(3)	(4)
Estimation method	IV FE	IV FE	IV FE	IV FE
Dependent variable	$N_{\text{app}}^{\text{XYE}}$	$N_{\text{app}}^{\text{non-XYE}}$	$N_{\text{app}}^{\text{cit5}}$	$N_{\text{app}}^{\text{cit5, non-XYE}}$
1(Invalidated) × 1(Post)	-0.637^{***}	0.122^{**}	-1.633^{**}	-0.249
	(0.130)	(0.051)	(0.718)	(0.181)
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes***
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***
Underidentification test	76.9	76.9	28.3	28.3
Weak identification test	77.5	77.5	28.6	28.6
Number of oppositions	29,009	29,009	18,742	18,742
Number of inventors	65,415	65,415	42,390	42,390
Observations	1,276,729	1,276,729	811,006	811,006

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Column (1) shows the causal effect of invalidation on the number of applications which receive an X-, Y-, or E-reference in the EPO examiner's search report. Such references are indicative of potentially novelty destroying prior art and hence constitute a proxy for subsequent failure to receive a patent grant. Column (2) presents regression results for the number of applications which do not receive such a reference. While the number of XYE-cited applications significantly decreases, the number of patent families, which are more likely to receive a grant, increases. Column (3) displays the effect on the number applications weighted by the forward citations they receive in a five-year window after filing. Column (4) uses the number of non-XYE-cited applications, weighted by the five-year forward citation number, as the dependent variable. The citation-weighted variables in Column (3) and (4) are winsorized at the 99th percentile to mitigate noise introduced by outliers. Without winsorizing, we obtain coefficients of very similar magnitude, but larger standard errors. To allow for a full observation of the citation window, the sample is truncated five years earlier, resulting in fewer observations. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010). For an analogous table using the Morrison et al. (2017) inventor disambiguation, see Table B.9 in the appendix. For analogous tables on the subsamples of European and foreign inventors, see Tables B.10 and B.11.

than the average patent application. Hence, secrecy should be more attractive for inventions that constitute a substantial technical advance (cf. Anton and Yao, 2004; Zaby, 2010). Given that the decrease after invalidation is concentrated in applications of questionable novelty, it seems implausible that a shift to secrecy is the main driver of the effect.

From a welfare perspective, decreases in disclosure matter, given that enhancing knowledge transfer is one of the core intended benefits of the patent system (Williams, 2017). In view of the decrease in forward-citation-weighted applications, this might be of particular concern. However, given that the decrease in forward citations is driven by applications of uncertain novelty, the observed forward citation patterns might reflect a replacement effect: Subsequent applications could have also referred to closely related precedent work instead of the non-novel application itself. In such a case, decreases in disclosure might not be a first-order concern.

2.3.3 Direction of Patenting

In Table 2.5, we explore in how far our results can be explained by changes to the direction of patenting. Inventors may shift their efforts to other technology areas in response to an invalidation. Inventors could also only frame their patents differently to steer applications to examiners from other EPO technology units. In Columns (1) and (2) of Table 2.5 we split subsequent patent applications by whether they were filed in the same area than the invalidated patent or another area. We find similar effects for both.

Galasso and Schankerman (2018) find that after an invalidation of litigated patents, firms decrease patenting especially when the invalidated patent was in their core technology area. In Columns (3) and (4) we thus split our sample by whether the invalidation occurred in the inventor's expert technology area. We find very similar effects for both, although the estimates are imprecise when the invalidation occurs in a different area than the inventor's expert technology. In line with the findings of Galasso and Schankerman (2018), the effects for invalidations in the expert area are mostly attributable to fewer filings in the same technology area (Column 5), which is also where most filings occur. However, we also find significant effects for subsequent applications in other areas (Column 6).[26]

2.3.4 Applicant and Inventor Heterogeneity

To assess the heterogeneity of the invalidation effect on subsequent patent filings, we split our samples by applicant and inventor characteristics. Figure 2.5 shows how results differ with respect to patent applicants. As can be seen from the figure, the confidence bounds of all subsamples overlap with the point estimate of the overall sample. If anything, those firms with above median patent applications per employee are less affected than those below the median, unlike in Galasso and Schankerman (2018). An absence of substantial effect

[26]In Tables B.13 and B.14 we show that these results are similar for European and non-European inventors.

Table 2.5: Effect of invalidation: Direction

	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE
Dependent variable	$N_{\text{app}}^{\text{same ar}}$	$N_{\text{app}}^{\text{other ar}}$	N_{app}	N_{app}	$N_{\text{app}}^{\text{same ar}}$	$N_{\text{app}}^{\text{other ar}}$
Subsample	Full	Full	Non-Expert	Expert	Expert	Expert
1(Invalidated) × 1(Post)	−0.282***	−0.233**	−0.567	−0.503***	−0.350***	−0.153**
	(0.098)	(0.091)	(0.365)	(0.153)	(0.121)	(0.061)
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes**
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Underidentification test	76.9	76.9	26.5	68.4	68.4	68.4
Weak identification test	77.5	77.5	26.7	68.9	68.9	68.9
Number of oppositions	29,009	29,009	9,915	25,090	25,090	25,090
Number of inventors	65,415	65,415	15,047	50,368	50,368	50,368
Observations	1,276,729	1,276,729	291,083	985,646	985,646	985,646

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

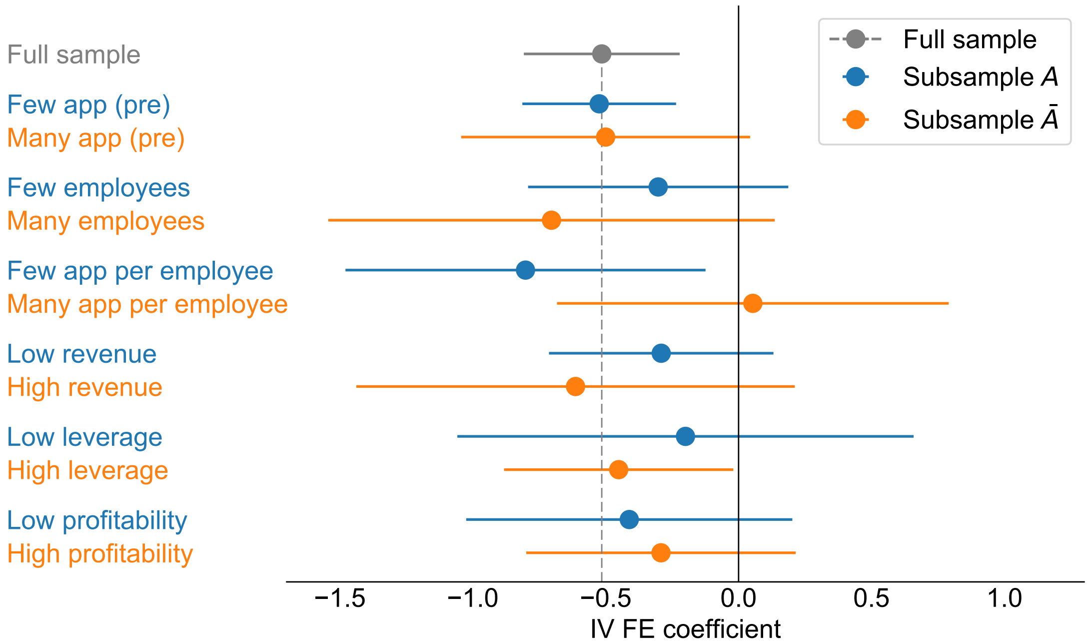
Notes: Columns (1) and (2) present the effect of invalidation on the number of applications in the same and other technology areas as the opposed patent, respectively. Column (3) shows the invalidation effect for inventors who experience their first opposition outside their area of expertise, i.e., outside the area in which they have filed most patents prior to opposition outcome. Columns (4)-(6) show the effect for the complimentary subsample of inventors whose first opposition is in their expert technology area. Column (4) presents the effect on the all applications, Columns (5) and (6) present the effects on applications in the same and other areas as the opposed patent, respectively. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010). For an analogous table using the Morrison et al. (2017) inventor disambiguation, see Table B.12 in the appendix. For analogous tables on the subsamples of European and foreign inventors, see Tables B.13 and B.14 in the appendix.

heterogeneity along applicant characteristics would be surprising if the impact of invalidation on subsequent filing behavior was a function of the effect on the firm. Therefore, explanations proposed in the literature, such as impacts on firm survival (Farre-Mensa et al., 2017; Gaulé, 2018), are unlikely to drive our effects.[27] However, our results complement the finding that firm heterogeneity only accounts for around 3-5% of the variance in inventor's innovative performance (Bhaskarabhatla et al., 2017).

In addition to applicant characteristics, we explore the invalidation effect's heterogeneity with respect to inventor characteristics. Figure 2.6 displays the results of this exercise. Here,

[27]Note that due to data availability and the matching process between Patstat and Orbis, sample sizes are considerably smaller for some of the regressions, going along with weaker first-stage F-statistics (see Table B.15). Undocumented regressions show that inventors who work for firms with available data belong to a slightly more impacted subsample.

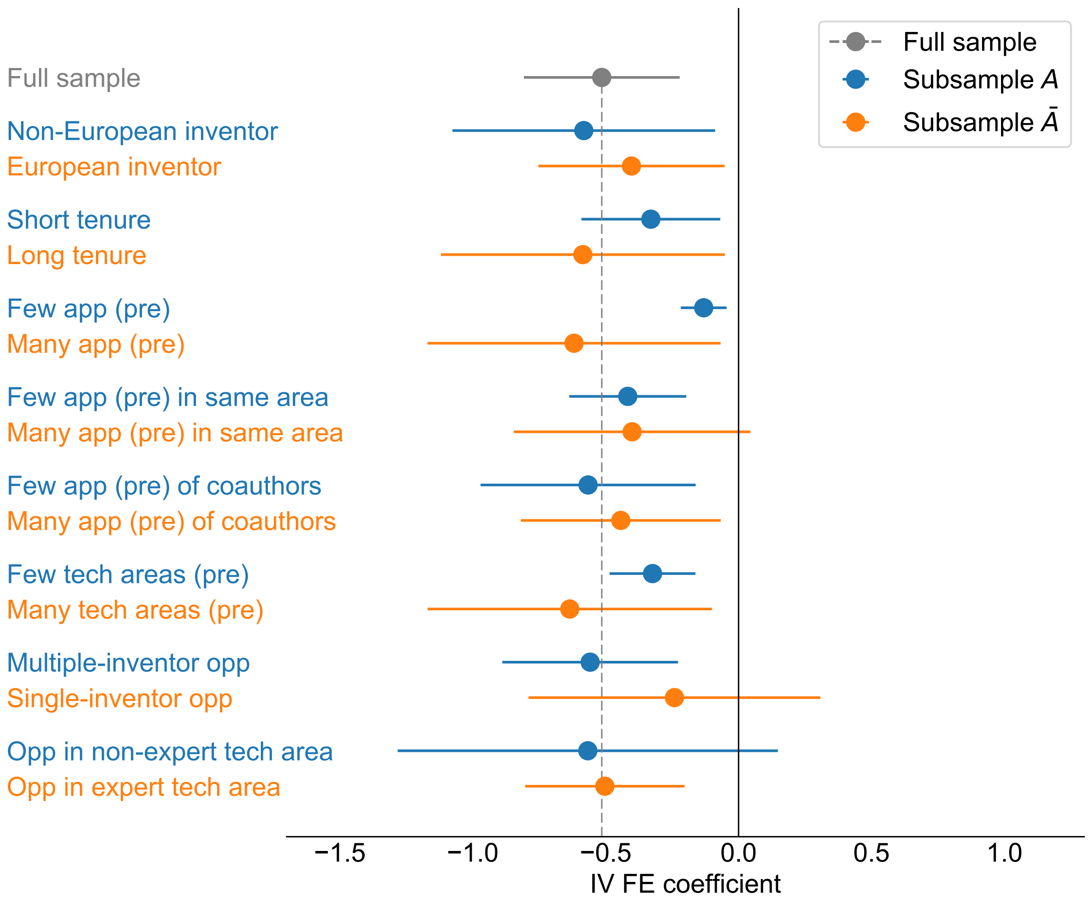
Figure 2.5: Effect of invalidation on number of applications: Applicant heterogeneity



Notes: Coefficient estimates of invalidation from instrumental variable (2SLS) fixed effects regressions on (inventor, year relative to opposition outcome)-level using Schaffer (2010). The baseline regression on the full sample is shown in gray, together with a dashed line for the ease of comparison. Pairs of blue and orange markers indicate coefficients in complementary subsamples. For each pair, the sample is split at the median of an applicant characteristic: the prior number of applications, the number of employees, the number of applications per employee, revenue (deflated), leverage (defined as total liabilities over total assets), and profitability (defined as ebitda over total assets). The dependent variable is in each case $y_{it} = N_{\text{App},it}$. Error bars indicate the respective coefficient's 95% confidence interval. For the corresponding regression table, see Table B.15 in the appendix.

differences between subsamples are somewhat more pronounced. Inventors with a below median number of patent filings before the opposition are less impacted than those with above median applications. Analogously, those who filed patents in a below median number of technology areas before the opposition are less affected by an invalidation. Consistently, those having below median tenure (defined as the time since their first patent application) are less impacted as well, even though this difference is smaller. These results do not support explanations proposed in the literature, such as inventors receiving information about the quality of their ideas (Chan et al., 2014; Azoulay et al., 2015, 2017), changes in inventor income streams (Harhoff and Hoisl, 2007; Toivanen and Väänänen, 2012), or other impacts on inventor careers such as labor mobility (Melero et al., 2017). If any of these explanations were true, we would expect larger effects for young and inexperienced inventors who are still uncertain about their productivity and who still have their careers ahead of them. However, if anything, our results point towards these inventors being less affected by invalidations.

Figure 2.6: Effect of invalidation on number of applications: Inventor heterogeneity



Notes: Analogous to Figure 2.5, but using inventor instead of applicant characteristics. The IV FE coefficient of $\mathbf{1}(\text{Invalidated}_i)\,\mathbf{1}(\text{Post}_t)$ is shown for the full sample (gray, dashed gray line), and for sample splits by inventor origin, tenure, number of applications, number of applications in the same technology area as the opposed patent, co-inventor patenting experience, number of technology areas in prior applications, and by whether the opposition occurred in the inventor's area of expertise, i.e., the area in which she has filed most patents prior to opposition outcome. The dependent variable is in each case $y_{it} = N_{\text{App},it}$. Error bars indicate the respective coefficient's 95% confidence interval. For the corresponding regression table, see Table B.16 in the appendix.

2.4 Conclusion

We study the impact of patent invalidation during post-grant review on affected inventors' subsequent patenting. In this context, patent opposition at the European Patent Office provides a unique setting for causal identification. It is inexpensive and frequent, rendering our sample much less selective than those in previous work. In addition, the rich EPO data allows us to study responses in more detail. To identify causal effects, we leverage the random participation of the patent's original examiner in the opposition division as an instrumental variable for invalidation. The presence of original examiners decreases the likelihood of invalidation and is largely driven by the availability of *other* qualified personnel at the EPO.

Our results show that inventors file fewer patents in response to an invalidation. This effect is driven by a decrease in the number of subsequent applications associated with novelty-threatening prior art. It thus appears unlikely that a shift towards secrecy fully explains the results. We can further exclude that we observe a mere substitution of patenting at the EPO – the effect is not driven by patenting shifts to national authorities or the WIPO. If firm success was driving the invalidation effect, differences across applicants would be likely. However, our findings apply broadly throughout the sample, without strong heterogeneities along applicant characteristics. Our data points to slight differences for inexperienced inventors, who appear to be less impacted by an invalidation. If inventor mobility or signals about inventor or idea quality were mainly underlying the effect, we would expect the opposite. Assessing the relative importance of different channels of the invalidation effect may constitute an interesting avenue for future work.

Being one of the first to provide evidence on the consequences of patent invalidation for *individual* inventors, this paper complements recent research on the firm level. Importantly, our study further contributes to the assessment of social costs and benefits of post-grant review. Despite having gained substantial interest, empirical evidence on the impacts of opposition procedures remains scarce. While invalidations in opposition seem to decrease the quantity of inventors' subsequent applications, we find that the effect is concentrated in low-quality filings. From this angle, post-grant review at the EPO appears to benefit the patent system.

3

Selection of Patents for Litigation

Inferring the Distribution of Patent Quality

3.1 Introduction

To provide ex-ante incentives to technological innovators, most countries rely on patents. In principle, by granting a temporary monopoly right, under-provision of non-excludable inventions is mitigated. However, concomitant deadweight loss and slower economic growth may outweigh social benefits if existing patent rights stifle competition and hinder subsequent innovation. This concern is of particular relevance for patents of dubitable quality, of insufficient inventive step, or of indeterminate scope. Patents comprising negligible advances can create harmful uncertainty for competing innovators, when an accurate assessment of legal stability is elusive. Even if expectations can consistently be formed, substantial risk arises for competitors from unjustified infringement suit, from costs associated with licensing or inventing around, and from increased search costs. While it is no surprise that the quality of granted patents has been subject to substantial debate in recent years[1], results illuminating the underlying validity distribution remain scarce. To a large extent, this is a consequence of the fact that only around 1% of all patents are ever scrutinized in nullity proceedings.[2] The high

[1]See for example Federal Trade Commission (2003); Lemley and Shapiro (2005); Jaffe and Lerner (2007); Farrell and Shapiro (2008); Bessen and Meurer (2008); Hilty (2009); Mann and Underweiser (2012); Henkel and Zischka (2016); Schankerman and Schuett (2016).

[2]See Section 3.8 and Footnote 34 for a detailed description of the legal institutional framework in Germany.

invalidation rates observed in court rulings may thus be a result of substantial selection, and a poor estimator for quality in the patent population.

This paper characterizes latent properties of the patent litigation system and studies the prevalence of low-quality patents. To this end, I develop and calibrate a divergent expectations model[3] of the selection of patents for litigation. To overcome the difficulties of extrapolation outlined above, patent heterogeneity is represented in a multi-dimensional fashion, comprising both legal stability and value. In the model, a patent holder, whose intellectual property grants him exclusion rights in a Cournot product market, is faced with a symmetric competitor. While the associated monopoly and duopoly rents are known exactly, both parties observe the focal patent's inventive step with error, leading to value-dependent divergent expectations about its validity.[4] In a first stage, the potential infringer decides whether to enter the market protected by the focal patent. Disputes are thus endogenous. In a second stage, resembling the setting developed by Priest and Klein (1984), the two parties can either come to a settlement of their dispute, or enter litigation if expectations are sufficiently diverse given the commercial value of the patented invention. Courts then reveal the true inventive step[5], and judge a patent to be valid or invalid. The resulting market structure is either a monopoly, if the competitor chooses not to enter or if the patent is judged valid and infringed, or a duopoly, if the dispute is settled or if the patent is invalidated.

To characterize the actual state of the patent litigation system, I exploit the imposed structure of the model and calibrate its parameters to reproduce litigation and invalidation rates observed for German (DE) patents and the German components of European (EP) bundle patents. Of the around 1% of DE and EP patents which become subject of an nullity suit, more than three quarters are judged fully or partially invalid by the German Federal Patent Court (Bundespatentgericht, BPatG) (Hess et al., 2014).[6]

The main results of the study are the following. First, the share of latently invalid patents is considerably lower for the patent population in its entirety (35-50%) than for the subsamples of settled (90-92%) and litigated patents (75%, fixed at empirical rate). I define patents to be "latently invalid," which have successfully passed examination at the patent office, but which would be fully or partially invalidated in court if they became subject of annulment proceedings. This result contrasts related findings in the literature, in which estimates range from 65% to above 80% (Henkel and Zischka, 2016; Schankerman and Schuett, 2016).[7] Consequently, the present paper challenges conclusions relating to the inefficiency of the patent

[3] The divergent expectations framework was originally developed by Priest and Klein (1984).

[4] All probability distributions are common knowledge, uncertainty about them is not part of the model. Parties are thus able to form consistent expectations.

[5] Whether one views courts to reveal or to define the true inventive step, is only a semantic matter. See the discussion in Section 3.8 for details.

[6] Hess et al. (2014) do not find significant differences in the invalidation rates for German patents and the German components of European bundle patents. Henkel and Zischka (2016) report very similar invalidation rates for first instance (BPatG), second instance (Bundesgerichtshof, BGH) and combined first or second instance decisions.

[7] I will return to a discussion of potential origins of these differences in Section 3.5.

office in weeding out applications of poor quality. A latent invalidity rate of about 40% instead of 80% leaves considerably more room for the view that patent offices may be operating within the range of a socially optimal "rational ignorance" of true validity (Lemley, 2001).

Second, a ceteris paribus simulation of policy reform shows that raising the courts' judgment threshold for validity is effective in stimulating entry of competitors to otherwise monopolistic product markets. Third, while such reform is predicted to go along with increased litigation rates, its adverse impact can be dissolved by raising court fees in a feasible manner.

Fourth, the calibrated model displays substantial selection with respect to patented invention value, in line with findings in the empirical literature (Lanjouw and Schankerman, 2001, 2003; Harhoff et al., 2003a). Patents that never become subject of a dispute, due to lack of market entry, constitute the majority of all patents (75%). Corresponding patented invention values average to 0.76 of the population mean. Settled patents (24%) have a value of about 1.4 times the average. While this is already indicative of selection with respect to value, it becomes substantial for litigated patents. Their average patented invention value is 8.7 times higher than the population mean. Furthermore, the model predicts that patents with an invention value below a threshold of approximately 400 k€ never enter litigation. Especially the latter prediction may be testable in future empirical work.

Limitations of the pursued approach include the abstraction from bifurcated courts for infringement and invalidation (as in the German system), from patent thicket structures, from asymmetric litigants and non-practicing patent holders, from licensing to downstream firms, and from systematically varying legal and settlement costs. Further calibrations exploring heterogeneity across technology areas with different litigation and invalidity rates and across jurisdictions with alternative rules for the allocation of legal costs, constitute interesting avenues for future research. In addition, a comprehensive welfare assessment requires the development of a holistic general equilibrium model, comprising an explicit representation of input factors and knowledge production functions.

The present paper is related to different strands of literature. It relates most closely to recent work on the optimal structure of examination at the patent office, pre- and post-grant fees, and challenges in courts by Schankerman and Schuett (2016). The authors find that pre-grant fees are more effective in deterring low-quality applications than post-grant fees. Calibrations of their model to US data suggest that patenting is socially excessive, and that examination at the patent office does not eliminate low-grade patents. With regard to patent litigation in particular, the following studies are related to the research agenda of this paper. Crampes and Langinier (2002) develop a model of patent litigation with endogenous monitoring effort of the patent holder and an endogenous entry decision of the imitator and analyze it in both simultaneous and sequential game frameworks. Also focusing on an endogenous selection of disputes, Bessen and Meurer (2006) set out a model in which the incumbent's and the entrant's investments modify the probability distribution of successful suit in their favor, and derive empirically testable implications. Farrell and Shapiro (2008) study the welfare implications of determining patent validity prior to licensing as compared to "probabilistic patents"[8] which are valid with a certain probability only. Their model describes licensing to downstream oligopolists, with royalty rates dependent on patent strength. A divergent expectations model in the context of patent licensing is developed by Marco and Walsh (2006). The authors find that asymmetric stakes do not substantially impact litigation and invalidation rates. Meurer (1989) devises a model of patent litigation and settlement with asymmetric information and discusses implications for patent licensing. A less closely related model discussing informational spillovers from patent litigation in the context of multiple firm entry is developed by Choi (1998). In the larger context of litigation theory, Priest and Klein (1984) develop a model for the selection of disputes for litigation, as opposed to settlement. Conditional on the true characteristics of the dispute relative to a given legal standard, both parties form independent expectations of the likelihood of plaintiff and defendant verdicts. The negotiation stage of the present paper's model is based on this framework of divergent expectations.[9] Bebchuk (1984) studies a model of litigation and settlement under informational asymmetry and explores how the respective likelihoods change under different assumptions for stakes, the nature of information, and the allocation of litigation costs.[10]

Concerning empirical approaches, a study by Henkel and Zischka (2016) poses the most closely related research question. It examines correlates of selection into first and second instance annulment proceedings[11] and estimates shares of latent invalidity for the patent population. The authors conduct interviews and surveys among experts and legal practitioners, from which they deduce that patents entering annulment proceedings are comparably likely to be revoked as an average patent. This approach is supplemented by estimating Heckman selection models on a dataset of BPatG and BGH court decisions.[12] Out-of-sample predictions for a set of matched patents unchallenged in annulment proceedings[13] suggest that the share of latently invalid patents in the patent population is larger than 80%. De Rassenfosse et al. (2016) compile a sample of patents filed in at least two of the five largest patent offices. To account for differences in the offices' validity thresholds, they estimate a latent variable model. They find single-digit rates of "weak" patents that are inconsistently granted with regard to the respective office's threshold. However, in addition to thresholds, patent offices are hardly comparable in their general examination procedure, e.g., concerning refusals and options for deferment.

[8]For a discussion of "probabilistic patents" also see Lemley and Shapiro (2005).

[9]For empirical tests of the Priest and Klein (1984) model across different case types, see Siegelman and Waldfogel (1999). For intellectual property cases, the authors find that structural estimates of the Priest and Klein (1984) model are in accordance with independent measures of the model parameters.

[10]For an empirical comparison of the divergent expectations and the asymmetric information frameworks, see Waldfogel (1998).

[11]The first instance being the German Federal Patent Court (BPatG) and the second instance being the German Federal Court of Justice (BGH).

[12]For identification, the authors leverage the size of the defendant, claiming that this variable is highly relevant for the selection equation, while it does not enter the outcome equation. The authors do not find a significant effect of the Heckman correction.

[13]The matching is based on the patents' application filing month. Plaintiff size variables are adjusted to the average of adjudicated patents.

Lanjouw and Schankerman (2001) compile a dataset of patents litigated at US district courts and show that the likelihoods of nullity and infringement suits significantly increase with the number of claims and the number of forward citations per claim. This result is consistent with the finding of this paper that particularly valuable patents become subject of litigation. Similar results have been obtained for patents challenged in post-grant opposition (Harhoff and Reitzig, 2004). Allison et al. (2004) study characteristics of valuable patents *under the presumption* that litigated patents are a subset of the most valuable. Marco (2004) estimates win rates for patent validity and infringement suits based on observable patent characteristics. He finds that selection biases the win rate in validity, but not in infringement proceedings. Somaya (2003) provides evidence that asymmetric ("strategic") stakes increase the likelihood of non-settlement. Cremers et al. (2017) compare cases of patent litigation across four European countries, finding differences in caseloads and outcomes, as well as inconsistency of verdicts for patents litigated in multiple jurisdictions. Concerning differences *among* litigated patents, Allison et al. (2009) find that the most-litigated patents differ significantly from patents litigated only once, with respect to technology area, proxies of value, and applicant type. Lanjouw and Lerner (2000) review empirical work on the enforcement of intellectual property rights in the context of a stylized model of the patent litigation process. An extensive review of both theoretical and empirical results is given by Weatherall and Webster (2014).

This paper's contribution to the literature is twofold. First, it complements prior work on the economics of the patent litigation system (e.g., Crampes and Langinier, 2002; Bessen and Meurer, 2006) by characterizing latent properties and the resulting selection mechanics. While previous studies have mostly focused on either theoretical modeling *or* descriptive empirics, this paper develops a structural model that can reproduce empirical outcome rates of patent disputes. It provides new insights concerning patent validity, and its interaction with selection into litigation, where prior evidence is scarce. At the same time, it confirms well-established empirical findings identifying patent value as a driver of litigation propensity (Lanjouw and Schankerman, 2001, 2003; Harhoff et al., 2003a). The model allows to disentangle origins of selection: Calibration results suggest that separate stages drive the selection with respect to validity and value.

Second, the study contributes to the literature by reassessing the prevalence of low-quality patents. A considerable amount of prior work has investigated theoretical repercussions of exclusion rights with questionable validity. In contrast, evidence concerning the *extent* of the problem remains scarce (Schankerman and Schuett, 2016; Henkel and Zischka, 2016). To narrow this gap, this paper suggests a novel approach to estimate the rate of latent invalidity in the patent population. The results may serve as a benchmark for policy makers and practitioners, for instance, in assessing whether examination at the patent office is effective (Lemley, 2001) and to what extent the presumption of validity in litigation is reasonable (Lichtman and Lemley, 2007).

The remainder of the paper is structured as follows. Section 3.2 develops a structural theoretical model of the selection process. A sketch of the model's solution is subsequently presented in Section 3.3.[14] Section 3.4 presents a calibration of the model to empirically observable outcome rates of the patent litigation system. Based on the fitted parameters, Section 3.5 is concerned with the prediction of unobservable characteristics, most prominently the share of latently invalid patents in the population. Section 3.6 examines the sensitivity of the model calibration when varying parametric assumptions. Section 3.7 studies the simulated impact of policy reform with respect to the courts' validity threshold and litigation cost. Section 3.8 discusses limitations of the approach and proposes directions for further research. Section 3.9 concludes.

3.2 A Model of the Selection of Patents for Litigation

To model the selection of patents for litigation, I devise a divergent expectations model based on the framework developed by Priest and Klein (1984). In order to keep the model estimable, I prioritize procedural elements of prime importance for the selection mechanics, while abstracting from second-order institutional details. The model thus features comprehensive representations of patent validity and value, and separates the entry and the negotiation stages. In contrast, it abstracts from heterogeneous product market structures and the separation of infringement and annulment proceedings ("bifurcation"), among others. In the following, I introduce the model's structure and assumptions in a concise and straightforward way. See Section 3.8 for a detailed comparison of the model and the institutional setting in Germany and Europe and for a comprehensive discussion of the model's limitations.

Figure 3.1 shows the general structure of the model. First, a patent is drawn from the population and subsequently observed with error by both the patent owner (potential future plaintiff, p) and the potential infringer (future defendant, d).[15] In the second stage, the potential infringer decides whether to enter the market and to (potentially) infringe the patent. The decision is based on the expected profits given his observations, taking possible litigation into account. Finally, in the third stage, the parties come to a settlement if the plaintiff's minimum settlement demand A is below the defendant's maximum settlement offer B, or enter litigation otherwise. When forming expectations about litigation in court, parties take their respective observations into account. The judgment can have the outcomes "patent valid and infringed," which corresponds to the plaintiff winning, "patent valid and not infringed" or "patent invalid," which correspond to the defendant winning, with p_c being the exogenous probability that a

[14] A detailed derivation of the analytical results can be found in Appendix C.1.

[15] The parties' roles in trial are meant with respect to the infringement proceeding, in which the patent owner is the plaintiff and the potential infringer is the defendant. While the two switch roles in an annulment proceeding, I will keep referring to the parties with respect to their role in the infringement proceeding throughout the paper, to avoid confusion. Besides, I will use the female gender for the patent holder and the male gender for the potential infringer.

valid patent is considered infringed.

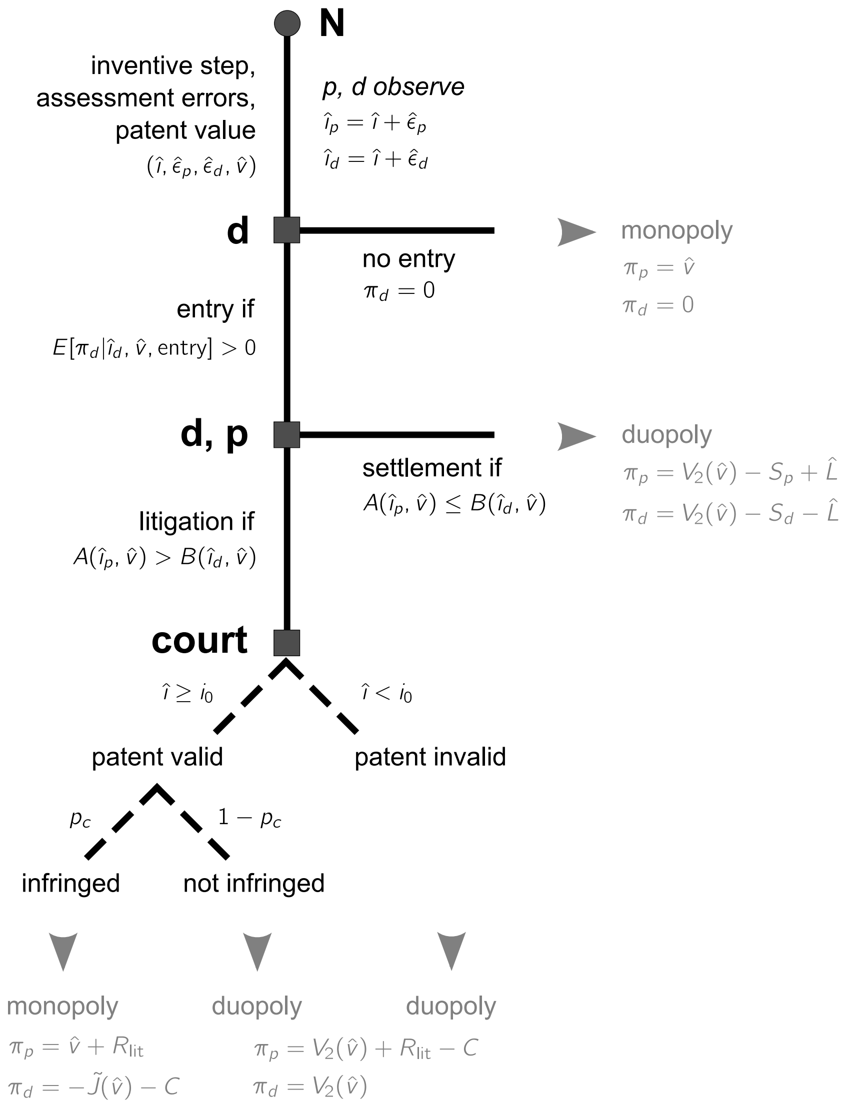
In the model, a patent is characterized by two features: (i) the inventive step $\hat{\imath}$ and (ii) the value $\hat{v}$ associated with the patented invention. Concerning the requirements for a patent, article 52 of the European Patent Convention states that *"patents shall be granted for any inventions, in all fields of technology, provided that they are new, involve an inventive step and are susceptible of industrial application"* (EPO, 1973). Consequently, from a formal point of view, patentability is a multi-dimensional concept. Accordingly, the European Patent Office's (EPO) guidelines for examination treat novelty and inventive step[16] as distinct criteria (EPO, 2017, Part G, Chapters VI and VII). Nonetheless, the question for the presence of an inventive step is meant to arise only if the invention is novel (cf. G-VII, 1). Besides, the existence of an industrial application is a rather low hurdle for the patentee, excluding only few inventions beyond the other requirements (EPO Case Law of the Boards of Appeal, 2018). In favor of simplicity, I thus abstract from the multi-dimensionality of patent validity. Instead, I employ a one-dimensional random variable $\hat{\imath} : \Omega \to \mathbb{R}$ that represents a patent's inventive step relative to the state of the art $i_0 \equiv 0$, where I denote the probability space as $(\Omega, \mathscr{F}, \mathbb{P})$. $\hat{\imath}$ combines the notions of novelty and inventive step: If $\hat{\imath} < i_0$, the patented invention does not constitute a novel and sufficient departure from the state of the art. As such, the one-dimensional conceptualization of validity is in line with reasons for invalidity judgments observed for German and European patents at the German Federal Patent Court. A large majority of annulments is effected on the grounds of a lack of inventive step (53%) or a lack of novelty (20%) (Hess et al., 2014). Besides the inventive step, a patent's selection for litigation may be determined by its value. In the model, patented invention value $\hat{v}$ is defined as the profits made by a monopolist based on her enforced exclusion right. This has to be distinguished from the value of the patent right as such, which is given by the difference in profits from an invention with and without patent protection. See Section 3.4.3 for a description of how this distinction is operationalized in the calibration of the model.

Stage 1: Patent Population

In a first step, a patent with a true inventive step $\hat{\imath}$ and a patented invention value $\hat{v}$, which are independent random variables, is drawn from the population.[17] Subsequently, the inventive step is observed with error, by both the plaintiff and the defendant, $\hat{\imath}_p = \hat{\imath} + \hat{\varepsilon}_p$ and $\hat{\imath}_d = \hat{\imath} + \hat{\varepsilon}_d$, where $\hat{\varepsilon}_p$ and $\hat{\varepsilon}_d$ are once again independent random variables. During litigation in court, the true inventive step is revealed and the patent will be considered valid if its inventive step is above the (exogenously given) state of the art i_0, i.e. if $\hat{\imath} \geq i_0$. We are free to choose $i_0 \equiv 0$, since only the inventive step relative to the state of the art will be relevant.

[16] In US patent law, the conceptual analogue to the "inventive step" criterion is called "non-obviousness."
[17] See Section 3.8 for a discussion of the independence assumption.

Figure 3.1: Model structure



Notes: *Stage 1:* A patent's inventive step $\hat{\imath}$, the plaintiff's (p) and the defendant's (d) respective assessment errors $\hat{\epsilon}_p$ and $\hat{\epsilon}_d$, and patented invention value $\hat{v}$ are drawn by nature, with the underlying distributions being common knowledge. p and d observe the inventive step with error, while they correctly assess the value of the patented invention. *Stage 2:* d enters the market if, given his information, he can expect higher profits π_d than in the case of not entering. *Stage 3:* If p's minimum settlement demand $A(\hat{\imath}_p, \hat{v})$ is below or equal to d's maximum settlement offer $B(\hat{\imath}_d, \hat{v})$, the parties come to an agreement with respective negotiation costs of S_p and S_d, otherwise enter litigation. In case of a settlement, d pays an amount $\hat{L} \in [A(\hat{\imath}_p, \hat{v}), B(\hat{\imath}_d, \hat{v})]$ to p and in turn obtains a license. $V_2(\hat{v})$ denotes the (symmetric) duopoly profits of p and d, respectively. In case the parties do not settle due to divergent expectations resulting from different observations $\hat{\imath}_p$ and $\hat{\imath}_d$, the court verdict can have three different outcomes. First, the patent can be valid and infringed, resulting in a compensation payment by d to p, such that p is reimbursed for the losses incurred after d's entry prior to dispute. Second, the patent can be judged valid, but not infringed, or third, it can be judged invalid, both cases resulting in a duopoly with p having to bear the total legal cost C (British Rule). $\tilde{J}(\hat{v})$ denotes the compensation payment net of d's pre-dispute duopoly profits.

Stage 2: Entry Decision

The potential defendant will enter the market if the expected profits given his observations are larger than the profits in the case of not entering the market ($\pi_d = 0$),

$$\begin{aligned}
& E[\pi_d \,|\, \hat{\imath}_d,\, \hat{v},\, \text{entry}] \\
= \quad & \mathbb{P}(\underbrace{A(\hat{\imath}_p, \hat{v}) \leq B(\hat{\imath}_d, \hat{v})}_{\Rightarrow \text{ settlement if entry}} \mid \hat{\imath}_d, \hat{v}) \left(V_2(\hat{v}) - S_d - \hat{L} \right) \\
& + \mathbb{P}(\underbrace{A(\hat{\imath}_p, \hat{v}) > B(\hat{\imath}_d, \hat{v})}_{\Rightarrow \text{ litigation if entry}}, \text{valid} \mid \hat{\imath}_d, \hat{v}) \left(p_c\, (-\tilde{J}(\hat{v}) - C) + (1 - p_c)\, V_2(\hat{v}) \right) \\
& + \mathbb{P}(A(\hat{\imath}_p, \hat{v}) > B(\hat{\imath}_d, \hat{v}), \text{invalid} \mid \hat{\imath}_d, \hat{v})\; V_2(\hat{v}) - \; C_{\text{entry}} \\
> \;\; & 0\,. \qquad (3.1)
\end{aligned}$$

The conditional expected profits are composed of the profits in case of settlement, the profits in case of litigation with a valid patent, and the profits in case of litigation with an invalid patent, times the respective conditional probabilities, minus market entry costs. $A(\hat{\imath}_p, \hat{v})$ is the plaintiff's minimum settlement demand (asking price), $B(\hat{\imath}_d, \hat{v})$ is the defendant's maximum settlement offer (bidding price). For the case of a settlement, $A(\hat{\imath}_p, \hat{v}) \leq B(\hat{\imath}_d, \hat{v})$, d can expect profits $V_2(\hat{v}) - S_d - \hat{L}$, where $V_2(\hat{v})$ denotes the profits each competitor makes in a duopoly setting, S_d denotes d's settlement costs, and $\hat{L} \in [A(\hat{\imath}_p, \hat{v}), B(\hat{\imath}_d, \hat{v})]$ denotes the licensing fee. Patented invention value $\hat{v}$ represents monopoly profits. Assuming that competition can be modeled as a Cournot oligopoly with linear demand,[18] it follows that in an oligopoly with n firms, each makes profits of $V_n(\hat{v}) = 4\hat{v}/(n+1)^2$. Consequently, in a symmetric duopoly,

$$V_2(\hat{v}) = \frac{4}{9}\,\hat{v}\,. \qquad (3.3)$$

For the case of litigation, $A(\hat{\imath}_p, \hat{v}) > B(\hat{\imath}_d, \hat{v})$, there are three possible verdict outcomes. First, the patent may be valid, $\hat{\imath} \geq i_0$, and considered infringed by the court, in which case

[18] For the linear Cournot setting, I assume that the price of the final good is given by $p = a - b\sum_{i=1}^{n} x_i$, where x_i denotes the quantity supplied by firm i. The corresponding profit is $\pi_i = (p-c)x_i$, where c are the firm's marginal production costs (equal for all firms, since all use the same technology described in the patent). Each firm seeks to maximize profits, $0 \stackrel{!}{=} \partial\pi_i/\partial x_i$, resulting in an optimal quantity of $x_i^* = (a-c)/2b - 1/2\sum_{j,j\neq i} x_j$. In Nash Equilibrium, all firms achieve this goal, playing mutually best responses. In a symmetric equilibrium, each firm produces $x^* = (a-c)/b(n+1)$ and makes profits of $\pi^{n,*}(\mathbf{x}^*) = (a-c)^2/b(n+1)^2$. Rewritten in terms of monopoly profits $\pi^{1,*} = (a-c)^2/4$, I thus obtain

$$\pi^{n,*} = \frac{4}{(n+1)^2}\,\pi^{1,*}\,. \qquad (3.2)$$

Total oligopoly profits decline with increasing n, $\pi_{\text{total}} = \sum_{i=1}^{n} \pi^{n,*} = n\pi^{n,*} = \frac{4n}{(n+1)^2}\,\pi^{1,*}$.

the defendant has to pay a compensation $J(\hat{v})$ to the plaintiff and in addition has to bear the total legal cost C. I assume valid patents to be considered infringed by the court with the exogenous probability p_c. If the judgment does not include any additional fines, $J(\hat{v})$ will be chosen such that the patent owner is compensated for the losses incurred due to illegal infringement. These losses are equal to the difference between the profits in the (symmetric) duopoly and the monopoly profits of the patent holder. Consequently, for the linear Cournot duopoly I obtain

$$J(\hat{v}) = \frac{\bar{t}}{T}\,(\hat{v} - V_2(\hat{v})) = \frac{\bar{t}}{T}\,\frac{5}{9}\,\hat{v}\,, \tag{3.4}$$

where $\bar{t}$ is the average time the defendant can make duopoly profits – either before he is detected and a court order is issued or before a settlement is agreed upon. T denotes the legal patent lifetime. In Eq. (3.1) and in Figure 3.1, $\tilde{J}(\hat{v})$ denotes the compensation the defendant has to pay to the plaintiff if convicted of infringement, net of his average profits prior to dispute, which are given by $\bar{t}\,V_2(\hat{v})/T$. Hence, for the linear Cournot setting,

$$\tilde{J}(\hat{v}) = J(\hat{v}) - \frac{\bar{t}}{T}\,V_2(\hat{v}) = \frac{\bar{t}}{T}\,(\hat{v} - 2V_2(\hat{v})) = \frac{\bar{t}}{T}\,\frac{1}{9}\,\hat{v}\,. \tag{3.5}$$

Second, the patent may be valid, yet not considered infringed, in which case the suit is unsuccessful, enabling the defendant to make duopoly profits $V_2(\hat{v})$ for the patent's entire lifetime without any payment obligations. The legal expenses C are in this case borne by the plaintiff. Third, the patent may be invalid, $\hat{\imath} < i_0$, the profit outcomes of which are assumed equivalent to the previous case, i.e., duopoly profits $V_2(\hat{v})$ for both parties, with the legal cost paid by the plaintiff.

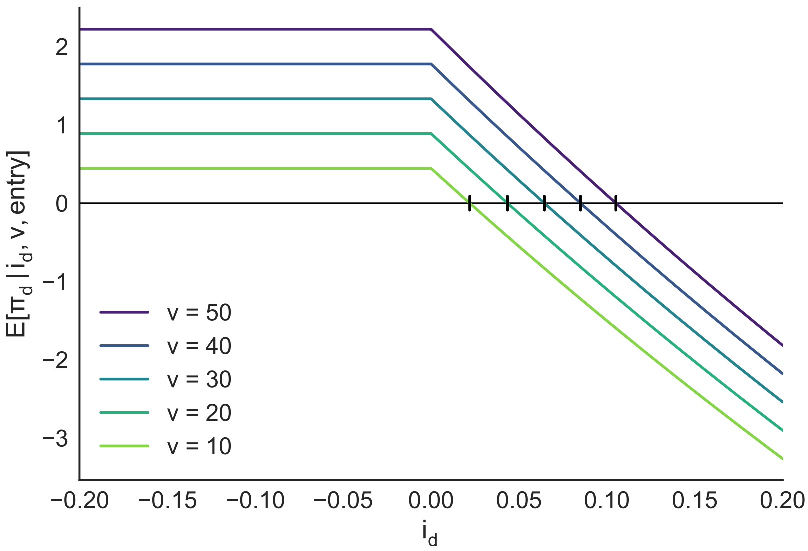
Figure 3.2 shows $\mathbb{E}[\pi_d \mid \hat{\imath}_d = i_d, \hat{v} = v, \text{entry}]$ as a function of i_d for the distributional assumptions and the parameters obtained in Section 3.4.

Stage 3: Litigation and Settlement

The negotiation stage is based on the divergent expectations framework developed by Priest and Klein (1984). The plaintiff and the defendant will be able to settle if the plaintiff's minimum settlement demand $A(\hat{\imath}_p, \hat{v})$ (asking price) is below or equal to the defendant's maximum settlement offer $B(\hat{\imath}_d, \hat{v})$ (bidding price), i.e., if $A(\hat{\imath}_p, \hat{v}) \le B(\hat{\imath}_d, \hat{v})$. If however, due to different observations of the inventive step and resulting divergent expectations, p's minimum settlement demand exceeds d's maximum settlement offer, $A(\hat{\imath}_p, \hat{v}) > B(\hat{\imath}_d, \hat{v})$, the parties will not come to an agreement and the patent will enter litigation.

Successful settlement negotiations involve costs S_p and S_d for the plaintiff and the defendant, respectively. As part of an agreement, the defendant pays a fee $\hat{L} \in [A(\hat{\imath}_p, \hat{v}), B(\hat{\imath}_d, \hat{v})]$ to the plaintiff and in return obtains a license enabling him to make duopoly profits. I assume the patent owner to hold sufficient bargaining power to achieve a licensing payment $\hat{L} = B(\hat{\imath}_d, \hat{v})$

Figure 3.2: Expected profits (potential infringer)



Notes: Expected profits of the defendant in case of entry, $\mathbb{E}[\pi_d \mid \hat{\imath}_d = i_d, \hat{v} = v, \text{entry}]$, as a function of the observed inventive step i_d for different patented invention values v. Distributional assumptions and parameters are chosen according to Section 3.4. The short vertical lines crossing the zero-profit line indicate the root $i_d^{\max}(v)$ of $\mathbb{E}[\pi_d \mid \hat{\imath}_d = i_d, \hat{v} = v, \text{entry}]$, as defined in Appendix C.1.3. The roots define the maximum value of $\hat{\imath}_d$, for which d will still enter the market given $\hat{v}$.

whenever $A(\hat{\imath}_p, \hat{v}) \leq B(\hat{\imath}_d, \hat{v})$. If the parties cannot settle, the patent enters litigation. In case of an unsuccessful suit, either through invalidation of the patent or a no-infringement verdict, the defendant continues to make duopoly profits for the rest of the patent lifetime without any payment obligations, while the plaintiff has to bear the total legal costs. In contrast, in case of a successful suit, the plaintiff can sustain his monopoly position and is reimbursed for the profits lost prior to the dispute, whereas the defendant is obliged to pay for the total legal expenses (British Rule).

To abstain from filing suit against the defendant, the plaintiff will demand at least the difference in expected gains from litigation and from settlement. Settlement results in deterministic gains $\pi_p^{\text{set}} = V_2(\hat{v}) - S_p$, i.e., duopoly profits minus settlement cost. In contrast, the expected gains from litigation $E[\pi_p^{\text{lit}} \mid \hat{\imath}_p, \hat{v}, \text{entry}]$ depend on p's information at this point: her observation $(\hat{\imath}_p, \hat{v})$ and the fact that d has entered the market. Hence,

$$\begin{aligned} A(\hat{\imath}_p, \hat{v}) &= E[\pi_p^{\text{lit}} \mid \hat{\imath}_p, \hat{v}, \text{entry}] - \pi_p^{\text{set}} \\ &= R_{\text{lit}} + \mathbb{P}(\text{valid} \mid \hat{\imath}_p, \hat{v}, \text{entry})\big(p_c \hat{v} + (1 - p_c)(V_2(\hat{v}) - C)\big) \\ &\quad + \mathbb{P}(\text{invalid} \mid \hat{\imath}_p, \hat{v}, \text{entry})\big(V_2(\hat{v}) - C\big) - \big(V_2(\hat{v}) - S_p\big) \\ &= \mathbb{P}(\text{valid} \mid \hat{\imath}_p, \hat{v}, \text{entry})\, p_c \left(\hat{v} - V_2(\hat{v}) + C\right) + S_p - C + R_{\text{lit}}\,. \end{aligned} \tag{3.6}$$

The exogenous parameter R_{lit} represents the plaintiff's gain from building a reputation for litigiousness (in monetary terms) when entering litigation. In other words, it is the value the plaintiff (consciously or unconsciously) assigns to scaring off potential future infringers.[19] The final expression for $A(\hat{\imath}_p, \hat{v})$ in Eq. (3.6) can be interpreted in terms of relative payouts: In case of a settlement, legal costs never have to be paid, but settlement costs always occur. In case of litigation, the only time the plaintiff does not have to pay the legal expenses is if he wins the case, i.e., if the patent is valid and considered infringed. Compared to a settlement and the other litigation outcomes, he then also makes additional profits of $\hat{v} - V_2(\hat{v})$.

At the same time, to avoid litigation the defendant will offer no more than his gain π_d^{set} from settlement minus the expected gain $E[\pi_d^{\text{lit}} \,|\, \hat{\imath}_d, \hat{v}]$ from litigation (given his information in the situation after entering the market). In other words, he offers at most the expected loss due to litigation as compared to a settlement,

$$\begin{aligned} B(\hat{\imath}_d, \hat{v}) &= \pi_d^{\text{set}} - E[\pi_d^{\text{lit}} \,|\, \hat{\imath}_d, \hat{v}] \\ &= V_2(\hat{v}) - S_d - \mathbb{P}(\text{valid} \,|\, \hat{\imath}_d)\big(p_c(-\tilde{J}(\hat{v}) - C) + (1 - p_c)V_2(\hat{v})\big) \\ &\qquad\qquad - \mathbb{P}(\text{invalid} \,|\, \hat{\imath}_d)\, V_2(\hat{v}) \\ &= \mathbb{P}(\text{valid} \,|\, \hat{\imath}_d)\, p_c \big(V_2(\hat{v}) + \tilde{J}(\hat{v}) + C\big) - S_d\,. \end{aligned} \tag{3.7}$$

The final expression has an intuitive interpretation: Compared to a settlement, which will always induce costs of S_d, the defendant loses the amount $V_2(\hat{v}) + \tilde{J}(\hat{v}) + C$ if he loses the case, i.e., if the patent is valid and if he is convicted of infringement. Except for settlement costs, the other litigation outcomes (patent valid, yet no infringement verdict, and patent invalid) are equivalent to settlement from the defendant's perspective: There is no compensation to be paid, legal costs are covered by the plaintiff, and duopoly profits can be made for the entire lifetime of the patent.

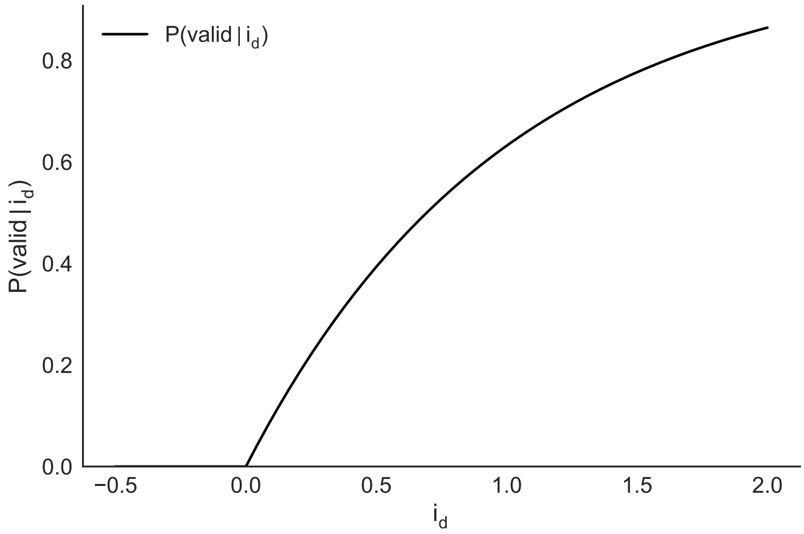
Figures 3.3 and 3.4 show the probabilities $\mathbb{P}(\text{valid} \mid \hat{\imath}_d = i_d)$ and $\mathbb{P}(\text{valid} \mid \hat{\imath}_p = i_p, \hat{v} = v, \text{entry})$ as functions of i_d and i_p, respectively.[20] To form an expectation about validity, the entrant can only draw from his observation $\hat{\imath}_d$ of the inventive step (cf. Eq. (C.11) in Appendix C.1.3). In contrast, the patent holder can draw from an additional piece of information: She has observed that the potential infringer has entered the market. Hence, she can to a certain degree infer the inventive step $\hat{\imath}_d$ the entrant has observed. Since entry is dependent on the relation of $\hat{\imath}_d$ and $\hat{v}$, her validity estimate is thus also a function of value (see Eq. (C.17)). Figure 3.4 shows $\mathbb{P}(\text{valid} \mid \hat{\imath}_p = i_p, \hat{v} = v, \text{entry})$ as a function of i_p for different patented invention values v.

Figure 3.5 helps to form an intuition for how the outcome (indicated by colored/hatched areas) depends on the parties' observations. The panels depict the dependence on observed inventive steps $(\hat{\imath}_p, \hat{\imath}_d)$ for a series of patented invention values $\hat{v}$. It is evident that the selection

[19]For a discussion of reputation building in patent litigation, see e.g. Lanjouw and Schankerman (2001) and Agarwal et al. (2009).

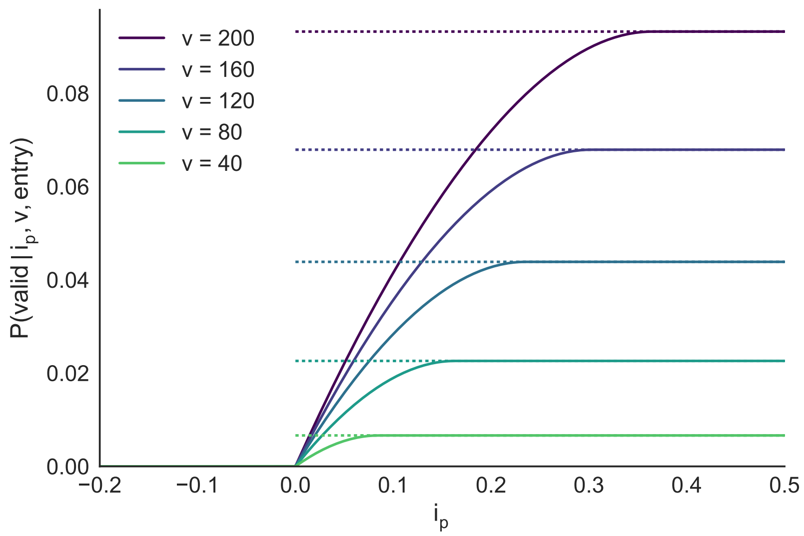
[20]The underlying distributional assumptions and parameters are derived in Section 3.4.

Figure 3.3: Expected validity (potential infringer)



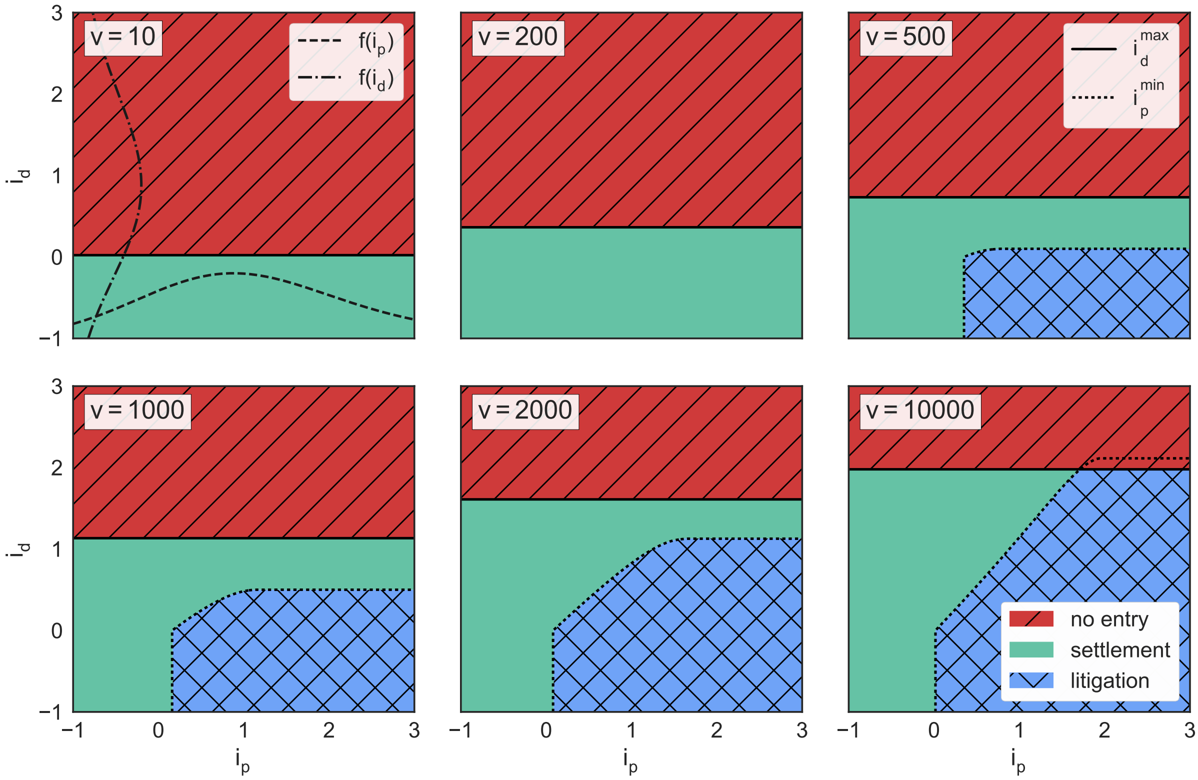
Notes: Probability for the patent to be valid given d's information, $\mathbb{P}(\text{valid} \mid \hat{\imath}_d = i_d) = F_{\varepsilon_d}(i_d - i_0)$, as a function of i_d, for the distributional assumptions and parameters derived in Section 3.4. Since the error is assumed to be non-negative, the probability that the patent is valid is zero for $\hat{\imath}_d < i_0 \equiv 0$. For large $\hat{\imath}_d$, the probability converges to one. See also Appendix C.1.3.

Figure 3.4: Expected validity (patent holder)



Notes: Probability for the patent to be valid given p's information, $\mathbb{P}(\text{valid} \mid \hat{\imath}_p = i_p, \hat{v} = v, \text{entry})$, as a function of i_p for different patented invention values v. Distributions and parameters are again chosen according to Section 3.4. In contrast to $\mathbb{P}(\text{valid} \mid \hat{\imath}_d = i_d)$ depicted in Figure 3.3, the probabilities do not converge to one for $i_p \to \infty$. This is due to the additional information p has, namely the fact that he has already observed the entry of d and may thus deduce $\hat{\imath}_d \leq i_d^{\max}(v)$.

Figure 3.5: Outcomes – Interaction of patented invention value and inventive step observations



Notes: The panels depict (i_p, i_d)-planes for different patented invention values v. Red hatched shading indicates situations where no entry occurs, green shading indicates settlement outcomes and blue cross-hatched shading litigation. For patented inventions of value $v = 10\,\text{k€}$ and $v = 200\,\text{k€}$ the decision between no entry and a settlement is entirely due to the defendant's perception $\hat{\imath}_d$, while litigation never occurs. For increasing patented invention value, the probability for no entry decreases, while settlement and litigation occur in a larger number of cases. The straight horizontal line separating the red and the green regions is precisely given by $i_d^{\max}(v)$ and the dotted line separating the green and the blue regions by $i_p^{\min}(i_d, v)$, both of which are defined in Appendix C.1.3. The dashed and dashed-dotted lines in the $v = 10$ panel indicate the (rescaled) probability density functions of $\hat{\imath}_p$ and $\hat{\imath}_d$, respectively.

to different outcomes is determined by the interplay of $\hat{\imath}_p$, $\hat{\imath}_d$, and $\hat{v}$. A few observations are noteworthy. First, entry only depends on the potential infringer's observations, $\hat{\imath}_d$ and $\hat{v}$. For larger values $\hat{v}$, his decision threshold $i_d^{\max}$ is shifted upwards. Second, litigation never takes place for patents of low value (first two panels). For increasing patented invention value, however, it occurs for an extending region of $(\hat{\imath}_p, \hat{\imath}_d)$ pairs. The location of these regions in the lower right corner is intuitive: Parties are unable to settle if the patent holder observes a large inventive step $\hat{\imath}_p$, while the entrant considers the patent to be likely invalid. In the opposite case of divergent expectations, where the potential infringer observes a large inventive step $\hat{\imath}_d$, no entry occurs. The dashed and dashed-dotted lines in the first panel indicate the probability density functions of $\hat{\imath}_p$ and $\hat{\imath}_d$, respectively.

3.3 Model Solution

Given the vector of parameters of the model, predictions for aggregate quantities can in principle be derived in a straightforward fashion. The purpose of this section will be to develop an intuition for how one may proceed and where potential difficulties and pitfalls may arise. A comprehensive list of all relevant analytical results is given in Appendix C.1.

As an example, consider the probability that a patent is invalid given that it is subject to litigation, $\mathbb{P}(\text{invalid} \mid \text{litigation})$. By the definition of conditional probability,

$$\mathbb{P}(\text{invalid} \mid \text{litigation}) = \frac{\mathbb{P}(\text{invalid} \wedge \text{litigation})}{\mathbb{P}(\text{litigation})} . \tag{3.1}$$

For litigation to take place, two conditions have to be met. First, the defendant has to enter the market, which he does if his expected profits are larger than in the case of not entering, $\mathbb{E}[\pi_d \mid \hat{\imath}_d, \hat{v}, \text{entry}] > 0$. Second, the parties should not be able to settle, i.e., the plaintiff's asking price should be larger than the defendant's bidding price, $A(\hat{\imath}_p, \hat{v}) > B(\hat{\imath}_d, \hat{v})$. The denominator is thus given by

$$\mathbb{P}(\text{litigation}) = \int_0^\infty dv\, f_v(v) \int_{-\infty}^\infty di\, f_i(i) \\ \int_0^\infty d\varepsilon_p\, f_{\varepsilon_p}(\varepsilon_p) \int_0^\infty d\varepsilon_d\, f_{\varepsilon_d}(\varepsilon_d)\, \mathbb{1}_{\mathbb{E}[\pi_d \mid i_d = i+\varepsilon_d, v, \text{entry}]>0}\, \mathbb{1}_{A(i_p,v)>B(i_d,v)} . \tag{3.2}$$

Finally, a patent is invalid if its inventive step is smaller than the validity threshold, $\hat{\imath} < i_0$. Hence, the expression for the numerator contains an additional indicator function,

$$\mathbb{P}(\text{invalid} \wedge \text{litigation}) = \int_0^\infty dv\, f_v(v) \int_{-\infty}^\infty di\, f_i(i) \\ \int_0^\infty d\varepsilon_p\, f_{\varepsilon_p}(\varepsilon_p) \int_0^\infty d\varepsilon_d\, f_{\varepsilon_d}(\varepsilon_d)\, \mathbb{1}_{\mathbb{E}[\pi_d \mid i_d = i+\varepsilon_d, v, \text{entry}]>0}\, \mathbb{1}_{A(i_p,v)>B(i_d,v)}\, \mathbb{1}_{i<i_0} . \tag{3.3}$$

Up to this point, the analysis has been straightforward. However, the explicit evaluation of these expressions involves several subtleties that need to be taken care of.

Clearly, for any distributional assumptions for the four elementary random variables $(\hat{v}, \hat{\imath}, \hat{\varepsilon}_p, \hat{\varepsilon}_d)$, it is advisable to proceed analytically as far as possible to make the subsequent numerical integration viable and efficient. This is especially true for the nature of the integrands this model inherently produces. Since decisions are discrete, as in "'entry' if expected profits larger than zero, 'no entry' otherwise," which translates into indicator functions in the above expressions, the integrands are discontinuous. Without further adjustments, this leads to convergence issues in quadrature algorithms. Note that numerical integration will for most distributional assumptions be inevitable at some point, because closed-form solutions to the integrals may not exist and, more crucially, because some of the quantities are only implicitly defined. For example, d's expected profits $\mathbb{E}[\pi_d \mid \hat{\imath}_d, \hat{v}, \text{entry}]$ indirectly depend on p's asking price, which is a function of $\mathbb{P}(\text{valid} \mid \hat{\imath}_p, \hat{v}, \text{entry})$, which in turn depends on the expected profits. While analytical closed-form definitions might thus be elusive, numerical root-finding allows for deriving these functions at any given point.

Verification through Monte Carlo Simulation

In order to avoid errors in the analytical derivations and the corresponding numerical implementations, I carry out a Monte Carlo simulation to verify that results agree within the variance of the simulation. For that purpose, a large number of tuples of random numbers $(\hat{v}, \hat{\imath}, \hat{\varepsilon}_p, \hat{\varepsilon}_d)$, representing a patent and the parties' assessments, are drawn from their respective distributions and subjected to the selection rules constituting the model. Exact probabilities are then compared to the relative frequencies in the simulation. For quantitative results see Figure C.5 in the appendix. It shows that within the precision of the simulation, analytical results are reproduced perfectly.

3.4 Model Calibration

In order to reproduce aggregate patent system characteristics found empirically, I will calibrate the model by tuning its parameters appropriately. This section explains in detail which assumptions and methods are used for determining each model parameter. A summary of methods and results is provided in Table 3.1.

3.4.1 Distributional Assumptions

In order to fit the model to empirical data, one has to commit to explicit distributional assumptions for the random variables of the model. Despite the fact that more flexible distributions with more parameters always yield a better fit, I use standard distributions with few parameters, paying tribute to the scarcity of observable patent system characteristics available for calibration.

Let me start with the distribution of patented invention value $\hat{v}$, which is the least stylized random variable of the model, having a direct analogue in reality. There exists a noteworthy body of literature[21] which has studied the distribution of patent value and its relation to widely observable proxies, most notably forward citation count. While it seems commonly accepted that it is a highly skewed, fat tailed distribution, with most patents having very little or no value, and a slowly decaying probability of some patents having very high value, the precise functional form is difficult to pin down empirically. There is some evidence (Harhoff et al., 2003b) that the tail of the patented invention value distribution is best approximated by a

[21] See for example Schankerman and Pakes (1986); Lanjouw (1998); Schankerman (1998); Harhoff et al. (1999, 2003a,b, 2015); Gambardella et al. (2010); Fischer and Leidinger (2014); Kogan et al. (2017).

log-normal distribution, a finding I will adopt in the following by assuming

$$\ln \hat{v} \sim \mathcal{N}(\mu_v, \sigma_v^2), \tag{3.1}$$

where $\mathcal{N}(\mu, \sigma^2)$ denotes a normal distribution of mean μ and variance σ^2. Contrary to the parameters of the remaining distributions, I will be able to extract μ_v and σ_v from a direct fit of the cumulative distribution function to simulated values provided in the literature (Harhoff et al., 2015), as explained in the next section.

For the inventive step $\hat{\imath}$, which is a stylized concept abstracting from the multidimensional nature of the patent offices' patentability requirements, I assume a normal distribution,

$$\hat{\imath} \sim \mathcal{N}(\mu_i, \sigma_i^2). \tag{3.2}$$

This is in line with the intuition that both patents with very small and very large inventive steps are extremely rare. On the one hand, the unlikeliness of very low inventive steps is justified by the patentability requirements, or at least the risk of failing to meet these requirements. Even if the patent office has limited resources for examination, obvious low-quality applications will be filtered out. In the population of granted patents, extreme cases will thus be absent. Besides, an applicant would incur substantial extra costs if she applied for a huge number of patents comprised of minuscule inventions. On the other hand, the unlikeliness of very high inventive steps is a consequence of competition on the market for technology. Competition induces parties to apply early and to obtain multiple patents to mitigate the risk of invalidation after a plea of annulment. In view of the central limit theorem, considering a patent's inventive step as the sum of a (large) number of small insights provides an additional plausible justification for the use of the normal distribution.

The assessment errors $\hat{\varepsilon}_p$ and $\hat{\varepsilon}_d$, in contrast, arise from a process of a very different nature. First of all, it is reasonable to assume that both parties assess the inventive step of a potentially contested patent professionally, through a designated department or a specialized law firm. Systematic bias by whether an invention was developed internally or externally should thus be negligible. Consequently, the two parties should have similarly distributed assessment errors. Rather than bias, the error stems from the expected amount of prior art submitted in the course of an annulment suit. Assessing the likelihood that patentability-destroying prior art exists is inevitably noisy without a very costly search. Nonetheless, under the supposition of professionalism, one would assume that the probability density decreases very quickly with increasing assessment errors. Now, if parties always correctly distinguish relevant and irrelevant prior art when they find it, i.e., if the error emerges from the search process alone, only *too little* prior art can be found. This is in line with the finding of Hess et al. (2014, Section E.II) that (a) in almost all annulment proceedings, plaintiffs introduce new prior art, which (b) subsequently plays a central role in the proceeding. I thus assume that the inventive step of a patent can only be *over*estimated erroneously, i.e., I assume that errors are larger than zero. Exponential distributions provide a decent reflection of these considerations, with the most likely error being zero, and a quickly decreasing probability of very large errors. I thus assume

$$\begin{aligned} \hat{\varepsilon}_p &\sim \mathrm{Exp}(\lambda_p) \\ \hat{\varepsilon}_d &\sim \mathrm{Exp}(\lambda_d)\,, \end{aligned} \tag{3.3}$$

where $\mathrm{Exp}(\lambda)$ denotes an exponential distribution with parameter $\lambda > 0$.

For a list of the corresponding probability density and cumulative distribution functions, see Appendix C.1.1.

3.4.2 Parameters Fixed Exogenously

Definition of scale

Since the inventive step is an abstract concept, which is meaningful only relative to the state of the art i_0 and up to a normalization factor, I am free to choose i_0 and the scale arbitrarily. As the definition of zero, I choose $i_0 \equiv 0$ without loss of generality. Fixing the scale could in principle be done through either the standard deviation σ_i of the inventive step or through the parameter λ of either party's assessment error distribution. For convenience I choose to set $\lambda_p \equiv 1$.

Legal and settlement costs

The following legal and settlement cost parameters are consistent with data on the average costs of patent litigation in Germany (Harhoff, 2009, p. 31). I fix expected total legal cost to

$$C = 200,000\,€\,. \tag{3.4}$$

Supposing that plaintiff and defendant incur similar negotiation costs when coming to a settlement, I fix S_p and S_d to an equal amount of

$$S_p = S_d = S = 50,000\,€\,. \tag{3.5}$$

I thus assume that legal and settlement costs do not vary systematically with the value of the patented invention. See Section 3.8 for a detailed discussion.

Further, when entering litigation, I assume the plaintiff to derive a benefit R_{lit} from obtaining a reputation as someone who is willing to defend his patent rights. Incorporating some notion of this kind into the model seems indispensable, given that a granted patent right will only benefit its holder if she can credibly commit to legally uphold her exclusion rights in case of infringement. In monetary terms, I set this benefit to

$$R_{\text{lit}} = 10,000 \text{ €} \tag{3.6}$$

for the baseline model. Both S/C and R_{lit}/C are varied over a large range in Section 3.6 to explore the model calibration's sensitivity to the above choices.

Time scales

A German (and European) patent's lifetime T is

$$T = 20 \text{ years}. \tag{3.7}$$

Concerning the average time $\bar{t}$ an entrant can make duopoly profits before a court order is issued, I assume

$$\bar{t} = 2 \text{ years}. \tag{3.8}$$

Only the ratio of these parameters enters the model, namely through the compensation payment after an infringement verdict, net of average profits made prior to dispute, $\tilde{J}(\hat{v}) = \frac{\bar{t}}{T}\frac{1}{9}\hat{v}$, as derived in Eq. (3.5).

3.4.3 Fit of the Patented Invention Value Distribution

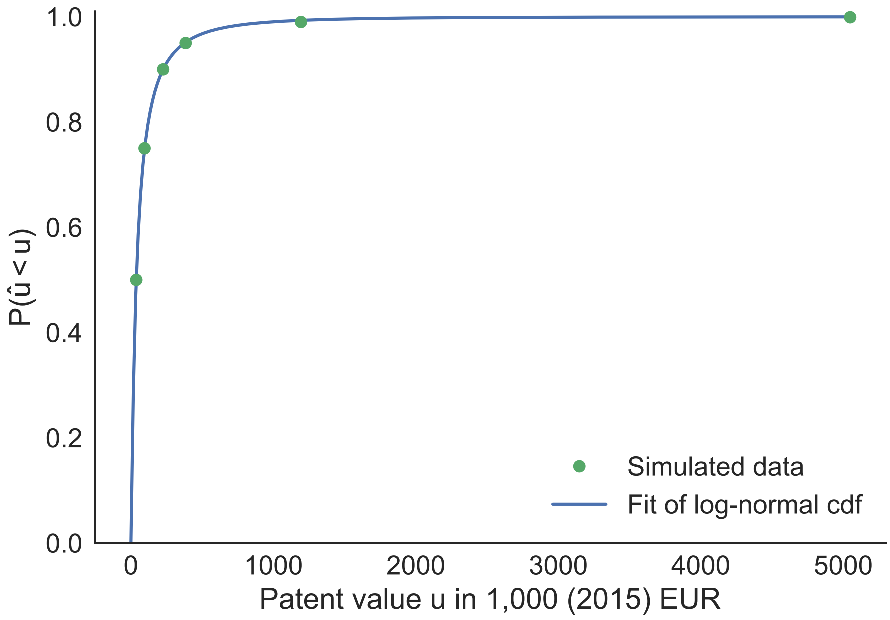
To determine the parameters of the patented invention value distribution, I fit a log-normal cumulative distribution function to simulated data provided by Harhoff et al. (2015, p. 23, Table 3). They estimate quantiles of the patent population's value distribution by fitting a model of deferred examination to data on patent applications filed at the German patent office between 1989 and 1996. Figure 3.6 shows the fit of the log-normal cumulative distribution function to the simulated data using non-linear least squares.[22] Denoting values in units of 1,000€ $_{2015}$ I obtain as optimal parameters

$$\begin{aligned} \mu_u &\approx 3.623 \\ \sigma_u &\approx 1.402, \end{aligned} \tag{3.9}$$

which corresponds to an expected patent value of about $\mathbb{E}[\hat{u}] \approx 100,000$ €$_{2015}$. This value differs by approximately 12% from the mean simulated in the paper, which seems reasonable given that the expected value of the log-normal distribution is very sensitive to small variations of the parameters. The simulated data by Harhoff et al. (2015) used above are estimates

[22] Units are changed from 1989 USD to 2015 EUR by accounting for an inflation of 94% (Williamson, 2016, "real value") and an exchange rate of approximately 0.9205 EUR/USD (ECB, 2016, exchange rate of Nov 6th, 2015).

Figure 3.6: Fit of the patent value distribution



Notes: Fit of a log-normal cumulative distribution function to the simulated patent value distribution provided by Harhoff et al. (2015, p. 23, Table 3).

for the private value $\hat{u}$ of granted patent rights, which stands in a close relationship with the monopoly rents $\hat{v}$ used as the fundamental value representation in the model developed here. $\hat{v}$ can be seen as the combined value of the invention per se and the patent protection. As an approximate representation of the private value of a patent right in the model I thus use $\hat{u} = \hat{v} - V_2(\hat{v})$, i.e., the difference between monopoly and duopoly rents, or, in other words, the difference between the value of the patent-protected invention and the value of the unprotected invention. Consequently, given the linear Cournot setting and the properties of the log-normal distribution (see Eq. (3.3) and footnotes 18 and 24), one immediately obtains

$$\begin{aligned} \mu_v &= \mu_u + \ln\left(\frac{9}{5}\right) && \approx 4.211 \\ \sigma_v &= \sigma_u && \approx 1.402\,. \end{aligned}$$

This corresponds to an average patented invention value of approximately 180,000 $€_{2015}$.

Note that the parameters (μ_u, σ_u) and thus the corresponding distribution differ significantly from the values derived in Harhoff et al. (2003b), who estimate parameters for the *tail* of the patented invention value distribution.[23] The log-normal parameters obtained from a

[23]The authors asked the interviewees to estimate the loss in profit their firm would have incurred, had it been precluded from use of the patented invention. This has to be distinguished from the value of the patent right per se. However, the two could not always be disentangled (Harhoff et al., 2003b, Section 12.3.2).

Table 3.1: Determination of (baseline) model parameters

Symbol	*Value*	*Calibration method*	*Description*
Distributional parameters			
μ_v	$= 4.211$	direct fit (Sec. 3.4.3)	distr. of patent value
σ_v	$= 1.402$	direct fit (Sec. 3.4.3)	
μ_i	$= 0.1931$	optimization (Sec. 3.4.5)	distr. of inventive step
σ_i	$= 0.9568$	optimization (Sec. 3.4.5)	
λ_p	$\equiv 1$	definition of scale (Sec. 3.4.2)	distr. of p's assessment error
λ_d	$= \lambda_p$	simplifying assumption (Sec. 3.4.4)	distr. of d's assessment error
Fundamental model parameters			
i_0	$\equiv 0$	definition of zero (Sec. 3.4.2)	validity threshold
C	= 200 (k€)	exogenous parameter (Sec. 3.4.2)	total legal cost
S_p	= 50 (k€)	exogenous parameter (Sec. 3.4.2)	p's settlement cost
S_d	= 50 (k€)	exogenous parameter (Sec. 3.4.2)	d's settlement cost
T	= 20 (yr)	exogenous parameter (Sec. 3.4.2)	patent lifetime
$\bar{t}$	= 2 (yr)	exogenous parameter (Sec. 3.4.2)	time prior to dispute
R_{lit}	= 10 (k€)	exogenous parameter (Sec. 3.4.2)	gain in litigation reputation
C_{entry}	$\equiv 0$	simplifying assumption (Sec. 3.4.4)	no entry cost
p_c	$= 1$	simplifying assumption (Sec. 3.4.4)	entry $\Leftrightarrow$ infringement

fit to the tail imply a substantially higher skewness[24] of the distribution (6953 vs 23) and a substantially higher average patent value[25] of 10,600,000€$_{2015}$. Since especially the latter suggests that a fit to the tail of the value distribution does not result in parameters representative of the entire distribution, I do not employ the parameter estimates in Harhoff et al. (2003b), but choose to fit to the simulated patent values in Harhoff et al. (2015).

3.4.4 Simplifying Assumptions

Since I will only use two patent system characteristics to calibrate the remaining model parameters, I reduce the model's complexity by introducing the following simplifications. First, I assume the plaintiff's and the defendant's assessment error distributions to be equal, $\lambda_d = \lambda_p \equiv 1$, which one may see as a consequence of the professionalism assumption established in Section 3.4.1. Second, I suppose that entry costs do not matter for the defendant's

[24]Note that while the skewness only depends on the σ-parameter of the log-normal distribution, a change of units only affects the μ-parameter, which can be seen as a (non-linear) scaling parameter in the pdf and cdf (cf. appendix C.1.1): $(\ln(x) - \mu)/\sigma = \ln(x/e^{\mu})/\sigma$.

[25]Inflation 1996-2015 (1996 = survey year in Harhoff et al. (2003b)): 60% (Williamson, 2016, "real value"), fixed exchange rate: 1.9558 DM/EUR.

entry decision, $C_{\text{entry}} = 0$. Third, I set the (exogenous) conviction probability p_c of a valid patent to be considered infringed by the court to 1. This means that a defendant who has entered a market protected by a valid patent is always infringing. Entry and infringement become synonymous. Fourth, I assume plaintiff and defendant to incur equal settlement costs, as described in Section 3.4.2.

3.4.5 Fit of the Remaining Parameters

Definition of target characteristics

I calibrate the remaining model parameters (μ_i, σ_i) such that the model reproduces the following aggregate quantities, which are consistent with data on German patents and the German components of European bundle patents litigated at the German Federal Patent Court (Hess et al., 2014): First, the share of all patents becoming subject to litigation is set equal to 1.2%. Second, the share of patents in nullity proceedings which are partially or fully invalidated is set to 75%.

Minimization algorithm

To make use of a multi-dimensional minimization algorithm, one has to define an objective function g to be minimized. I employ the Euclidean norm of the relative difference vector $\boldsymbol{r}$ of the target characteristics $\boldsymbol{c}^t$ defined above and the corresponding model predictions $\boldsymbol{c}^m(\boldsymbol{p})$, where $\boldsymbol{p}$ denotes the parameter vector,

$$g(\boldsymbol{p}) = \| \boldsymbol{r} \| = \sqrt{\sum_i \left(\frac{c_i^t - c_i^m(\boldsymbol{p})}{c_i^t} \right)^2} \,. \tag{3.10}$$

In this way, I give equal weight to the relative differences of each target characteristic, which may differ considerably in absolute magnitude.

For the minimization itself I use standard multi-dimensional minimization routines: the Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm (Nocedal and Wright, 2006, p. 136ff.) for unconstrained minimization and the L-BFGS-B algorithm for bound constrained minimization (Byrd et al., 1995).[26]

For the target characteristics defined above, the optimal parameters are approximately given by[27]

$$\mu_i = 0.1931$$
$$\sigma_i = 0.9568 \,.$$

[26] In SciPy, both are accessible via the `scipy.optimize.minimize` interface.

[27] Technical note: This result was obtained using constrained minimization with bounds $\mu_i \in [-10, 10]$, $\sigma_i \in [0.001, 10]$.

3.4.6 Uniqueness and Accuracy of Calibration

The model can be uniquely calibrated to perfectly replicate the aggregate patent system characteristics defined in Section 3.4.5. While this may seem trivial at first sight, given that I am freely tuning two model parameters to essentially produce two model outcomes, one should keep in mind that the parameters influence the predictions in a highly non-linear and interdependent way.

Two concerns may arise with regard to fitting a non-linear model. First, the existence of several local minima may obscure the minimization algorithm's path to the optimal point in parameter space. As a result, one may underestimate the model's capability of reproducing empirical outcome rates. If relaxing simplifying assumptions then proves insufficient, one may even reject its general suitability to represent the litigation selection process. Second, the optimal parameters may not be unique, if several local minima exist whose depth is comparable to that of the global minimum. This may not pose a major problem as long as the predictions of the unobservable characteristics of interest are identical for all optimal parameter vectors. Yet, if the corresponding predictions differ substantially, unambiguous conclusions cannot be drawn in a straightforward fashion. For the calibration implemented here, however, the above considerations are of no significance, since the optimum turns out to be the unique minimum, as shown in Figures C.1 and C.2 in the appendix.

Moreover, the calibration results allow to assess whether the simplifications of Section 3.4.4 are overtly restrictive. Since the simplifying assumptions prove to be sufficiently lax to allow for a calibration exactly reproducing the observable outcome rates, corresponding concerns are alleviated.

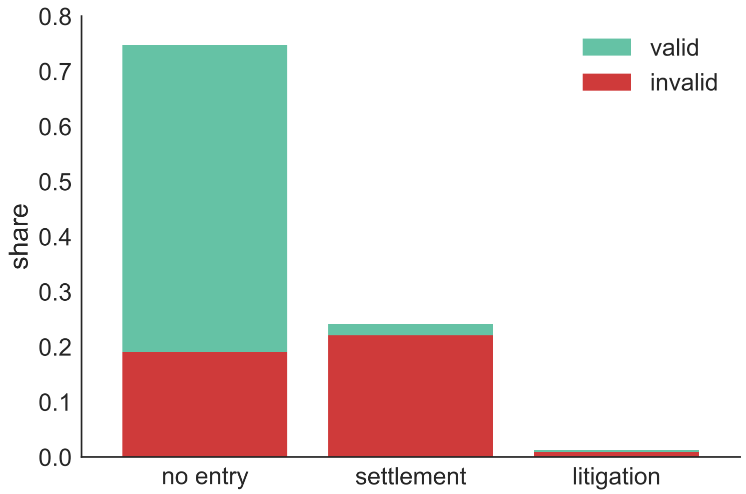
3.5 Model Predictions

Equipped with the parameters determined in Section 3.4, I am now in the position to predict unobservable patent system characteristics of interest. As a first application, I derive the share of latently invalid patents in the patent population, i.e., the share of all patents which *would* be fully or partially invalidated if they became subject to a nullity proceeding. In the model, this corresponds to deriving

$$\mathbb{P}(\hat{\imath} < i_0) = F_i(i_0) = \Phi\left(\frac{i_0 - \mu_i}{\sigma_i}\right) \approx 42.0\,\%\,. \tag{3.1}$$

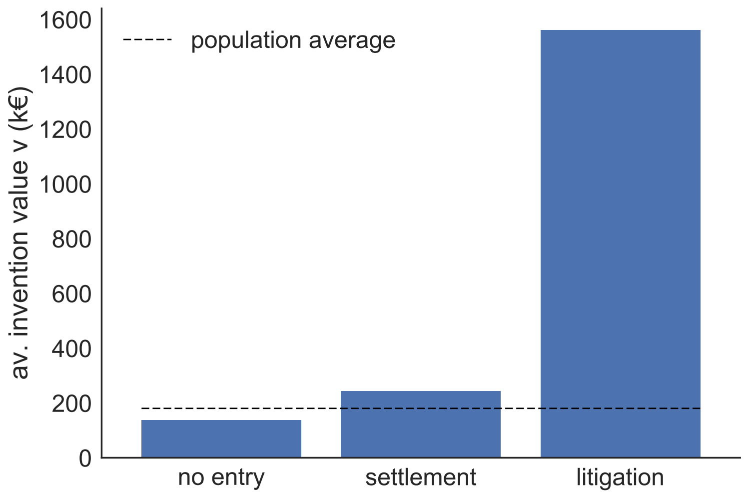
This result may come as a surprise, given that I demanded 75% of all patents subject to nullity proceedings to be judged invalid. Figures 3.7 and 3.8 shed light on the drivers of this outcome. For invalid patents, i.e., patents with $\hat{\imath} < i_0$, entry occurs in approximately every second case, $\mathbb{P}(\text{no entry}\,|\,\text{invalid}) = 45.4\%$. In contrast, for most valid patents the potential infringer never

Figure 3.7: Outcome distribution (baseline calibration)



Notes: Outcome distribution and conditional validity for the baseline calibration of the model (see Table 3.1).

Figure 3.8: Patented invention values (baseline calibration)



Notes: Average invention values by outcome for the baseline calibration of the model (see Table 3.1).

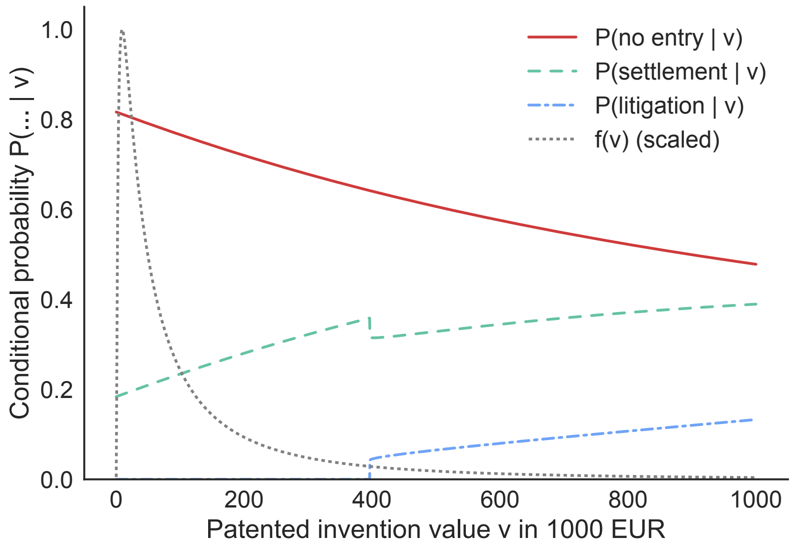
enters the market,

$$\mathbb{P}(\text{no entry} \,|\, \text{valid}) = 96.0\%, \tag{3.2}$$

because he cannot expect to make positive profits given the large inventive step $\hat{\imath}_d$ he has observed. A large inventive step means small chances in winning a potential suit, which goes along with an unfavorable position in settlement negotiations (high bidding and expected asking prices). He will only enter if the perceived validity is sufficiently moderate in relation to the value of the patented invention; higher values potentially leading to higher returns from entry. As a result, the model's first stage, i.e., the endogeneity of disputes, has profound implications for validity and value at later stages. While invalidity rates lie at 42.0% in the patent population and at 25.5% in the case of no entry in the baseline calibration, they are considerably higher for litigated patents (75.0%) and the highest for settled patents (91.5%). Hence, latent invalidity is predicted to be considerably lower than estimated in Henkel and Zischka (2016) and still noticeably lower than in Schankerman and Schuett (2016), whose estimates range from 65% to above 80%. Generally, for findings based on expert interviews and surveys, differences might partly be explained by the calibration results. The rate of latent invalidity is higher in settlements than in litigation. A legal practitioner only observing patents which become subject of a dispute might thus be led to the fallacious conclusion that litigated patents on average have a smaller inventive step than the average patent in the population, and that they are accordingly less stable from a legal point of view.

Concerning the second patent characteristic, patented invention value $\hat{v}$, the baseline calibration again suggests substantial selection (see Figure 3.8). Patents which never become subject of a dispute constitute the majority of all patents, with around 74.7%. They are associated with an average patented invention value of 138 k€, which corresponds to 0.76 of the population mean of 180 k€. Patented invention values for settled patent disputes (24.1%) average to 244 k€, or 40% more than the population mean. While this is already indicative of selection with respect to value, the negotiation stage induces substantial value selection for litigated patents. Parties are aware of the considerably higher cost associated with trial in court as opposed to settlement. Hence, even under divergent expectations concerning validity, the infringer's maximum settlement demand B will exceed the patent holder's minimum settlement demand A, thus allowing parties to settle, unless the stakes are very high. If patents are litigated, the average patented invention value lies at 1.56 million €, or 8.7 times the population mean. The ratio is even more extreme for litigated patents which are valid. According to the calibration, they are 14.5 times as valuable as the average patented invention. The finding that litigated patents are substantially more valuable than the average is in line with results in the empirical literature, which has found a significant, positive relationship between typical proxies for value and the likelihood of infringement and nullity proceedings (Lanjouw and Schankerman, 2001, 2003). Harhoff et al. (2003a) find that patents which have survived

Figure 3.9: Outcome probabilities as a function of patented invention value



Notes: Outcome probabilities conditional on patented invention value. The gray dotted line indicates the probability density function $f(v)$ of patented invention values.

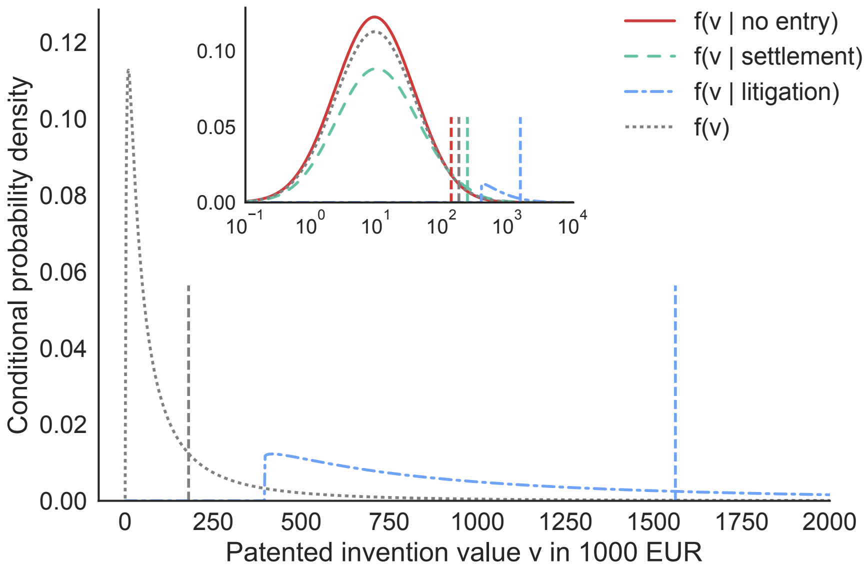
an annulment proceeding are 42.6 times more valuable than an unchallenged patent. In the model, the closest analogy is the ratio $\mathbb{E}[v \mid \text{valid, litigation}]/\mathbb{E}[v \mid \text{no entry}]$. According to the baseline calibration, $\mathbb{E}[v \mid \text{valid, litigation}] = 2.62$ million € and $\mathbb{E}[v \mid \text{no entry}] = 138$ k€. Hence, litigated valid patents are on average 19 times as valuable as patents that never become subject of a dispute. The two findings thus fall within the same order of magnitude.

Figures 3.9 and 3.10 provide a few further insights. First, as visible in Figure 3.9, entry becomes much more likely for valuable patents. Over a relevant range of patented invention values, the probabilities for settlement and for litigation increase by a similar amount (despite different curvature), at the expense of the probability for no entry occurring. Second, due to fixed legal costs, litigation is only entered if patented invention value is sufficiently high. In fact, the litigation probability is zero for patented inventions below a minimum threshold value, which lies at approximately

$$v_{\text{lit, min}} \approx 396.3\,\text{k€}\,, \tag{3.3}$$

a value which is considerably above the median of 67.44 k€ and the mean of 180.2 k€. This is clearly visible in Figure 3.10, which displays the value distribution conditional on litigation $f(v \mid \text{litigation})$. The existence of a threshold value is not only intuitive, it may also be testable in future empirical work. Finally, from inspecting the inset in Figure 3.10, it seems that the conditional distributions are closely related to the log-normal distribution. Deviations are the largest when conditioning on litigation, where the distribution essentially only comprises the log-normal tail.

Figure 3.10: Patented invention value distribution by outcome



Notes: Patented invention value distribution conditional on litigation (blue dash-dotted line) in comparison to the unconditional distribution (gray dotted line). Using a logarithmic x-axis, the inset additionally shows the density functions conditional on no entry (red solid line) and on settlement (green dashed line). Dashed vertical lines indicate the corresponding expectation values.

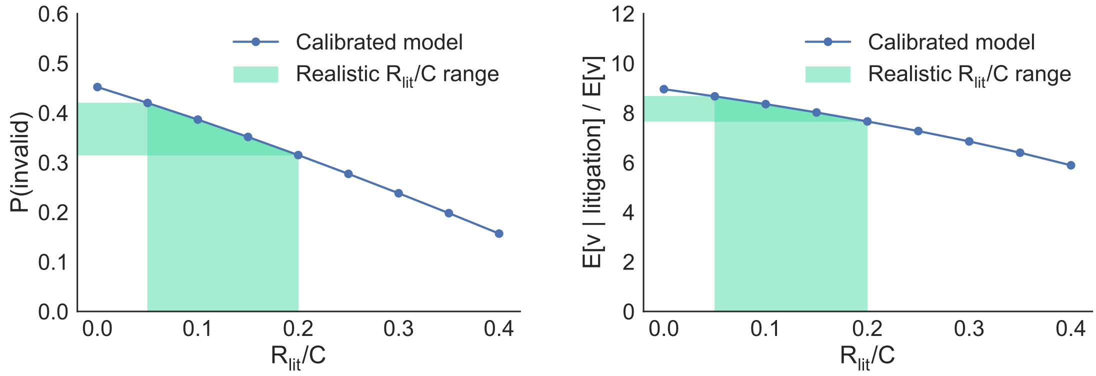
In the appendix, Figures C.3 and C.4 display the joint probability density functions of $\hat{\imath}$ and $\hat{v}$. By definition, $\hat{\imath}$ and $\hat{v}$ are independent random variables and are hence uncorrelated in the patent population (cf. Figure C.3). However, due to selection, they exhibit positive correlation within each outcome subsample (cf. Figure C.4 for the subsample of litigated patents).

In summary, the calibration results suggest that the entry and the negotiation stages drive different dimensions of selection. While selection with respect to validity primarily is a consequence of the potential infringer's decision at the entry stage, selection with respect to value is predominantly driven by the negotiation stage.

3.6 Sensitivity Analysis

In this section, I report results on the sensitivity of the model's predictions when calibrating under varying parameter assumptions. I start with the parameter R_{lit}, which represents the patent holder's gain from building a reputation for litigiousness (in monetary terms) when entering litigation, that I have so far set in an ad-hoc fashion. Figure 3.11 shows the results of a series of calibrations from $R_{\text{lit}} = 0$ to $R_{\text{lit}} = .4C$. As highlighted in Figure 3.11, for a plausible range between 5% and 20% of total legal cost, the estimated share of latently invalid patents in the population varies between 42.0% and 31.5%, respectively (left panel). The average value of litigated patents (right panel) shifts from 156 k€ to 138 k€, i.e., from 8.67 to 7.66

Figure 3.11: Calibration sensitivity – Reputation parameter



Notes: Calibration sensitivity with respect to R_{lit}/C. The left panel shows the predicted share of latently invalid patents $\mathbb{P}(\text{invalid})$ under calibrations with different litigation reputation parameters R_{lit} (as a share of total legal cost C). Analogously, the right panel displays the expected patented invention values of litigated patents $\mathbb{E}[v|\text{litigation}]$ in units of the population average $\mathbb{E}[v]$. The model is in each case calibrated to reproduce $\mathbb{P}(\text{litigation}) = 1.2\%$ and $\mathbb{P}(\text{invalid} \mid \text{litigation}) = 75\%$.

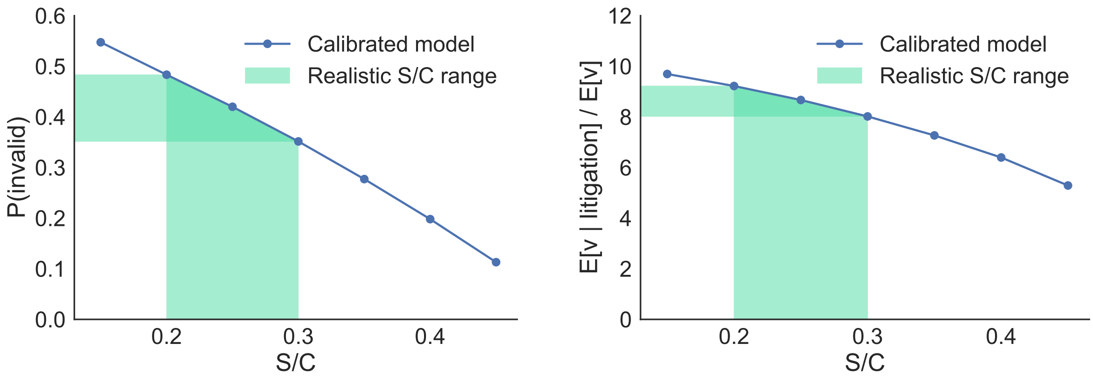
times the value of an average patent in the population.

A second dimension of sensitivity worth exploring is settlement cost as a fraction of total legal cost, S/C. Note that throughout the analysis in this section I maintain the assumptions of Section 3.4.4, in particular the assumption of identical settlement cost for both plaintiff and defendant, $S_p \equiv S_d =: S$. Figure 3.12 displays the change of the probability $\mathbb{P}(\text{invalid})$ of latent invalidity for a random patent in the population (left panel) and the expected value $\mathbb{E}[v|\text{litigation}]$ of a litigated patent (right panel) for calibrations under different assumptions of S/C. Varying S/C between 20% and 30% (green shaded area), while maintaining the remaining exogenous parameters as indicated in Table 3.1, moves the fitted share of latently invalid patents from 48.3% to 35.2%. At the same time, the average value of a litigated patent $\mathbb{E}[v|\text{litigation}]$ is shifted from 166 k€ to 144 k€ in calibration, which corresponds to 9.22 $\mathbb{E}[v]$ and 8.02 $\mathbb{E}[v]$, respectively.

In summary, I observe that for a broad range of parametric assumptions for R_{lit}/C and S/C, calibrations of the model lead to similar conclusions as the baseline case: the share of latently invalid patents in the population is consistently estimated to be below 50%, and litigated patents to be between 7 and 10 times as valuable as a patent in the population, on average.

Finally, I explore the sensitivity of the model calibration to inaccuracy in the distribution of patent values. Note that while technically similar, this exercise is accounting for a conceptually different source of error than the preceding discussion. Whereas variations of R_{lit}/C and S/C address exogenously fixed parameters, the parameters μ_v and σ_v of the log-normal distribution of patent values have been determined by a fit to data provided in the literature (cf. Sections 3.4.2 and 3.4.3). In the following, I thus examine in how far the model calibra-

Figure 3.12: Calibration sensitivity – Settlement cost



Notes: Calibration sensitivity with respect to S/C. The left panel shows the predicted share of latently invalid patents $\mathbb{P}(\text{invalid})$ under calibrations with different settlement cost parameters $S_p \equiv S_d =: S$ (as a share of total legal cost C). Analogously, the right panel displays the expected patented invention value of litigated patents $\mathbb{E}[v|\text{litigation}]$ in units of the population average $\mathbb{E}[v]$. The model is in each case calibrated to reproduce $\mathbb{P}(\text{litigation}) = 1.2\%$ and $\mathbb{P}(\text{invalid} \mid \text{litigation}) = 75\%$.

tion would change if the results in the literature were different. However, I limit the analysis to modifications of mean patent value $\mathbb{E}[v] = \exp(\mu_v + \sigma_v/2)$, while holding constant standardized higher moments, such as skewness and kurtosis, and thus preserving the intuitive "distributional shape". This can easily be achieved by confining parameter variation to μ_v, a shift of which by $\Delta\mu_v$ is equivalent to a rescaling of patented invention value by a factor of $\exp(\Delta\mu_v)$, as shown in Footnote 24. Hence, mean and standard deviation are rescaled by the same factor and standardized moments are unaffected.[28]

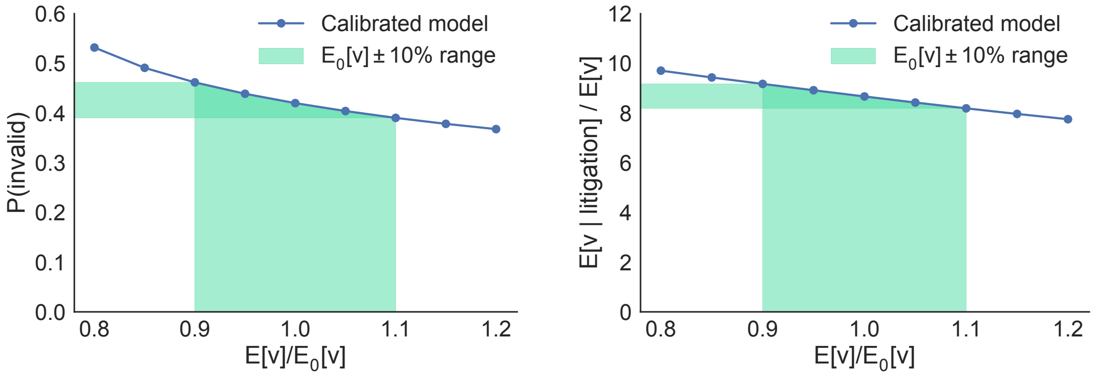
Figure 3.13 depicts the results of this final calibration exercise. When tuning $\mathbb{E}[v]$ over a range of ±10% around the baseline average patented invention value $\mathbb{E}_0[v]$ (green shaded area), the calibrated share of latently invalid patents $\mathbb{P}(\text{invalid})$ varies between 46.1% and 39.0% (left panel). Over the same range, which corresponds to the interval $\mathbb{E}[v] \in [162\,\text{k€}, 198\,\text{k€}]$, the ratio of the average value of a litigated patent and a random patent decreases from around 9.17 to 8.19 (right panel). Note that in absolute terms, $\mathbb{E}[v \mid \text{litigation}]$ increases with $\mathbb{E}[v]$, as one would expect.

Hence, in addition to alternative parameter regimes, the baseline conclusions are qualitatively robust to misspecification of the distribution of patented invention value. For instance, such imprecisions could arise from measurement error that biases the results in the literature which were used in the fit of the value distribution (see Section 3.4.3). Besides, misspecification could be the result of inappropriate functional form assumptions (cf. Eq. 3.1).

[28]The former is an immediate consequence of the linearity of the expectation and the behavior of the variance under multiplication by a scalar a, $\text{Var}[a\hat{x}] = a^2\text{Var}[\hat{x}]$, the latter of the definition of standardized moments $\tilde{\mu}_k$,

$$\tilde{\mu}_k = \frac{\mu_k}{\sigma^k} = \frac{\mathbb{E}[(\hat{x}-\mu)^k]}{\text{Var}[\hat{x}]^{k/2}} = \frac{\mathbb{E}[(a\hat{x}-a\mu)^k]}{\text{Var}[a\hat{x}]^{k/2}} .$$

Figure 3.13: Calibration sensitivity – Distribution of patented invention value



Notes: Calibration sensitivity with respect to the distribution of patented invention value. The left panel shows the predicted share of latently invalid patents $\mathbb{P}(\text{invalid})$ under calibrations with different $\mathbb{E}[v]$ (in units of the baseline value $\mathbb{E}_0[v]$). Analogously, the right panel displays the expected patented invention value of litigated patents $\mathbb{E}[v|\text{litigation}]$ in units of the population average $\mathbb{E}[v]$. Note that while the relative factor decreases, $\mathbb{E}[v|\text{litigation}]$ in fact increases with $\mathbb{E}[v]$ (not explicitly shown). The model is in each case calibrated to reproduce $\mathbb{P}(\text{litigation}) = 1.2\%$ and $\mathbb{P}(\text{invalid} \mid \text{litigation}) = 75\%$.

3.7 Impact Simulation of Policy Measures

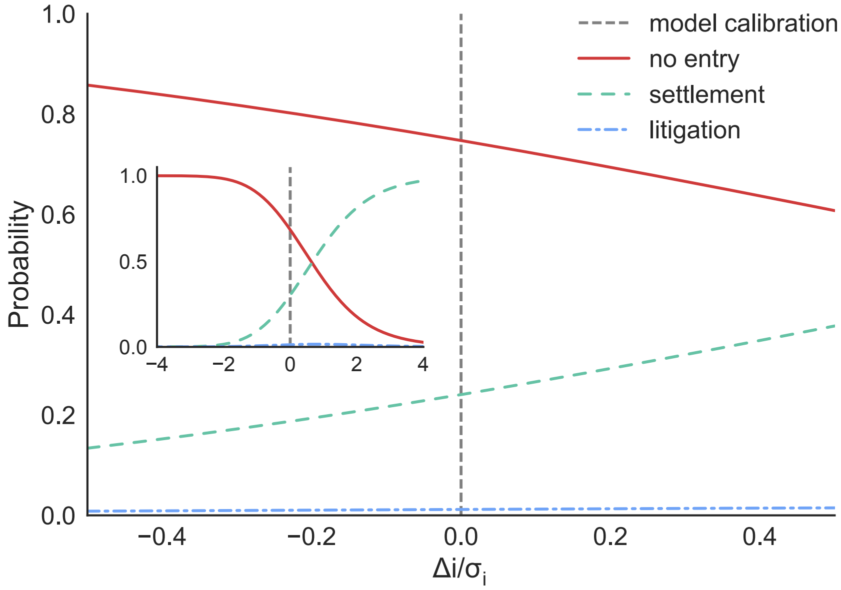
I now turn to an impact analysis of different policy measures. In each case, I compare the modified outcomes to the predictions of the calibrated baseline model defined by the parameters in Table 3.1. Note that the subsequent analysis does not allow for the prediction of general equilibrium effects, but that it is addressing a ceteris paribus counterfactual: Holding constant the remaining characteristics of the patent population, would the impact of policy reform be sizeable? This is non-trivial, even within the stylized world of the model. Depending on the initial state, i.e., the latent characteristics of the patent litigation system, policy reform may have highly non-linear consequences, with major and costly reform potentially translating into negligible change.[29] In the following discussion, “raising the inventive step threshold” refers to the *practice* of the patent office and the courts, not necessarily a change in the wording of the law. Such changes can be effectuated independently in the patent office and the courts. For example, patent examiners can be given more time per application, allowing for more rigorous prior art searches. While such reform increases the de-facto threshold for patent grants, court decisions are unaffected.

3.7.1 Raising the Courts’ and the Patent Office’s Inventive Step Thresholds

First, let me discuss the case when the patent office and the courts raise their respective inventive step thresholds in an analogous manner. To this end, suppose that the patent office’s intensified screening efforts result in $\hat{\imath} \sim \mathcal{N}(\mu_i' = \mu_i + \Delta i, \sigma_i^2)$, while the courts raise their

[29]See Section 3.7.2 for a more detailed discussion in the context of Figure 3.14.

Figure 3.14: Outcome probabilities under changes of court strictness



Notes: Outcome probabilities under ceteris paribus changes Δi of court strictness i_0. At $\Delta i = 0$ (vertical dashed line), the model is calibrated to reproduce $\mathbb{P}$(litigation) = 1.2% and $\mathbb{P}$(invalid | litigation) = 75%. The inset shows a wider range of ± four standard deviations.

validity criterion to $i_0' = i_0 + \Delta i$. Then, from the model's perspective, we find ourselves in an equivalent situation to the one prior to the policy change – nothing has changed in terms of outcome rates; the model is sensitive only to changes in $\mu_i - i_0$. Of course, the absolute number of patent *applications* may change if applicants adjust within a new general equilibrium.[30] This consideration, however, lies outside of the scope of the theoretical approach pursued here, which models the selection process into litigation that the population of granted patents is subject to.

3.7.2 Raising the Courts' Inventive Step Validity Threshold

With the preceding intervention in mind, let me now outline the case where the distribution of inventive steps in the patent population is unchanged, and hence the patent office's effort requirements per application, while the courts raise their validity criterion to $i_0 + \Delta i$, as before.[31] Figure 3.14 depicts the model's predictions for the outcome probabilities of no entry occurring (red solid line), of settlement (green dashed line), and of litigation (blue dotted line) for different levels Δi of court strictness relative to the calibrated baseline case. Let me give an example of how to read the graph. Raising the threshold i_0 by $0.1\,\sigma_i$ leads to a decrease of

[30]Concerning the optimal strictness and effort level of the patent office, Lemley (2001) provides a comprehensive analysis for the US patent system.

[31]Note that in the model, an increase Δi in the courts' validity threshold i_0 is equivalent to a decrease Δi in the average inventive step.

$\mathbb{P}$(no entry) from 74.7% to 72.1%. At the same time, the probability of settlement increases from 24.1% to 26.6% and the probability of litigation from 1.2% to 1.27%.

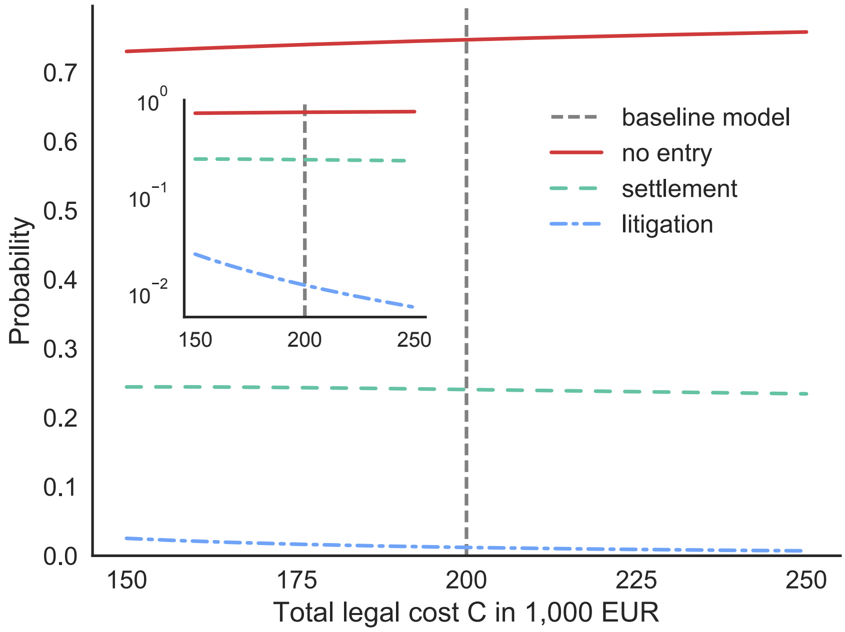
Hence, infringers enter with a higher rate, resulting in a relative increase of the probability of settlement by 10.6% and of the probability of litigation by 5.7%. This is intuitive: In terms of validity before the courts, the patent population is now less stable, causing a dilution of a litigation's deterrence potential. Such policy intervention can in principle have highly non-linear effects depending on the system's initial state, as is especially evident in the inset of Figure 3.14. The calibrated model however suggests that the patent litigation system is in a situation where the intervention has an almost linear impact, resulting in the aforementioned notable effect sizes.

3.7.3 Raising Litigation Cost

Legal costs constitute a different means of tuning the litigation system's selection mechanics. However, while courts could in principle charge arbitrarily high fees for patent cases, the extent to which a policy intervention can reduce total legal cost, is naturally bounded from below. Figure 3.15 explores ceteris paribus changes of total legal cost C around the baseline assumption of $C = 200\,\text{k€}$. Increasing expected total legal cost by 25% relative to the baseline, from 200 k€ to 250 k€, goes along with an increase of the probability of no entry occurring from 74.7% to 75.8%. At the same time, the probabilities of settlement and litigation decrease from 24.1% to 23.4% and from 1.20% to 0.708%, respectively. Speaking in relative terms, $\mathbb{P}$(no entry) and $\mathbb{P}$(settlement) are rather insensitive to changes in total legal cost, while $\mathbb{P}$(litigation) is considerably reduced. This observation is conspicuous when using a logarithmic y-axis, as in the inset of Figure 3.15. From a policy perspective, a decrease of litigation cases by around 41% may seem desirable, abstracting from general equilibrium adjustments. However, in the model, it comes at the cost of reduced entry, which is in turn detrimental for competition.

In summary, given the relative impact on the probabilities of entry and litigation observed in Subsections 3.7.2 and 3.7.3, combining the measures of increasing court validity thresholds and raising court fees might provide an interesting lever to stimulate entry without incurring an upsurge in litigation. To give an example, if the validity threshold is increased by 0.2 standard deviations of the population's inventive step, and court fees are raised by 8.86 k€ (4.43% of baseline total legal cost), the rate of entry increases by 5.1 percentage points, from 25.3% to 30.4%, while the probability of litigation remains unchanged.

Figure 3.15: Outcome probabilities under changes of total legal cost



Notes: Outcome probabilities under ceteris paribus changes of total legal cost C. Over a range of ± 25% relative to the baseline model cost (vertical dashed line), $\mathbb{P}$(no entry) and $\mathbb{P}$(settlement) change relatively little in relative terms, while P(litigation) decreases visibly, as one would expect. This is particularly visible in the inset, in which a logarithmic y-axis is used. At $C = 200\,\text{k€}$ (vertical dashed line), the model is calibrated to reproduce $\mathbb{P}(\text{litigation}) = 1.2\%$ and $\mathbb{P}(\text{invalid} \mid \text{litigation}) = 75\%$.

3.8 Discussion and Outlook

In this section, I discuss the model assumptions' degree of abstraction and outline avenues for further research.

3.8.1 General Setup of the Model

In a first step, let me discuss design choices concerning the general setup of the model. With regard to product market structure, only two possible outcomes are observed in the model: a monopoly, in case of no entry or in case the entrant is successfully sued by the patent holder, or a duopoly, in case of settlement or unsuccessful suit. Both are modeled in a linear Cournot setting, which excludes "strategic" duopolies, in which the parties are able to maintain monopoly prices, either through direct agreement, or indirectly, via adjusted licensing fees. This is in line with antitrust guidelines in the EU and in the US, which prohibit any such anti-competitive practices (European Commission, 2014; U.S. Department of Justice and the Federal Trade Commission, 2017). As an alternative approach, one could maintain the assumption of a duopolistic market structure as a consequence of settlement, but replace it with a situation of perfect competition if the patent is invalidated. However, concerning patent litigation, the implicit assumption of unlimited entry of new firms seems implausible for capital- and knowledge-intensive industries with high fixed costs or sunk investments (cf. Tirole, 1988, Chapter 8). While the model in principle allows for monetary barriers to entry by choosing $C_{\text{entry}} > 0$, the assumptions of Section 3.4.4 refrain from additional impediments beyond the limitation to two competitors. Besides, a more refined model could relax the assumption of perfectly symmetric parties, thus allowing for non-practicing patent holders, a phenomenon increasingly observed in patent litigation in Europe (Darts-ip, 2018), and for competitors inhomogeneous in size.

With regard to the market for technology and its relation to the product market, the model abstracts from the substantial complexity introduced by overlapping intellectual property rights, or "patent thickets" (Galasso and Schankerman, 2010; von Graevenitz et al., 2013). Besides, it abstracts from "complex" products comprised of a multitude of protected inventions (Cohen et al., 2000) and from general purpose technologies, where a single patent can affect multiple product markets (Gambardella and Giarratana, 2013). Instead, the model implicitly makes the strong assumption of a one-to-one correspondence of each patent to an associated product market. While this may constitute an accurate representation for discrete technology areas, such as chemistry, it is a rather stylized depiction for complex technologies, such as telecommunications.

Concerning the institutional setup for challenges of granted patents, I distinguish between proceedings conducted by the patent offices and litigation in the courts. Post-grant opposition, which can be filed within nine months after grant at both the German and the European Patent Office, is not explicitly represented in the model. Rather, the patent population characterized in the calibration of Section 3.4 is to be understood as the ensemble of granted patents, which either remain unchallenged in the nine-month window (around 93-95% of all granted patents) or which survive post-grant opposition.[32] Litigation, in contrast, is a central element of the model. Prior to court proceedings, entrants can always make duopoly profits over a time period $\bar{t}$, reflecting imperfections in the detection of infringement (see Section 3.4.2).[33] If settlement fails, infringement and nullity decisions are taken by a single court of last instance. For the example of the German patent litigation system, this constitutes an abstraction from two institutional features. First, litigation in Germany is bifurcated, with infringement and annulment proceedings being heard by different courts.[34] While nullity suits are most commonly a reaction to infringement charges (Henkel and Zischka, 2016), the two proceedings

[32]Around one third of opposed patents remains unaltered, one third is amended and one third is fully invalidated. See (Harhoff et al., 2007, p. 31) and Chapter 1.

[33]The model abstracts from further imperfections in screening, including never-detected patent infringement. Incorporating such notions could be credible in a model with more complex product market structures.

[34]In Germany, infringement proceedings are treated as standard civil procedures. As such, they are conducted by the courts of ordinary jurisdiction (Landgerichte, Oberlandesgerichte, Bundesgerichtshof). In contrast, annulment proceedings are heard by the Federal Patent Court (Bundespatentgericht), whose judgments can be appealed to the Federal Court of Justice (Bundesgerichtshof, BGH). The BGH hence serves a double role as last instance: as an overseer of the application of the law in infringement proceedings and as a reviewer of the contested decision in both legal and factual regard for appealed validity judgments. (Kühnen, 2013)

can be advanced independently. As a result, it is possible to incur an infringement verdict for a patent which is subsequently invalidated[35] (Cremers et al., 2016). The model does not allow for such (temporary) outcomes. Second, decisions of the first instance Federal Patent Court (Bundespatentgericht, BPatG) can be appealed, resulting in a hearing at the Federal Court of Justice (Bundesgerichtshof, BGH). While in the model, settlements can only be reached prior to court hearings, based on the information available at this point in time, litigation over several instances provides a wider scope for finding agreements. Parties may settle prior to the filing of a suit (unobserved), as in the model, or withdraw or settle in the course of the first or second instance proceedings (in the case of appeal). This happens for more than half of the cases brought to trial (Henkel and Zischka, 2016). The later parties settle, the more information is revealed, potentially shifting the odds to one or the other side. In either case, a progression to the next instance reflects the parties' persisting inability to settle, indicating that expectations may still diverge substantially.

The assumption of perfect courts (reveal true $\hat{\imath}$) does not impose a loss of generality from the model's perspective: What the courts perceive as the inventive step, can just be seen as the definition of the underlying "truth." Under appropriate distributional assumptions, the extent to which the part of the assessment error associated with imperfect courts is also *formally* placed at the courts, as opposed to the parties, is irrelevant. In the description of the model chosen here, the parties' assessment error simply contains the uncertainty arising from imperfect courts in its entirety. Introducing $\hat{\imath}_p$ and $\hat{\imath}_d$ as the sum of a true, underlying inventive step $\hat{\imath}$ and the parties' assessment errors $\hat{\varepsilon}_p$ and $\hat{\varepsilon}_d$ thus amounts to nothing more than a way to intuitively introduce correlation between the parties' observations.

Generally, the design of the model developed in this paper is tailored to allow for a characterization of the patent litigation system through calibration. Priority is thus given to an accurate representation of continuously distributed patent characteristics relevant for selection, while maintaining a certain degree of analytical tractability. Conversely, the analysis of the model does not allow for a comprehensive welfare assessment, which would require an extension to a dynamic general equilibrium model, with more flexible technology and product market structures, including downstream businesses and consumers, and an explicit modeling of input factors and knowledge production functions. In addition, such a model would have to comprise a notion of cumulative invention and a framework of repeated interaction. The model developed in this paper is limited to a static incorporation of this idea, through the introduction of the litigation reputation parameter R_{lit}.

3.8.2 Technical Simplifications

In a second step, let me outline some more specific technical simplifications, made in favor of analytical and computational tractability, and to avoid a cluttered and ultimately opaque,

[35] Of the cases where infringement was decided first, 5.9% see a full or partial infringement verdict which is followed by a full invalidation of the focal patent (Cremers et al., 2016, Table 1).

incomprehensible model. I start by discussing the properties of the random variables representing the patent's inventive step, $\hat{\imath}$, and the value of the patented invention, $\hat{v}$. While the requirements for patentability have a multi-dimensional nature in reality (technical character, novelty, inventive step, and industrial application), they are streamlined into the one-dimensional variable $\hat{\imath}$ in the model.[36] Nonetheless, this choice does not entail a major divergence from an exact representation, since especially the latter is a rather low hurdle in practice, excluding only few inventions beyond the other criteria (EPO Case Law of the Boards of Appeal, 2018). A stronger assumption revolves around the treatment of patented invention value $\hat{v}$. As opposed to the inventive step, which parties observe with error, the model assumes $\hat{v}$ to be perfectly observable by both the patent holder and the potential entrant. Divergent expectations are thus limited to the assessment of legal stability of the patent right. In contrast, monopoly and duopoly rents are a deterministic function of $\hat{v}$. While this is undoubtedly a departure from the actual challenge of such estimates, a restriction of this or similar kind is inevitable to keep the model tractable for calibration. Though it may be reasonable to forgo assessment errors for value rather than legal stability, it would be interesting to explore the implications of the opposite or an intermediate assumption in future work.

Further room for refinement lies in the relaxation of the assumption of statistical independence of the inventive step $\hat{\imath}$ and patented invention value $\hat{v}$. The intuition behind this assumption is that a patent protecting an incremental invention might be just as likely to block access to an interesting market, as one constituting a major advance. Keep in mind that in the context of the model, this is a statement conditional on being granted. Value could still be correlated to a patent's technological area and scope (Lerner, 1994; Merges and Nelson, 1990). Recent empirical evidence (Kelly et al., 2017, p. 22, footnote 8) however suggests that inventive step and private value are indeed positively correlated, $\mathrm{Corr}(\hat{\imath}, \hat{v}) > 0$. Since correlation excludes factorization of the joint probability density, $f(i, v) \neq f_i(i) f_v(v)$, incorporating this notion into the model would go along with a major impediment to analytical tractability.[37] Besides, fundamental correlation of $\hat{\imath}$ and $\hat{v}$ might blur the analysis of co-occurrence patterns due to selection. This is best explained by Figures C.3 and C.4 in the appendix. While $\hat{\imath}$ and $\hat{v}$ are uncorrelated in the patent population, due to selection they are positively correlated conditional on litigation. Despite these caveats, it might be worthwhile to explore the sensitivity of the calibration to different levels of correlation, or, in a first attempt, to simulate how outcome rates change ceteris paribus when correlation is gradually introduced. More generally, the exploration of alternative distributional assumptions for $\hat{v}$, $\hat{\imath}$, $\hat{\varepsilon}_p$ and $\hat{\varepsilon}_d$ to those motivated in Section 3.4.1, is left for future work.

In the context of the inventive step, the model introduces a simplification of court decisions. Depending on the revealed $\hat{\imath}$ and the validity threshold i_0, courts judge a patent to

[36] For details, see Section 3.1.

[37] Note that analytical intermediate results analogous to those presented in Appendix C.1 may be indispensable for an exact solution of the model. Since relevant integrands inherently contain discontinuities, as discussed in Section 3.3, adding further layers of numerical integration may be unfeasible.

be either valid or invalid in its entirety. The model thus abstracts from the notion of partial invalidity, which for the purpose of calibration is subsumed under "invalid." The calibration results concerning validity have consequently been interpreted as the latent share of patents which are *fully or partially* invalid. Results by Henkel and Zischka (2016) suggest that 47% of partial annulments comply with the plaintiff's claim and can thus be considered fully invalid. The same might apply to a number of cases where plaintiffs claimed full, but courts decided on partial invalidation.

A different kind of simplification lies in the treatment of total legal and settlement cost as constant parameters. Keep in mind that the quantities C and S are supposed to reflect what parties *expect* when making their decisions. Hence, introducing a probability distribution over legal costs of mean C does not make a difference for risk-neutral parties. If, however, C and S are expected to systematically depend on patented invention value $\hat{v}$ or the true inventive step $\hat{\imath}$, the model could be extended correspondingly. From a technical point of view, this naturally comes at the cost of additional parameters. While a linear relationship, and hence a single additional parameter, may be sufficient for $C(\hat{v})$, settlement costs likely depend on $\hat{\imath}_p$, $\hat{\imath}_d$ and $\hat{v}$ in a non-linear and potentially non-symmetric way.

Two dimensions of heterogeneity lend themselves to further calibrations of the model in follow-on research. First, it may be worthwhile to explore in how far the selection intensity varies by technology area. For instance, the distribution of inventive steps may differ due to particular appropriation environments, due to different levels of technological maturity, due to varying innovation cycles, or due to differing incentives for strategic patenting. Lanjouw and Schankerman (2001, Table 1) show that while the ratio of infringement and annulment cases is comparable across technology areas, overall litigation rates differ considerably. Furthermore, differing market sizes, business models, and levels of competition may lead to heterogeneous patent value distributions across technologies. Exploiting patent renewal data, the empirical literature has found that patent value differs substantially by technology areas (Lanjouw, 1998; Schankerman, 1998). In this context, an extension to the model developed here could consider the possibility that patents primarily held to facilitate cross-licensing might be subject to lower litigation risk, all else equal. For calibration in specific technology subsamples, this may be particularly relevant.[38]

Second, it may be informative to study selection for jurisdictions with differing litigation regulation. For example, under a system of American rule, in which both parties bear their respective litigation costs, conclusions concerning the unobservable validity distribution may differ, even if observed outcome rates are comparable. Besides, the prevalence of suits filed by non-practicing entities strongly depends on the respective field. In fact, annulment rates observed across European countries and applicant types are heterogeneous (Darts-ip, 2018,

[38]For the case of the US semiconductor industry, Lanjouw and Schankerman (2003) argue that litigation is disincentivized as a consequence of cross-licensing practices in an oligopolistic market structure. Nonetheless, evidence by Ziedonis (2003) suggests that litigation rates in the semiconductor industry have risen relative to R&D investment after 1985.

Figures 5 and 7). A challenge to extending the analysis to technology subsamples or other countries is that the calibration of the model necessitates reliable estimates of the patent value distribution.

3.9 Conclusion

In this paper I have developed a divergent expectations model for the selection of patents for litigation. Conceptually, it incorporates an entry decision stage introducing endogeneity of disputes and a negotiation stage separating settlements and litigation. Technically, it is based on two key notions: the stylized representation of a patent's inventive step, which parties observe with error, and an explicit modeling of patented invention values, unlike in previous studies. The paper characterizes the patent litigation system and illuminates the unobservable mechanics of the selection process in a quantitative manner. To this end, the model is calibrated to observable aggregate characteristics of the patent litigation system. The fitted model is in turn used to explore the current state of the system, most prominently the share of latently invalid patents in the population, and to simulate the impact of different forms of policy reform, given the system's current state.

The paper contributes to two strands of literature. First, it complements prior research on the economics of the patent litigation system. While most studies have focused on either theoretical modeling *or* descriptive empirics, this paper develops a structural model that can reproduce empirical outcome rates of patent disputes. Thereby, it provides new insights on the role of patent validity in the selection for litigation. Prior evidence in this dimension is scarce. Besides, the model is the first to explicitly account for the skewed distribution of patent value. Prior empirical findings identifying patent value as a driver of litigation propensity are confirmed. The model however allows to disentangle the origins of selection: Calibration results suggest that the drivers of selection with respect to validity and value lie in separate stages. Second, the paper contributes to prior work on the issue of low-quality patents. Most of the literature has discussed potential negative consequences *conceptually*. Evidence on the *extent* of the issue, however, remains scarce. To advance in this direction, this paper suggests a novel approach to estimate the rate of latent invalidity in the patent population.

The key results are fourfold. First, for reasonable parameter assumptions, the model suggests that despite the fact that 75% of litigated patents are fully or partially invalidated, the share of patents in the population which would be invalidated if they became subject of court proceedings, may lie as low as between 35% and 50%. This outcome is an indication for the presence of a substantial selection bias concerning not only the value of patents, but also their validity – a result not accurately reflected in previous studies. More specifically, the calibration reveals the competitor's entry decision as the pivotal stage for the selection with respect to validity. While only 4% of valid patents become subject of a dispute, as many as 55% of invalid patents see the entry of a competitor. This result has profound implications for an assessment of the dysfunctionality of the patent examination and litigation systems. Although patent rights should indeed be viewed as probabilistic by their holders (Lemley and Shapiro, 2005), this paper suggests that a majority of patent owners can indeed rely on their patent protection – and, *as a result*, rarely incurs litigation.

Second, the model predicts that raising the courts' current validity threshold by 10% of a standard deviation of the patent population's inventive step distribution, could – ceteris paribus – translate into an increase of the probability of entry from 25.3% to 27.9%, an increase of around 10%. In consequence, such a reform may have profound impact on competitive market structures, potentially constituting a lever to transcend otherwise monopolistic regimes, with presumably large benefits for downstream firms and consumers. Besides, the intensified removal of marginally valid patents may spur follow-on innovation, at least in certain technology areas, as Chapter 1 and other recent studies suggest (Galasso and Schankerman, 2015). However, since weaker patent rights reduce ex-ante incentives to innovators, application number and quality may adjust in equilibrium and dampen the above estimates in the long run. Even under the assumption that applicant behavior remains unchanged, these benefits come at a certain price: The model predicts litigation rates to rise by around 5.8%, thus creating higher negotiation and legal cost for firms and possibly the public sector.

Third, given the latent characteristics of the litigation system, a detrimental impact of a reform as above, via increased rates of litigation, may be counteracted by increasing court fees for patent cases in a reasonable manner. Since such reform requires increased scrutiny only for the small fraction of cases handled by the courts, a cost-efficient level of "rational ignorance" at the patent office (Lemley, 2001) can be maintained. Consequently, the proposed combination of policy reforms appears feasible. That being said, court heterogeneity (Lemley, 2010; Gaessler and Lefouili, 2017) will likely persist and may pose a threat to successful implementation throughout the entirety of a jurisdiction.

Fourth, selection with respect to patented invention value is substantial for litigated patents, which are predicted to be 7-10 times more valuable than the average patent. The driver is the negotiation stage, where parties can either come to a settlement or enter litigation. A further finding of the calibrated model is that cases with patented invention values below a threshold of approximately 400 k€ never enter litigation. These predictions can be tested in future empirical work.

The results of this paper may serve as a benchmark for policy makers and practitioners, for instance, in assessing whether examination at the patent office is effective (Lemley, 2001), to what extent the presumption of validity in litigation is reasonable (Lichtman and Lemley, 2007), and in how far policy reform may have impact.

Further research required for a comprehensive welfare assessment includes the calibration of a general equilibrium model incorporating more flexible and more complex market structures, downstream licensees, a more realistic notion of cumulative invention and repeated interaction, and an explicit modeling of input factors and knowledge production functions.

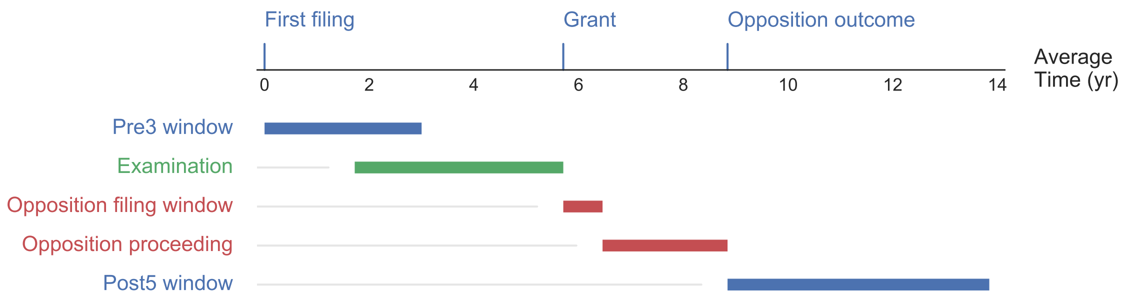
A

Appendix to Chapter 1

Patents and Cumulative Innovation

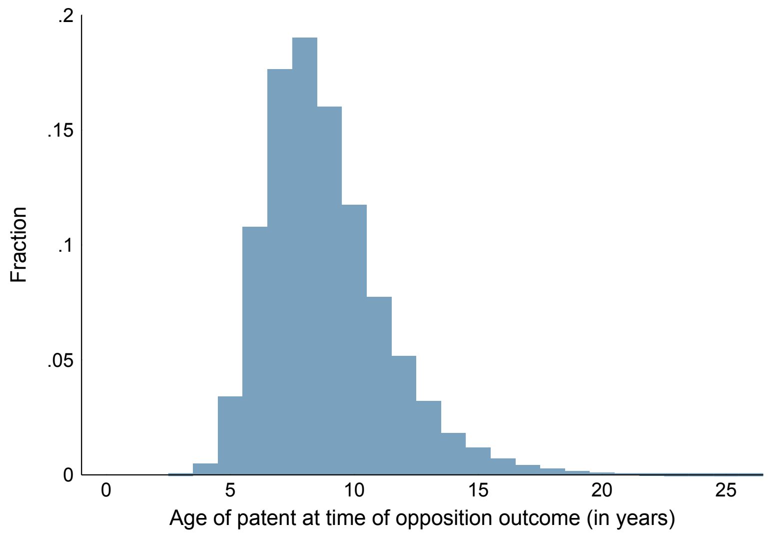
A.1 Figures

Figure A.1: Timeline for the average opposed patent in our sample



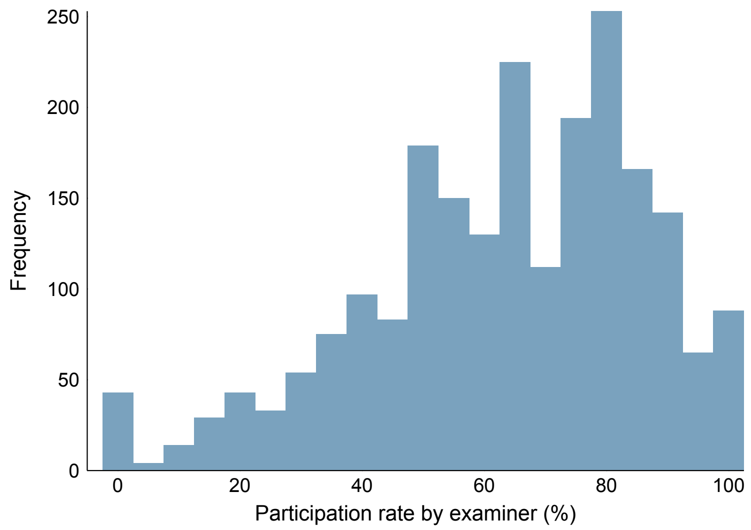
Notes: The Pre3 citation window covers the first three years after filing, the Post5 citation window covers the five years after the opposition outcome.

Figure A.2: Distribution of patent age



Notes: This graph includes all opposition proceedings (on patent level) which are part of our main sample of analysis.

Figure A.3: Distribution of examiner-specific participation rates



Notes: This graph shows the distribution of participation rates at examiner level. Examiners with less than 3 observations are excluded.

Figure A.4: Quantile-Quantile Plot: EP/WO examiner citations vs US citations

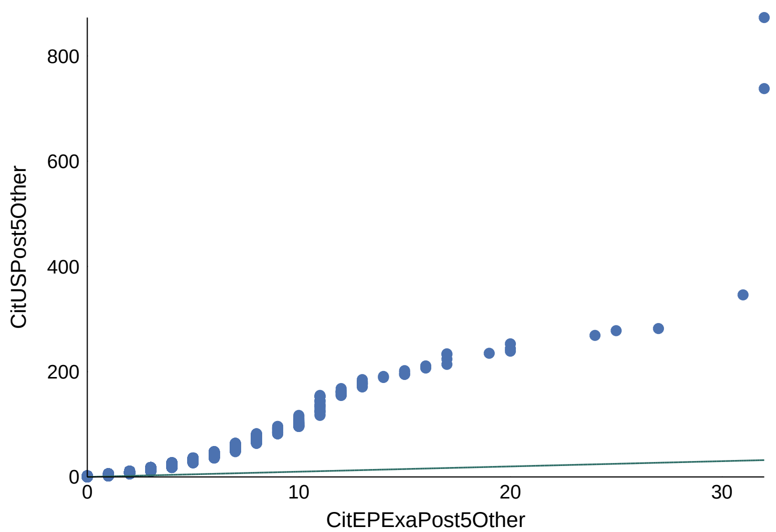
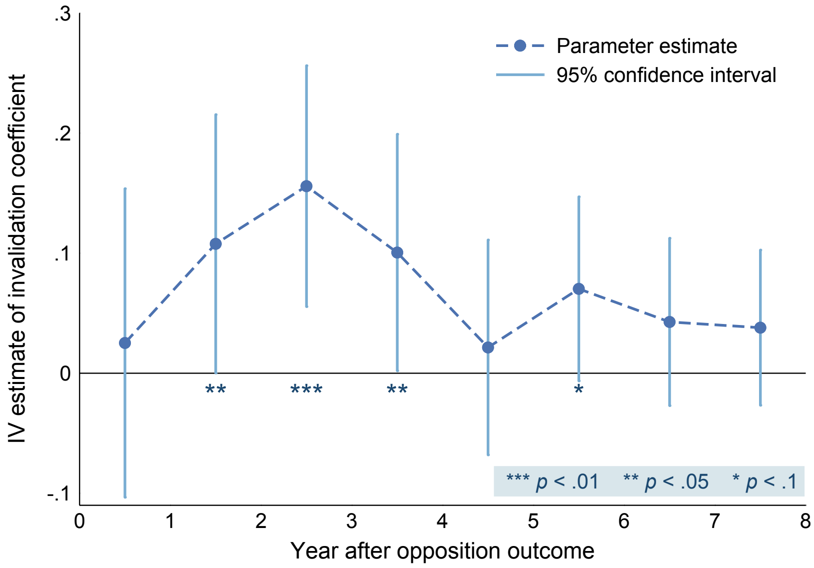
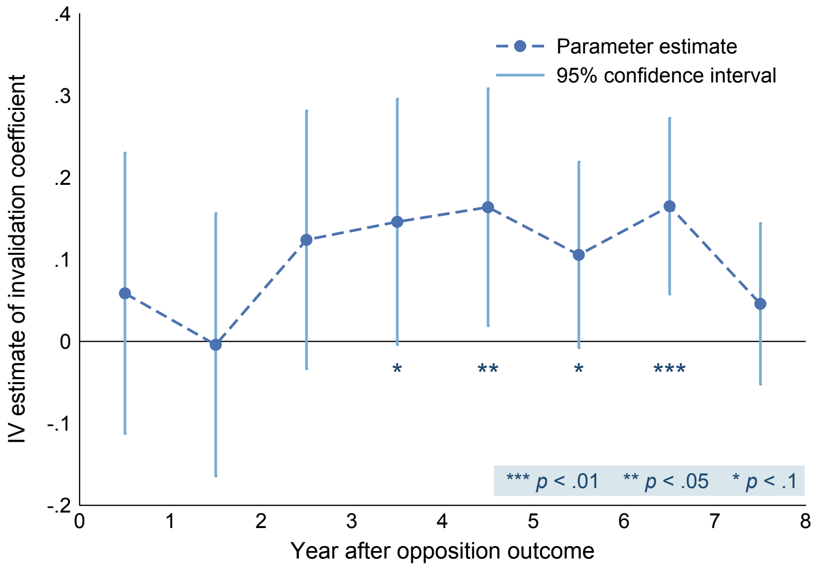


Figure A.5: Timing of the invalidation effect – Chemistry subsample



Notes: This figure is in direct analogy to Figure 1.4 in the main text, but with the sample restricted to chemistry patents. Blue points depict the coefficients of invalidation resulting from IV regressions for each year after opposition outcome, where as the dependent variable we use a dummy citation variable indicating whether or not a patent has been cited in the respective time span. The usual independent citation control variables (Pre3Self and Pre3Other) are also replaced by dummies. Error bars show the corresponding lower and upper 95% confidence limits. The significance levels are indicated by stars below each bar.

Figure A.6: Timing of the invalidation effect – Electr. Engineering / Instruments subsample



Notes: The IV regressions underlying this figure are restricted to electrical engineering and instrument patents, in direct analogy to Figure A.5.

A.2 Tables – Descriptives

Table A.1: Overview and definition of subsamples

Sample definition	N	%
All patents with filed opposition and grant date 1993-2011	49,938	100.00%
– destroyed files	8	0.02%
– unavailable files	150	0.30%
⇒ **available in online file inspection register**	49,780	99.68%
– no readable examiner information	1,203	2.41%
⇒ **with (primary) examiner information**	48,577	97.27%
– patent holder requests revocation	2,031	4.07%
– patent holder withdraws patent	514	1.03%
– opponent withdraws opposition	3,863	7.74%
– no readable opposition information	338	0.68%
– opposition proceeding still pending	470	0.94%
⇒ **with opposition division information**	41,358	82.82%
– first decision after 2011	8,283	16.59%
⇒ **sample of analysis**	33,075	66.23%

Table A.2: Opposition outcomes and appeals

	Oppositions	Appeal rate	Reversal rate
Electrical engineering			
Outcome: valid	982	0.39	0.18
Outcome: invalid	2,458	0.45	0.02
Instruments			
Outcome: valid	1,136	0.46	0.23
Outcome: invalid	3,086	0.50	0.03
Chemistry			
Outcome: valid	3,277	0.43	0.22
Outcome: invalid	9,734	0.50	0.02
Mechanical engineering			
Outcome: valid	3,496	0.43	0.21
Outcome: invalid	6,890	0.45	0.02
Other Fields			
Outcome: valid	743	0.48	0.17
Outcome: invalid	1,273	0.46	0.02

Notes: Reversal rate unconditional on appeal.

Table A.3: Groups of control variables

Group name	**Variables in group**
Year effects	Dummies for grant year Dummies for opposition outcome year
Age effects	Dummies for age in years
Technology effects	Dummies for technology class (34)
Patent characteristics	Dummy for PCT application Dummy for accelerated examination Dummy for examination in Munich Dummies for publication language Size of docdb family Number of IPC classes Number of inventors log(1 + Number of patent literature references)
Patent holder characteristics	Number of applicants Dummies for patent holder country Dummy for patent holder corporation Dummies for patent holder patent portfolio size: tertiles within technology: small – medium – large
Opponent characteristics	Number of opponents Dummies for opponent country Dummy for opponent corporation
Examination characteristics	Duration of examination Duration of wait until examination

A.3 Tables – Instrumental Variable and Complier Analysis

Table A.4: Differences between patents by opposition outcome

Dependent variable	β(Invalidated)	StdErr	t	p
Docdb family size	0.679***	0.108	6.278	0.000
PCT application (d)	0.033***	0.006	5.723	0.000
No of applicants	−0.003	0.004	−0.722	0.470
No of inventors	0.098***	0.020	4.835	0.000
No of claims	1.265***	0.109	11.578	0.000
No of IPC classes	0.006	0.027	0.217	0.828
No of PL refs	0.194***	0.035	5.514	0.000
log(CitEPExaPre3Other)	0.035***	0.007	5.414	0.000
log(CitEPExaPre3Self)	0.012*	0.005	2.463	0.014

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Results from OLS regressions of different patent characteristics on first opposition outcome and sets of indicator variables for technology area, grant year and opposition outcome year. Each row shows the coefficient, the robust standard error, the t-statistic, and the p-value of the indicator for invalidation. The two groups of patents differ significantly, indicating the necessity of the instrumental variable approach. One is added to all citation variables before taking the logarithm to include patents with no citations.

Table A.5: Differences between patents by examiner participation

Dependent variable	β(Ex. part.)	StdErr	t	p
Docdb family size	−0.092	0.128	−0.718	0.473
PCT application (d)	0.003	0.006	0.464	0.643
No of applicants	0.004	0.004	1.109	0.268
No of inventors	0.035†	0.021	1.654	0.098
No of claims	−0.002	0.124	−0.014	0.989
No of IPC classes	0.012	0.029	0.415	0.678
No of PL refs	0.003	0.037	0.083	0.934
log(CitEPExaPre3Other)	0.002	0.007	0.313	0.754
log(CitEPExaPre3Self)	0.004	0.005	0.837	0.403

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Results from OLS regressions of different patent characteristics on the instrumental participation variable and sets of indicator variables for technology area, grant year and opposition outcome year. Each row shows the coefficient, the robust standard error, the t-statistic, and the p-value of the "Examiner participation" indicator. Patents with and without participation of the granting examiner in opposition do not differ significantly. One is added to all citation variables before taking the logarithm to include patents with no citations.

Table A.6: Probit regressions of instrumental dummy variable "Examiner participation in opposition proceeding" on patent and examination characteristics

	(1)	(2)	(3)	(4)
Estimation method	Probit	Probit	Probit	Probit
Dependent variable	Exam. part.	Exam. part.	Exam. part.	Exam. part.
log(No of claims)	-0.031^{***}	-0.021^{***}	-0.004	-0.005
	(0.004)	(0.004)	(0.004)	(0.004)
log(CitEPExaPre3Other)	$-0.008^{\dagger}$	-0.004	0.001	0.001
	(0.005)	(0.005)	(0.005)	(0.005)
log(CitEPExaPre3Self)	0.003	0.007	0.005	0.007
	(0.006)	(0.006)	(0.007)	(0.007)
PCT application (d)		-0.045^{***}	-0.001	-0.002
		(0.006)	(0.007)	(0.007)
Accelerated examination (d)		-0.012	0.023^{**}	0.021^{*}
		(0.008)	(0.008)	(0.009)
Examined in Munich (d)		0.121^{***}	0.017^{*}	0.017^{*}
		(0.008)	(0.008)	(0.008)
Publication language: German (d)		0.013	0.011	0.011
		(0.010)	(0.010)	(0.010)
Publication language: English (d)		0.033^{**}	0.014	0.003
		(0.010)	(0.010)	(0.011)
Docdb family size		-0.001^{**}	0.000	0.000
		(0.000)	(0.000)	(0.000)
No of IPC classifications		0.006^{***}	0.001	0.001
		(0.001)	(0.001)	(0.001)
No of inventors		0.002	$0.003^{\dagger}$	$0.003^{\dagger}$
		(0.002)	(0.002)	(0.002)
log(Patent backward references)		0.003	0.002	0.001
		(0.005)	(0.006)	(0.006)
Duration of examination (yr)		-0.015^{***}	0.005	0.004
		(0.002)	(0.006)	(0.007)
Duration of wait (yr)		-0.014^{***}	0.008	0.007
		(0.003)	(0.007)	(0.007)
Year effects	No	No	Yes***	Yes***
Age effects	No	No	Yes*	Yes*
Technology effects	No	No	Yes***	Yes***
Patent holder characteristics	No	No	No	Yes*
Opponent characteristics	No	No	No	Yes
Model degrees of freedom	3	14	96	110
χ^2-statistic	73.7	572.9	2,751.0	2,772.1
Pseudo-R^2	0.002	0.014	0.072	0.073
Observations	33,075	33,075	33,075	33,075

Marginal effects; Robust standard errors in parentheses

(d) for discrete change of dummy variable from 0 to 1

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: One is added to all citation variables before taking the logarithm to include patents with no citations. A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.7: LATE discussion – Complier shares

	Binary instrument			
	Exam. part.	$\hat{p}(\text{Inv}) < q(.25)$	$\hat{p}(\text{Inv}) < q(.5)$	$\hat{p}(\text{Inv}) < q(.75)$
P(Invalidated)	0.7087	0.7087	0.7087	0.7087
P(Instrument = 1)	0.6770	0.2500	0.5000	0.7500
P(Complier)	0.0661	0.2110	0.1987	0.2046
P(Complier | Invalidated)	0.0301	0.2233	0.1402	0.0722
P(Complier | Not Inv.)	0.1535	0.1811	0.3411	0.5267

Notes: This table shows the share of complier patents in the full sample, P(Complier), the share among invalidated patents, P(Complier | Invalidated), and the share among non-invalidated patents, P(Complier | Not Inv.), with respect to different binary instruments. The first column uses the examiner participation indicator variable, the remaining columns transform the probit-predicted invalidation probability instrument $\hat{p}$ of Eq. (1.2) into binary instruments by splitting at the 25th, 50th, and 75th percentile, respectively. For the examiner participation instrument, the population share of compliers lies at around 6.6%, which is comprised of a share of 3.0% for invalidated patents and 15.4% for non-invalidated patents.

Following the notation of Angrist and Pischke (2009, Section 4.4.4), we can write a patent i's potential treatment status as D_{1i} when the instrument is $Z = 1$ and as D_{0i} when $Z = 0$. "Complier" patents are then defined as those whose treatment status is sensitive to the instrument, i.e., $D_{1i} = 0$ (no invalidation) and $D_{0i} = 1$ (invalidation) in the above context. In a potential outcomes framework, the Wald estimand can be interpreted as a local average treatment effect (LATE) on the subpopulation of compliers (Imbens and Angrist, 1994). They have to be distinguished from "always-takers" with $D_{1i} = D_{0i} = 1$, and "never-takers" with $D_{1i} = D_{0i} = 0$. The calculations of this table rely, inter alia, on the monotonicity assumption $D_{0i} \geq D_{1i} \forall i$, i.e., on excluding the existence of "defiers" with $D_{1i} = 1$ and $D_{0i} = 0$.

Table A.8: LATE discussion – Complier characteristics

Binary characteristic x	$\text{E}[x]$	$\text{E}[x \mid \text{complier}]$	$\text{E}[x \mid \text{complier}]$ / $\text{E}[x]$		$p(\text{Ratio} = 1)$
DOCDB family size > 8	0.480	0.496	1.033	(0.080)	0.678
PCT application (d)	0.436	0.425	0.975	(0.086)	0.770
No of applicants > 1	0.061	0.032	0.521	(0.315)	0.129
No of inventors > 2	0.421	0.369	0.878	(0.092)	0.182
No of claims > 11	0.460	0.470	1.021	(0.083)	0.796
No of IPCs > 2	0.393	0.335	0.854	(0.100)	0.142
No of PL lit refs > 4	0.497	0.480	0.966	(0.080)	0.667
CitEPExaPre3Other > 0	0.407	0.387	0.952	(0.093)	0.606
CitEPExaPre3Self > 0	0.230	0.175	0.761	(0.142)	0.092

Notes: This table explores in how far the complier subpopulation differs from the full sample of opposed patents with respect to a series of patent characteristics. Since the underlying calculation relies on characteristics being binary, count variables are split at their indicated median. The first column indicates the share $\text{E}[x] = \text{P}(x = 1)$ of patents with $x = 1$ in the entire population, the second column indicates the corresponding share $\text{E}[x \mid \text{complier}]$ among complier patents. The third column shows the relative likelihood that complier patents have the binary characteristic x indicated on the left. The corresponding robust standard errors shown in parantheses are derived using seemingly unrelated estimation. Most characteristics occur among complier patents with similar rates as in the full sample. Exceptions are the share of patents with more than one applicant and the share of patents with self citations (added by EP examiners), both of which are lower among complier patents. However, none of the ratios is significantly different from one on a 5% level, as shown in column four. Compliers are defined as in the notes of Table A.7.

A.4 Tables – Robustness

Table A.9: Impact of invalidation on EP/WO citations – sizes of focal and citing patent holders – chemistry subsample

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExa…Post5Other)	Large	Non-large	Large	Non-large
Patent holder subsample	Large	Large	Non-large	Non-large
Invalidated (d)	0.130	−0.043	0.159*	0.236*
	(0.128)	(0.154)	(0.066)	(0.102)
log(No of claims)	0.025*	0.030**	0.013†	0.031**
	(0.011)	(0.011)	(0.007)	(0.010)
log(CitEPExaPre3Other)	0.033**	0.063***	0.051***	0.070***
	(0.011)	(0.012)	(0.007)	(0.010)
log(CitEPExaPre3Self)	0.019	−0.011	0.027*	−0.005
	(0.012)	(0.013)	(0.011)	(0.013)
Year effects	Yes**	Yes***	Yes***	Yes***
Age effects	Yes	Yes	Yes***	Yes
Technology effects	Yes**	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes*	Yes	Yes	Yes
Patent holder characteristics	Yes**	Yes†	Yes*	Yes***
Opponent characteristics	Yes	Yes	Yes*	Yes†
Underidentification test	23.1	23.1	113.1	113.1
Weak identification test	63.0	63.0	197.8	197.8
Observations	4,328	4,328	8,670	8,670

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table explores the impact of invalidation on EP/WO examiner citations *in the chemistry subsample* with respect to the differences in size between the holder of the citing patent (dependent variable) and the holder of the focal patent (subsample). Columns (1) and (2) show the effect of invalidation on citations to patents held by large and non-large patent owners, respectively, for the subsample of patents held by large patent owners, Columns (3) and (4) analogously for the subsample of patents held by non-large patent owners. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.10: Impact of invalidation on EP/WO citations – patent thickets and patent fences – chemistry subsample

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExaPost5…)	Other	Other	Other	Other
Subsample	Thicket	No thicket	Fence	No fence
Invalidated (d)	−0.149	0.245*	0.282	0.326**
	(0.189)	(0.104)	(0.201)	(0.110)
log(No of claims)	0.052*	0.047***	0.017	0.048***
	(0.021)	(0.010)	(0.019)	(0.010)
log(CitEPExaPre3Other)	0.087***	0.098***	0.079***	0.104***
	(0.023)	(0.010)	(0.018)	(0.011)
log(CitEPExaPre3Self)	−0.003	−0.001	0.004	0.017
	(0.027)	(0.013)	(0.018)	(0.014)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes	Yes*	Yes	Yes
Technology effects	Yes**	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes	Yes†	Yes	Yes
Patent holder characteristics	Yes	Yes*	Yes	Yes†
Opponent characteristics	Yes	Yes	Yes	Yes
Underidentification test	44.8	77.2	33.4	109.1
Weak identification test	53.5	221.8	56.7	216.4
Observations	1,613	10,786	3,629	9,364

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table explores the different effects of invalidation on EP/WO examiner citations *in the chemistry subsample* in the presence or absence of patent thickets and patent fences. Columns (1) and (2) represent a sample split with respect to the presence of a patent thicket in the focal patent's technology area. We consider a thicket to be present if the area triples variable derived by von Graevenitz et al. (2011) lies at or above the 90th percentile in the full sample. Columns (3) and (4) show the effect of invalidation for a sample split with respect to the presence of a patent fence erected by the holder of the focal patent. We consider a fence to be present if we find at least one similar patent by the focal patent owner prior to opposition. The similarity measure we use is sensitive to the title, the claims, the technology area and the full text of the patent. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.11: Impact of invalidation on EP/WO citations – sizes of focal and citing patent holders – electrical engineering / instruments subsample

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExa...Post5Other)	Large	Non-large	Large	Non-large
Patent holder subsample	Large	Large	Non-large	Non-large
Invalidated (d)	0.016	−0.026	0.080	0.309*
	(0.166)	(0.253)	(0.107)	(0.150)
log(No of claims)	0.004	0.024	0.026**	0.067***
	(0.014)	(0.017)	(0.008)	(0.012)
log(CitEPExaPre3Other)	0.078***	0.103***	0.078***	0.109***
	(0.015)	(0.016)	(0.010)	(0.014)
log(CitEPExaPre3Self)	0.039†	0.003	0.015	0.072**
	(0.021)	(0.023)	(0.018)	(0.024)
Year effects	Yes†	Yes***	Yes***	Yes***
Age effects	Yes	Yes	Yes**	Yes
Technology effects	Yes*	Yes***	Yes***	Yes***
Patent characteristics	Yes*	Yes***	Yes***	Yes***
Examination characteristics	Yes	Yes	Yes	Yes
Patent holder characteristics	Yes	Yes*	Yes	Yes†
Opponent characteristics	Yes	Yes**	Yes	Yes
Underidentification test	42.8	42.8	46.9	46.9
Weak identification test	53.1	53.1	96.2	96.2
Observations	2,547	2,547	5,105	5,105

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table explores the impact of invalidation on EP/WO examiner citations *in the electrical engineering / instruments subsample* with respect to the differences in size between the holder of the citing patent (dependent variable) and the holder of the focal patent (subsample). Columns (1) and (2) show the effect of invalidation on citations to patents held by large and non-large patent owners, respectively, for the subsample of patents held by large patent owners, Columns (3) and (4) analogously for the subsample of patents held by non-large patent owners. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.12: Impact of invalidation on EP/WO citations – patent thickets and patent fences – electrical engineering / instruments subsample

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExaPost5...)	Other	Other	Other	Other
Subsample	Thicket	No thicket	Fence	No fence
Invalidated (d)	−0.187	0.319	0.092	0.400†
	(0.205)	(0.231)	(0.188)	(0.219)
log(No of claims)	0.076**	0.061***	0.062**	0.055***
	(0.026)	(0.013)	(0.019)	(0.014)
log(CitEPExaPre3Other)	0.171***	0.153***	0.146***	0.153***
	(0.026)	(0.014)	(0.022)	(0.014)
log(CitEPExaPre3Self)	0.107†	0.027	0.022	0.089***
	(0.055)	(0.021)	(0.027)	(0.026)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes*	Yes	Yes	Yes
Technology effects	Yes***	Yes***	Yes*	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes	Yes	Yes	Yes
Patent holder characteristics	Yes	Yes*	Yes*	Yes†
Opponent characteristics	Yes	Yes*	Yes*	Yes**
Underidentification test	32.0	63.7	41.8	39.8
Weak identification test	46.7	91.1	44.9	90.4
Observations	1,097	6,200	1,844	5,798

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table explores the different effects of invalidation on EP/WO examiner citations *in the electrical engineering / instruments subsample* in the presence or absence of patent thickets and patent fences. Columns (1) and (2) represent a sample split with respect to the presence of a patent thicket in the focal patent's technology area. We consider a thicket to be present if the area triples variable derived by von Graevenitz et al. (2011) lies at or above the 90th percentile in the full sample. Columns (3) and (4) show the effect of invalidation for a sample split with respect to the presence of a patent fence erected by the holder of the focal patent. We consider a fence to be present if we find at least one similar patent by the focal patent owner prior to opposition. The similarity measure we use is sensitive to the title, the claims, the technology area and the full text of the patent. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.13: Impact of invalidation on EP/WO citations – exclusion of particular cases

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExaPost5...)	Other	Other	Other	Other
Subsample	No dead patents	No acc exam	No rev appeals	No appeals
Invalidated (d)	0.270***	0.244**	0.317***	0.171†
	(0.072)	(0.087)	(0.070)	(0.091)
log(No of claims)	0.054***	0.050***	0.051***	0.050***
	(0.005)	(0.006)	(0.006)	(0.007)
log(CitEPExaPre3Other)	0.130***	0.124***	0.128***	0.140***
	(0.006)	(0.007)	(0.006)	(0.008)
log(CitEPExaPre3Self)	0.020*	0.019*	0.017*	0.011
	(0.008)	(0.009)	(0.008)	(0.011)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes*	Yes*	Yes*	Yes**
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes**	Yes***	Yes**	Yes*
Patent holder characteristics	Yes**	Yes**	Yes**	Yes
Opponent characteristics	Yes**	Yes***	Yes**	Yes
Underidentification test	217.8	151.1	289.6	43.0
Weak identification test	564.8	407.0	731.5	251.4
Observations	30,347	29,389	30,620	17,653

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.14: Baseline regressions with bootstrapped standard errors

	(1)	(2)	(3)	(4)
Estimation method	OLS	IV	IV	IV
Dep var: log(CitEPExaPost5...)	Other	Other	Self	Total
Invalidated (d)	−0.008	0.292***	0.074*	0.329***
	(0.007)	(0.079)	(0.033)	(0.081)
log(No of claims)	0.062***	0.051***	0.014***	0.059***
	(0.004)	(0.005)	(0.003)	(0.006)
log(CitEPExaPre3Other)	0.130***	0.128***	0.005†	0.127***
	(0.006)	(0.006)	(0.003)	(0.006)
log(CitEPExaPre3Self)	0.019*	0.020*	0.047***	0.050***
	(0.008)	(0.008)	(0.005)	(0.008)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes**	Yes*	Yes	Yes*
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes***	Yes*	Yes	Yes*
Patent holder characteristics	Yes***	Yes***	Yes***	Yes
Opponent characteristics	Yes***	Yes***	Yes	Yes***
Observations	33,075	33,075	33,075	33,075

Bootstrapped standard errors (500 replications) in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Analogous to Table 1.6 in the main text, but showing bootstrapped standard errors in parantheses (500 replications). All bootstrapped standard errors are quantitatively very similar to the robust standard errors in Table 1.6, resulting in identical significance levels for the invalidation coefficient.

Table A.15: Impact of invalidation on EP/WO citations – extensive margin

	(1)	(2)	(3)	(4)
Estimation method	OLS	IV	IV	IV
Dep var: log(CitEPextExaPost5…)	Other	Other	Self	Total
Invalidated (d)	−0.005	0.249***	0.071**	0.289***
	(0.006)	(0.067)	(0.026)	(0.069)
log(No of claims)	0.058***	0.048***	0.008***	0.053***
	(0.004)	(0.005)	(0.002)	(0.005)
log(CitEPextExaPre3Other)	0.135***	0.133***	0.003	0.131***
	(0.006)	(0.006)	(0.002)	(0.006)
log(CitEPextExaPre3Self)	0.015	0.017†	0.032***	0.040***
	(0.010)	(0.010)	(0.004)	(0.010)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes**	Yes*	Yes	Yes*
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes***	Yes**	Yes	Yes**
Patent holder characteristics	Yes***	Yes***	Yes***	Yes
Opponent characteristics	Yes***	Yes***	Yes	Yes***
Underidentification test		222.3	222.3	222.3
Weak identification test		505.5	505.5	505.5
Observations	33,075	33,075	33,075	33,075

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table is analogous to Table 1.6, but counts only one forward citation per unique follow-on inventor in the respective time frames. The results thus indicate the effect of invalidation on the extensive margin of follow-on innovation. Columns (1) and (2) provide a comparison between the OLS and the 2SLS regressions for the impact of invalidation on EP/WO examiner citations to patents held by other parties than the focal patent owner, as measured by EP/WO examiner forward citations in a 5-year window following the decision of the opposition proceeding. Columns (2)–(4) show 2SLS regressions for the impact of invalidation on the number of follow-on patents held by other parties than the focal patent owner, on the number of follow-on patents held by the focal patent owner herself and on the total number of follow-on patents, respectively. In each 2SLS regression the “Invalidated” dummy is instrumented with the corresponding probability predicted by a probit regression on the “Examiner participation” dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata’s ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.16: Impact of invalidation on EP/WO citation dummy variables

	(1)	(2)	(3)	(4)
Estimation method	OLS	IV	IV	IV
Dep var: (CitEPExaPost5...) > 0 (d)	Other	Other	Self	Total
Invalidated (d)	−0.001	0.247***	0.079*	0.269***
	(0.006)	(0.060)	(0.038)	(0.061)
log(No of claims)	0.052***	0.042***	0.015***	0.045***
	(0.004)	(0.005)	(0.003)	(0.005)
CitEPExaPre3Other > 0 (d)	0.101***	0.100***	0.010**	0.094***
	(0.006)	(0.006)	(0.003)	(0.006)
CitEPExaPre3Self > 0 (d)	0.016*	0.017*	0.041***	0.036***
	(0.007)	(0.007)	(0.004)	(0.007)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes*	Yes*	Yes	Yes**
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes***	Yes***	Yes	Yes***
Patent holder characteristics	Yes†	Yes†	Yes***	Yes
Opponent characteristics	Yes***	Yes**	Yes	Yes***
Underidentification test		221.1	221.1	221.1
Weak identification test		504.7	504.7	504.7
Observations	33,075	33,075	33,075	33,075

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table is analogous to Table 1.6, but has all citation variables replaced with the corresponding dummies indicating at least one citation. Columns (1) and (2) provide a comparison between the OLS and the 2SLS regressions for the impact of invalidation on EP/WO examiner citations to patents held by other parties than the focal patent owner, as measured by EP/WO examiner forward citations in a 5-year window following the decision of the opposition proceeding. Columns (2)–(4) show 2SLS regressions for the impact of invalidation on the number of follow-on patents held by other parties than the focal patent owner, on the number of follow-on patents held by the focal patent owner herself and on the total number of follow-on patents, respectively. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.17: Impact of invalidation on EP/WO citations – alternative treatment of "amended" patents

	(1)	(2)	(3)	(4)
Estimation method	OLS	IV	IV	IV
Dep var: log(CitEPExaPost5...)	Other	Other	Self	Total
Invalidated (d)	-0.020^{***}	0.224^{**}	0.042	0.234^{**}
	(0.006)	(0.072)	(0.031)	(0.075)
log(No of claims)	0.062^{***}	0.063^{***}	0.017^{***}	0.073^{***}
	(0.005)	(0.005)	(0.002)	(0.005)
log(CitEPExaPre3Other)	0.129^{***}	0.131^{***}	0.006^{*}	0.130^{***}
	(0.006)	(0.006)	(0.003)	(0.006)
log(CitEPExaPre3Self)	0.019^{*}	0.020^{*}	0.047^{***}	0.050^{***}
	(0.008)	(0.008)	(0.005)	(0.009)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes**	Yes*	Yes	Yes**
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes***	Yes**	Yes	Yes**
Patent holder characteristics	Yes**	Yes**	Yes***	Yes
Opponent characteristics	Yes***	Yes**	Yes	Yes**
Underidentification test		97.4	97.4	97.4
Weak identification test		426.8	426.8	426.8
Observations	33,075	33,075	33,075	33,075

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table is analogous to Table 1.6, but has cases where the patent remained valid in amended form with fewer claims lost than the global median treated as valid. Columns (1) and (2) provide a comparison between the OLS and the 2SLS regressions for the impact of invalidation on EP/WO examiner citations to patents held by other parties than the focal patent owner, as measured by EP/WO examiner forward citations in a 5-year window following the decision of the opposition proceeding. Columns (2)–(4) show 2SLS regressions for the impact of invalidation on the number of follow-on patents held by other parties than the focal patent owner, on the number of follow-on patents held by the focal patent owner herself and on the total number of follow-on patents, respectively. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.18: Impact of invalidation on EP/WO citations – technology and size – alternative treatment of "amended" patents

	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	IV	IV	IV	IV	IV	IV
Dep var: log(CitEPExaPost5...)	Other	Other	Other	Other	Other	Other
Subsample	Complex	Discrete	Large	Non-large	Complex or large	Discrete, non-large
Invalidated (d)	0.070	0.247^{**}	0.080	0.302^{***}	0.134	0.280^{**}
	(0.166)	(0.077)	(0.127)	(0.087)	(0.110)	(0.094)
log(No of claims)	0.072^{***}	0.053^{***}	0.049^{***}	0.070^{***}	0.067^{***}	0.055^{***}
	(0.008)	(0.006)	(0.008)	(0.006)	(0.006)	(0.008)
log(CitEPExaPre3Other)	0.154^{***}	0.108^{***}	0.112^{***}	0.140^{***}	0.135^{***}	0.118^{***}
	(0.010)	(0.008)	(0.010)	(0.008)	(0.008)	(0.010)
log(CitEPExaPre3Self)	0.031^{*}	$0.016^{\dagger}$	$0.020^{\dagger}$	0.031^{**}	$0.019^{\dagger}$	$0.027^{\dagger}$
	(0.014)	(0.010)	(0.011)	(0.012)	(0.010)	(0.014)
Year effects	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Age effects	Yes*	Yes	Yes	Yes***	Yes†	Yes†
Technology effects	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes*	Yes*	Yes	Yes***	Yes	Yes**
Patent holder characteristics	Yes*	Yes**	Yes	Yes	Yes†	Yes
Opponent characteristics	Yes*	Yes†	Yes*	Yes	Yes**	Yes
Underidentification test	21.4	85.4	28.2	76.9	36.3	83.7
Weak identification test	75.9	386.0	96.9	345.8	155.1	290.8
Observations	14,946	18,129	11,038	22,037	20,923	12,152

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table is analogous to Table 1.8, but has cases where the patent remained valid in amended form with fewer claims lost than the global median treated as valid. Columns (1) and (2) compare the effect in complex technologies to that in discrete technologies, Columns (3) and (4) compare the effect for patents held by large patent holders to that for patents held by non-large patent holders and Columns (5) and (6) compare the effect for patents which are in complex technologies or held by a large patent holder to that for patents which are in discrete technologies and held by a non-large patent holder. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.19: Impact of invalidation on EP/WO citations – citations added by non-focal examiners

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPOtExaPost5...)	Other	Other	Other	Other
Technology area	Electr Eng	Instruments	Chemistry	Mech Eng
Invalidated (d)	0.273	$0.428^{\dagger}$	0.292	0.211
	(0.283)	(0.256)	(0.184)	(0.170)
log(No of claims)	0.003	0.077^{**}	0.019	0.037^{*}
	(0.026)	(0.029)	(0.015)	(0.014)
log(CitEPOtExaPre3Other)	0.141^{**}	0.193^{**}	0.025	0.126^{***}
	(0.048)	(0.059)	(0.023)	(0.027)
log(CitEPOtExaPre3Self)	−0.034	0.035	−0.023	$0.065^{\dagger}$
	(0.068)	(0.066)	(0.026)	(0.035)
Year effects	Yes	Yes**	Yes***	Yes***
Age effects	Yes	Yes**	Yes***	Yes
Technology effects	Yes	Yes*	Yes	Yes***
Patent characteristics	Yes	Yes**	Yes***	Yes***
Examination characteristics	Yes	Yes	Yes	Yes
Patent holder characteristics	Yes	Yes	Yes†	Yes
Opponent characteristics	Yes	Yes	Yes	Yes
Underidentification test	10.6	19.3	28.7	9.7
Weak identification test	12.5	18.9	41.5	23.5
Observations	576	725	2,596	2,674

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: While in close analogy to Table 1.7, the EP examiner citation variables (both dependent and independent) in the IV regressions above include only those citations, for which we can exclude that they were made by the focal patent's examiner. Due to resulting data restrictions we have to limit the sample to patents with an application filing year ≥ 2001. While this reduces the number of observations and the citation count, the coefficients closely reproduce those of Table 1.7, ruling out potentially modified powers of recall when a focal examiner involved in the opposition proceeding is compiling subsequent search reports as a main driver of the observed effect. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

A.5 Tables – US Citations

The following tables are analogous to Tables 1.4 to 1.10 for EP/WO citations in the main text.

Table A.20: Characteristics of US forward citations by relationship to cited patent

	Self citations				Other citations			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Publication authority								
US (d)	1	0.00	1	1	1	0.00	1	1
Citation characteristics								
Citation lag (yr)	10.59	3.38	0	28	10.90	3.83	0	30
Docdb family size	7.28	6.60	1	134	5.77	6.22	1	254
Sector (citing applicant)								
Company (d)	0.99	0.11	0	1	0.86	0.35	0	1
Country (citing applicant)								
EPC (excl. GB) (d)	0.31	0.46	0	1	0.20	0.40	0	1
GB (d)	0.01	0.11	0	1	0.02	0.13	0	1
US (d)	0.58	0.49	0	1	0.62	0.49	0	1
JP (d)	0.09	0.28	0	1	0.08	0.27	0	1
Other (d)	0.02	0.12	0	1	0.08	0.27	0	1
Size (citing applicant)								
Large (d)	0.60	0.49	0	1	0.27	0.45	0	1
Medium (d)	0.28	0.45	0	1	0.23	0.42	0	1
Small (d)	0.12	0.32	0	1	0.50	0.50	0	1
Observations	18,315				137,592			

Notes: This table includes all forward citations of US applications to patents subject to opposition proceedings in our main sample of analysis. The unit of observation is the citation. In case of multiple citing applicants, we give preference according to the ordering of sector, country, and size. "Country" refers to the country of residence. Size categories are proxied by the number of patents (incl. applications) filed during the last five years prior to the opposition decision (large: 200 and more patents, medium: 20 and more patents, small: fewer than 20 patents.

Table A.21: Examiner participation and opposition outcome (US citations)

	(1)	(2)	(3)
Estimation method	Probit	Probit	Probit
Dependent variable	Invalidated (d)	Invalidated (d)	Examiner participation (d)
Exam. participation (d)	-0.066^{***}	-0.038^{***}	
	(0.005)	(0.006)	
log(No of claims)		0.039^{***}	−0.005
		(0.004)	(0.004)
log(CitUSPre3Other)		0.012^{**}	0.001
		(0.004)	(0.004)
log(CitUSPre3Self)		$-0.009^{\dagger}$	0.005
		(0.005)	(0.005)
Duration of examination (yr)		−0.003	0.004
		(0.006)	(0.007)
Duration of wait (yr)		0.009	0.007
		(0.007)	(0.007)
Year effects	No	Yes***	Yes***
Age effects	No	Yes*	Yes*
Technology effects	No	Yes***	Yes***
Patent characteristics	No	Yes***	Yes†
Patent holder characteristics	No	Yes**	Yes*
Opponent characteristics	No	Yes***	Yes
Model degrees of freedom	1	111	110
χ^2-statistic	154.3	1,822.5	2,772.1
Pseudo-R^2	0.004	0.061	0.073
Observations	33,075	33,075	33,075

Marginal effects; Robust standard errors in parentheses

(d) for discrete change of dummy variable from 0 to 1

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: The probit regressions in Columns (1) and (2) illuminate the relevance of the "Examiner participation" dummy for the outcome of the opposition proceeding. The invalidation predictions of the probit regression in Column (2)—or equivalent predictions for subsamples and other citation measures—are used as the instrument in the 2SLS instrumental variables regressions throughout the paper. Column (3) shows the probit regression of the "Examiner participation" dummy on the other exogenous variables. One is added to all citation variables before taking the logarithm to include patents with no citations. A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.22: Impact of invalidation on US citations

	(1)	(2)	(3)	(4)
Estimation method	OLS	IV	IV	IV
Dep var: log(CitUSPost5...)	Other	Other	Self	Total
Invalidated (d)	−0.027**	0.381**	0.200**	0.461***
	(0.010)	(0.118)	(0.062)	(0.121)
log(No of claims)	0.102***	0.086***	0.018***	0.089***
	(0.007)	(0.009)	(0.005)	(0.009)
log(CitUSPre3Other)	0.438***	0.433***	0.037***	0.428***
	(0.007)	(0.007)	(0.004)	(0.007)
log(CitUSPre3Self)	0.155***	0.159***	0.176***	0.218***
	(0.010)	(0.010)	(0.008)	(0.011)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes*	Yes†	Yes†	Yes†
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes**	Yes†	Yes	Yes†
Patent holder characteristics	Yes***	Yes***	Yes***	Yes***
Opponent characteristics	Yes***	Yes**	Yes	Yes**
Underidentification test		222.9	222.9	222.9
Weak identification test		505.8	505.8	505.8
Observations	33,075	33,075	33,075	33,075

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Columns (1) and (2) provide a comparison between the OLS and the 2SLS regressions for the impact of invalidation on US forward citations to patents held by other parties than the focal patent owner, as measured by US forward citations in a 5-year window following the decision of the opposition proceeding. Columns (2)–(4) show 2SLS regressions for the impact of invalidation on the number of follow-on patents held by other parties than the focal patent owner, on the number of follow-on patents held by the focal patent owner herself and on the total number of follow-on patents, respectively. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.23: Impact of invalidation on US citations – technology main areas

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitUSPost5...)	Other	Other	Other	Other
Technology area	Electr Eng	Instruments	Chemistry	Mech Eng
Invalidated (d)	−0.040	0.582	$0.307^{\dagger}$	0.047
	(0.297)	(0.398)	(0.171)	(0.209)
log(No of claims)	0.136^{***}	0.090^{***}	0.100^{***}	0.081^{***}
	(0.025)	(0.027)	(0.014)	(0.014)
log(CitUSPre3Other)	0.507^{***}	0.566^{***}	0.348^{***}	0.432^{***}
	(0.021)	(0.019)	(0.011)	(0.013)
log(CitUSPre3Self)	0.184^{***}	0.135^{***}	0.155^{***}	0.168^{***}
	(0.035)	(0.028)	(0.014)	(0.019)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes***	Yes	Yes	Yes***
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes	Yes*	Yes	Yes*
Patent holder characteristics	Yes	Yes*	Yes***	Yes***
Opponent characteristics	Yes	Yes*	Yes*	Yes
Underidentification test	32.2	49.3	123.2	43.9
Weak identification test	75.1	63.1	257.5	77.3
Observations	3,432	4,220	13,011	10,384

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Columns (1)–(4) show the impact of invalidation on US forward citations to patents held by parties other than the focal patent holder for the technology main area subsamples Electrical Engineering, Instruments, Chemistry and Mechanical Engineering, respectively. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.24: Impact of invalidation on US citations – technology and size

	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	IV	IV	IV	IV	IV	IV
Dep var: log(CitUSPost5...)	Other	Other	Other	Other	Other	Other
Subsample	Complex	Discrete	Large	Non-large	Complex or large	Discrete, non-large
Invalidated (d)	0.308	0.389^{*}	0.202	0.484^{***}	0.364^{*}	0.378^{*}
	(0.192)	(0.152)	(0.215)	(0.139)	(0.160)	(0.167)
log(No of claims)	0.087^{***}	0.091^{***}	0.086^{***}	0.081^{***}	0.092^{***}	0.076^{***}
	(0.013)	(0.012)	(0.016)	(0.011)	(0.011)	(0.014)
log(CitUSPre3Other)	0.510^{***}	0.359^{***}	0.395^{***}	0.448^{***}	0.460^{***}	0.381^{***}
	(0.011)	(0.010)	(0.012)	(0.009)	(0.009)	(0.012)
log(CitUSPre3Self)	0.163^{***}	0.157^{***}	0.172^{***}	0.161^{***}	0.166^{***}	0.145^{***}
	(0.017)	(0.013)	(0.015)	(0.014)	(0.013)	(0.017)
Year effects	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Age effects	Yes*	Yes	Yes*	Yes*	Yes	Yes
Technology effects	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Patent holder characteristics	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Opponent characteristics	Yes*	Yes**	Yes***	Yes	Yes**	Yes
Underidentification test	78.2	136.4	64.4	172.2	105.2	119.9
Weak identification test	191.2	314.7	149.2	351.3	270.8	240.3
Observations	14,946	18,129	11,038	22,037	20,923	12,152

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table shows the impact of invalidation on US forward citations to patents held by parties other than the focal patent holder for different sample splits. Columns (1) and (2) compare the effect in complex technologies to that in discrete technologies, Columns (3) and (4) compare the effect for patents held by large patent holders to that for patents held by non-large patent holders and Columns (5) and (6) compare the effect for patents which are in complex technologies or held by a large patent holder to that for patents which are in discrete technologies and held by a non-large patent holder. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.25: Impact of invalidation on US citations – sizes of focal and citing patent holders

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitUS...Post5Other)	Large	Non-large	Large	Non-large
Patent holder subsample	Large	Large	Non-large	Non-large
Invalidated (d)	0.175	0.088	0.269**	0.324*
	(0.169)	(0.204)	(0.093)	(0.132)
log(No of claims)	0.035**	0.084***	0.028***	0.079***
	(0.013)	(0.015)	(0.007)	(0.010)
log(CitUSPre3Other)	0.217***	0.337***	0.221***	0.397***
	(0.010)	(0.012)	(0.007)	(0.009)
log(CitUSPre3Self)	0.121***	0.132***	0.075***	0.143***
	(0.013)	(0.014)	(0.011)	(0.013)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes*	Yes	Yes	Yes†
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes	Yes	Yes	Yes*
Patent holder characteristics	Yes***	Yes***	Yes***	Yes***
Opponent characteristics	Yes***	Yes*	Yes	Yes†
Underidentification test	64.4	64.4	172.2	172.2
Weak identification test	149.2	149.2	351.3	351.3
Observations	11,038	11,038	22,037	22,037

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table explores the impact of invalidation on US citations with respect to the differences in size between the holder of the citing patent (dependent variable) and the holder of the focal patent (subsample). Columns (1) and (2) show the effect of invalidation on citations to patents held by large and non-large patent owners, respectively, for the subsample of patents held by large patent owners, Columns (3) and (4) analogously for the subsample of patents held by non-large patent owners. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

Table A.26: Impact of invalidation on US citations – patent thickets and patent fences

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitUSPost5...)	Other	Other	Other	Other
Subsample	Thicket	No thicket	Fence	No fence
Invalidated (d)	−0.326	0.227†	0.332	0.443***
	(0.259)	(0.130)	(0.220)	(0.134)
log(No of claims)	0.126***	0.091***	0.059***	0.089***
	(0.024)	(0.009)	(0.017)	(0.010)
log(CitUSPre3Other)	0.429***	0.439***	0.396***	0.443***
	(0.018)	(0.008)	(0.014)	(0.009)
log(CitUSPre3Self)	0.131***	0.152***	0.167***	0.172***
	(0.026)	(0.011)	(0.016)	(0.013)
Year effects	Yes***	Yes***	Yes***	Yes***
Age effects	Yes	Yes†	Yes	Yes†
Technology effects	Yes***	Yes***	Yes***	Yes***
Patent characteristics	Yes***	Yes***	Yes***	Yes***
Examination characteristics	Yes	Yes†	Yes	Yes*
Patent holder characteristics	Yes***	Yes***	Yes**	Yes***
Opponent characteristics	Yes	Yes**	Yes	Yes**
Underidentification test	64.3	178.6	68.9	171.8
Weak identification test	81.7	424.0	118.7	390.0
Observations	3,239	28,494	8,826	24,233

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table explores the different effects of invalidation on US citations in the presence or absence of patent thickets and patent fences. Columns (1) and (2) represent a sample split with respect to the presence of a patent thicket in the focal patent's technology area. We consider a thicket to be present if the area triples variable derived by von Graevenitz et al. (2011) lies at or above the 90th percentile in the full sample. Columns (3) and (4) show the effect of invalidation for a sample split with respect to the presence of a patent fence erected by the holder of the focal patent. We consider a fence to be present if we find at least one similar patent by the focal patent owner prior to opposition. The similarity measure we use is sensitive to the title, the claims, the technology area and the full text of the patent. One is added to all citation variables before taking the logarithm to include patents with no forward citations. In each 2SLS regression the "Invalidated" dummy is instrumented with the corresponding probability predicted by a probit regression on the "Examiner participation" dummy and all other exogenous variables. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by Stata's ivreg2 command (Baum et al., 2010). A comprehensive list of the control variables contained in the indicated groups can be found in Table A.3 in the appendix.

A.6 Construction of the Examiner Participation Dummy Variable

As explained in Section 1.4, we use the presence or absence of the primary examiner in the opposition division as an instrument to allow for causal inference concerning follow-on innovation for the sample of all opposed EP patents between 1993 and 2011. For this purpose, we first identify the relevant set of patents by the EPO PATSTAT Register – 2015 Autumn Edition. Second, to determine the names of the examination and opposition division's members, we download three types of (scanned) pdf-documents from the EPO database for each of the identified patents: the grant decision for the examination division and the minutes of the oral proceedings as well as the opposition outcome decision for the opposition division. We use two types of documents for the latter to reduce the likelihood of errors. Third, we extract and pre-process the image files included in the pdf-files and read the contained information to txt-files using optical character recognition (OCR) software. Fourth, using a keyword search specific to each document type and language, we identify and parse the names of the respective division's members to a standardized format with first and last names separated. Fifth, we check whether one person is a member of both the examination and the opposition division by comparing the names of both divisions with different string similarity measures.

Two aspects are worth noting. First, the use of both the minutes of the oral proceedings and the opposition decision document to identify the opposition division is legitimate, since the division holding the oral proceedings must be the same as the opposition division rendering the decision in writing, otherwise the decision is deemed to be void.[1] Second, in some cases we are unable to identify all relevant members, for example because the EPO database holds the wrong document under the specific link, and in some cases we might erroneously identify the substantive examiner as being present or absent, for example because the scanned document and thus the OCR is of poor quality. However, the read-out quality and success do not depend on the outcome of the opposition, since the corresponding decision document has the same format across all three outcomes, and thus does not affect identification.

[1] See for instance T 390/86 with a decision from 17 November 1987.

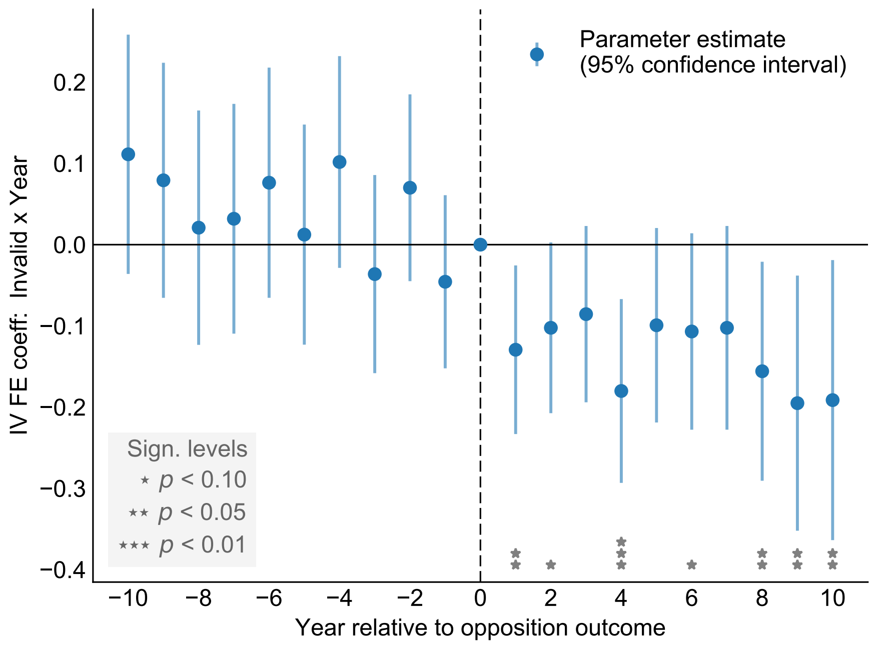
B

Appendix to Chapter 2

Marginal Patents and the Supply of Ideas

B.1 Figures

Figure B.1: Effect of invalidation on the propensity to file for a patent



Notes: Coefficient estimates of invalidation for years relative to opposition outcome from an instrumental variable (2SLS) fixed effects regression on (inventor, year relative to opposition outcome)-level using Schaffer (2010). The dependent variable $y_{it} = 1(N_{\text{App},it} > 0)$ indicates whether inventor i has filed a patent application in period t. The corresponding specification is given by $y_{it} = \sum_{\tau=-10}^{10} \beta_\tau \mathbf{1}(\text{Invalidated}_i)\,\mathbf{1}(t = \tau) + a_t + b_{t-t_{\text{af}}} + c_i + \varepsilon_{it}$. i and t are the indices for the inventor and the year relative to opposition outcome, respectively; fixed effects are described in the main text. The interactions are instrumented with $z_{i,t}^{\tau} = \mathbf{1}(\text{Examiner participation}_i)\,\mathbf{1}(t = \tau)$, where $\tau = -10, \ldots, 10$ denotes years relative to opposition outcome. Error bars indicate the respective coefficient's 95% confidence interval. Stars at the bottom of the figure indicate the significance levels of the coefficients.

B.2 Tables – Instrumental Variable and Complier Analysis

Table B.1: Regressions of instrumental variable on application and inventor characteristics

	(1)	(2)	(3)
Estimation method	OLS	OLS	OLS
Dependent variable	1(Ex part)	1(Ex part)	1(Ex part)
Level of observation	Opposition	Inventor	Inventor
Application characteristics			
DOCDB family size	0.000		0.000
	(0.000)		(0.000)
PCT application (d)	0.002		0.002
	(0.006)		(0.007)
No of applicants	0.015*		0.012
	(0.008)		(0.009)
No of inventors	0.002		0.003
	(0.002)		(0.002)
log(1 + Claims)	−0.005		0.001
	(0.005)		(0.006)
log(1 + Pat lit refs)	−0.002		0.004
	(0.005)		(0.006)
log(1 + Cit5)	0.006**		0.006
	(0.003)		(0.004)
XYE backwards cit (d)	0.000		0.000
	(0.006)		(0.007)
Inventor characteristics			
European inventor		−0.008	−0.005
		(0.007)	(0.007)
Tenure		0.000	0.000
		(0.001)	(0.001)
No of applications (pre)		0.000	0.000
		(0.000)	(0.000)
No of app in same area (pre)		0.000	0.000
		(0.001)	(0.001)
No of app of coauthors (pre)		0.000	0.000
		(0.000)	(0.000)
No of tech areas (pre)		0.001	0.001
		(0.002)	(0.002)
Opp in expert tech area		−0.006	−0.006
		(0.006)	(0.006)
App filing year effects	Yes***	Yes***	Yes***
Opp outcome year effects	Yes***	Yes***	Yes***
Technology effects	Yes***	Yes***	Yes***
Number of oppositions		29,009	29,009
Observations	29,009	65,415	65,415

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Regression of the instrumental variable 1(Examiner participation) on different application (Column 1) and inventor (Column 2) characteristics. Column (3) shows the regression on both application and inventor characteristics. Standard errors reported in parantheses are heteroskedasticity-robust in Column (1) and clustered on the opposition level in Columns (2) and (3).

Complier Analysis

Following the notation of Angrist and Pischke (2009, Section 4.4.4), we can write a patent i's potential treatment status as D_{1i} when the instrument is $Z = 1$ and as D_{0i} when $Z = 0$. "Complier" patents are then defined as those whose treatment status is sensitive to the instrument, i.e., $D_{0i} = 1$ (invalidation) and $D_{1i} = 0$ (no invalidation) in the above context. (Remember that examiner participation $Z = 1$ is associated with a lower likelihood of invalidation $D = 1$.) In a potential outcomes framework, the Wald estimand can be interpreted as a local average treatment effect (LATE) on the subpopulation of compliers (Imbens and Angrist, 1994). They have to be distinguished from "always-takers" with $D_{1i} = D_{0i} = 1$, and "never-takers" with $D_{1i} = D_{0i} = 0$. The calculations of the following tables rely, inter alia, on the monotonicity assumption $D_{0i} \geq D_{1i} \forall i$, i.e., on excluding the existence of "defiers" with $D_{1i} = 1$ and $D_{0i} = 0$.

Table B.2: LATE discussion – Complier shares

	Opposition level	Inventor level
P(Invalidated)	0.7050	0.7141
P(Examiner participation)	0.6807	0.6860
P(Complier)	0.0708	0.0688
P(Complier | Invalidated)	0.0321	0.0302
P(Complier | Not Inv.)	0.1634	0.1650
N	29,009	65,415

Notes: This table shows the share of complier patents in the full sample, P(Complier), the share among invalidated patents, P(Complier | Invalidated), and the share among non-invalidated patents, P(Complier | Not Inv.), on the opposition and the inventor level. In both cases, the population share of compliers lies at around 7%, which is comprised of a share of 3% for invalidated patents and 16-17% for non-invalidated patents.

Table B.3: LATE discussion – Complier application characteristics

Binary characteristic x	N	$E[x]$	$E[x\|com]$	$E[x\|com]$ / $E[x]$		p(Ratio=1)
DOCDB family size > 8	29,009	0.461	0.525	1.137	(0.085)	0.104
PCT application (d)	29,009	0.447	0.455	1.017	(0.084)	0.843
No of applicants > 1	29,009	0.065	0.025	0.383	(0.310)	0.046
No of inventors > 2	29,009	0.451	0.379	0.841	(0.086)	0.065
No of claims > 11	29,009	0.458	0.474	1.034	(0.083)	0.680
No of PL lit refs > 5	29,009	0.460	0.422	0.918	(0.083)	0.320
Cit (5yr-window) > 2	29,009	0.632	0.518	0.819	(0.057)	0.002
XYE references (d)	29,009	0.692	0.665	0.961	(0.052)	0.456

Notes: This table explores in how far the complier subpopulation differs from the full sample of opposed patents with respect to a series of patent characteristics. Since the underlying calculation relies on characteristics being binary, count variables are split at their median indicated in the first column. The second column indicates the number of opposed applications included in our baseline sample. The third column displays the share $E[x] = P(x = 1)$ of patents with $x = 1$ in the entire population, the fourth column displays the corresponding share $E[x\,|\,\text{complier}]$ among complier patents. The fifth column shows the relative likelihood that complier patents have the binary characteristic x indicated on the left. The corresponding robust standard errors shown in parantheses are derived using seemingly unrelated estimation. The p-values corresponding to a test of whether this ratio equals one are presented in the last column. On a 10% level, we find significantly smaller shares of complier patents with more than one applicant, with more than two inventors and with more than two citations in a five-year window after filing. Compliers are defined as described above.

Table B.4: LATE discussion – Complier inventor characteristics

Binary characteristic x	N	$E[x]$	$E[x\|com]$	$E[x\|com]$ / $E[x]$		p(Ratio=1)
European inventor	65,415	0.575	0.614	1.067	(0.081)	0.410
Tenure > 9.05	65,415	0.500	0.436	0.873	(0.069)	0.065
No of applications (pre) > 4	65,415	0.443	0.395	0.890	(0.074)	0.136
No of app in same area (pre) > 2	65,415	0.422	0.397	0.942	(0.082)	0.480
No of app of coauthors (pre) > 4	65,415	0.495	0.489	0.989	(0.065)	0.866
No of tech areas (pre) > 2	65,415	0.307	0.232	0.756	(0.099)	0.013
Opp in expert tech area	65,415	0.770	0.784	1.019	(0.037)	0.621

Notes: Analogous to the application-level analysis in Table B.3, this table explores in how far the complier inventor subpopulation differs from the full sample of first-opposition inventors with respect to a series of inventor characteristics (cf first column). The second column shows the number of inventors included in our baseline sample. On a 10% level, we find that significantly smaller shares of complier inventors with tenure above 9 years and with prior patenting in more than two technology areas. Standard errors indicated in parantheses are clustered on the opposition level.

B.3 Tables – Robustness

Table B.5: Effect of invalidation on number of applications: Robustness

	(1)	(2)	(3)	(4)	(5)
Estimation method	IV FE	IV FE	IV FE	IV FE	IV FE
Dependent variable	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}
Subsample	$\bar{N}_{\text{app}}^{\text{pre}} \leq q_{.95}$	$\bar{N}_{\text{app}}^{\text{pre}} \leq q_{.99}$	$N_{\text{area}}^{\text{pre}} \leq q_{.95}$	App pre	App pre+post
1(Invalidated) × 1(Post)	-0.427^{***}	-0.561^{***}	-0.386^{***}	-0.506^{***}	-0.986^{**}
	(0.097)	(0.125)	(0.131)	(0.149)	(0.402)
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes***	Yes***
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***	Yes***
Underidentification test	74.1	76.2	77.8	77.5	31.0
Weak identification test	74.7	76.8	78.4	78.2	31.1
Number of oppositions	28,355	28,901	28,521	28,849	16,505
Number of inventors	62,202	64,777	62,648	64,941	25,300
Observations	1,214,896	1,264,553	1,223,620	1,267,639	497,213

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Instrumental variable (2SLS) fixed effects regressions on (inventor, year relative to opposition outcome)-level. $\bar{N}_{\text{app}}^{\text{pre}}$ denotes the average yearly number of applications in the pre period, q_x denotes inventor population quantiles. $N_{\text{area}}^{\text{pre}}$ indicates the number of technology areas, in which an inventor has filed applications prior to opposition outcome. "App pre/post" indicates the subsample of inventors with applications in the pre *or* the post period (almost the full sample), "App pre+post" indicates the subsample of inventors with applications in both the pre *and* the post period (intensive margin). All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

B.4 Tables – Baseline Specification

Table B.6: Effect of invalidation: Number of applications (Morrison et al. (2017) inventor disambiguation)

	(1)	(2)	(3)	(4)	(5)
Estimation method	FE	FE	IV FE	IV FE	IV FE
Dependent variable	N_{app}	N_{app}	N_{app}	$\log(1+N_{\text{app}})$	1_{app}
Application authority	EP	EP	EP	EP	EP
1(Invalidated) × 1(Post)	−0.055***		−0.518***	−0.182***	−0.122**
	(0.009)		(0.197)	(0.065)	(0.050)
1(Exam part) × 1(Post)		0.027***			
		(0.010)			
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes***	Yes***
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***	Yes***
Underidentification test			39.8	39.8	39.8
Weak identification test			40.1	40.1	40.1
Number of oppositions	21,324	21,324	21,324	21,324	21,324
Number of inventors	47,419	47,419	47,419	47,419	47,419
Observations	909,521	909,521	909,521	909,521	909,521

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Analogous to Table 2.3 in the main text, but using the Morrison et al. (2017) inventor disambiguation. Fixed Effects (Column 1), reduced form fixed effects (Column 2) and instrumental variable (2SLS) fixed effects (Columns 3–5) regressions on (inventor, year relative to opposition outcome)-level. Columns (1)–(3) use different specifications for the same dependent variable, the number of applications. Columns (3)–(5) use the same IV FE estimator for different functional forms of the dependent variable: a linear-, a log- and an indicator variable specification. Since the Morrison et al. (2017) disambiguation does not include national patent applications, dependent variables analogous to those in Columns (6) and (7) of Table 2.3 can not be shown here. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

Table B.7: Effect of invalidation: Number of applications (European inventors)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Estimation method	FE	FE	IV FE	IV FE	IV FE	IV FE	IV FE
Dependent variable	N_{app}	N_{app}	N_{app}	$\log(1+N_{\text{app}})$	1_{app}	$N_{\text{app}}^{\text{nat}}$	$N_{\text{app}}^{\text{WO}}$
Application authority	EP	EP	EP	EP	EP	National	WIPO
1(Invalidated) × 1(Post)	−0.049***		−0.403**	−0.186***	−0.149***	0.098	−0.055
	(0.011)		(0.179)	(0.060)	(0.047)	(0.159)	(0.046)
1(Exam part) × 1(Post)		0.025**					
		(0.011)					
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Underidentification test			53.5	53.5	53.5	53.5	53.5
Weak identification test			53.9	53.9	53.9	53.9	53.9
Number of oppositions	18,553	18,553	18,553	18,553	18,553	18,553	18,553
Number of inventors	37,618	37,618	37,618	37,618	37,618	37,618	37,618
Observations	731,366	731,366	731,366	731,366	731,366	731,366	731,366

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Analogous to Table 2.3 in the main text, but for the subsample of European inventors. Fixed Effects (Column 1), reduced form fixed effects (Column 2) and instrumental variable (2SLS) fixed effects (Columns 3–7) regressions on (inventor, year relative to opposition outcome)-level. Columns (1)–(3) use different specifications for the same dependent variable, the number of applications. Columns (3)–(5) use the same IV FE estimator for different functional forms of the dependent variable: a linear-, a log- and an indicator variable specification. To test whether the reduction is driven by a shift to national or transnational patenting, Columns (6) and (7) display the effect on the number of patent families, which do not contain an EP application. First, in Column (6), only patent families are counted, which contain a national application in a European country, but do not contain EP or WIPO applications. Second, in Column (7), only patent families are counted, which contain at least one WIPO application, but no EP application. For Columns (6) and (7), we have used the same set of inventors as in the preceding columns. If we restrict the sample to inventors who have at least one "national" or at least one "WIPO" patent family in our sampling period, we find qualitatively similar results. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

Table B.8: Effect of invalidation: Number of applications (foreign inventors)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Estimation method	FE	FE	IV FE	IV FE	IV FE	IV FE	IV FE
Dependent variable	N_{app}	N_{app}	N_{app}	$\log(1+N_{app})$	1_{app}	N_{app}^{nat}	N_{app}^{WO}
Application authority	EP	EP	EP	EP	EP	National	WIPO
1(Invalidated) × 1(Post)	−0.038***		−0.582**	−0.199**	−0.132**	0.078	0.416
	(0.012)		(0.252)	(0.078)	(0.060)	(0.073)	(0.260)
1(Exam part) × 1(Post)		0.033**					
		(0.013)					
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes	Yes
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Underidentification test			28.2	28.2	28.2	28.2	28.2
Weak identification test			28.4	28.4	28.4	28.4	28.4
Number of oppositions	11,383	11,383	11,383	11,383	11,383	11,383	11,383
Number of inventors	27,797	27,797	27,797	27,797	27,797	27,797	27,797
Observations	545,363	545,363	545,363	545,363	545,363	545,363	545,363

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Analogous to Table 2.3 in the main text, but for the subsample of non-European inventors. Fixed Effects (Column 1), reduced form fixed effects (Column 2) and instrumental variable (2SLS) fixed effects (Columns 3–7) regressions on (inventor, year relative to opposition outcome)-level. Columns (1)–(3) use different specifications for the same dependent variable, the number of applications. Columns (3)–(5) use the same IV FE estimator for different functional forms of the dependent variable: a linear-, a log- and an indicator variable specification. To test whether the reduction is driven by a shift to national or transnational patenting, Columns (6) and (7) display the effect on the number of patent families, which do not contain an EP application. First, in Column (6), only patent families are counted, which contain a national application in a European country, but do not contain EP or WIPO applications. Second, in Column (7), only patent families are counted, which contain at least one WIPO application, but no EP application. For Columns (6) and (7), we have used the same set of inventors as in the preceding columns. If we restrict the sample to inventors who have at least one "national" or at least one "WIPO" patent family in our sampling period, we find qualitatively similar results. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

B.5 Tables – Quality of Applications

Table B.9: Effect of invalidation: Quality of applications (Morrison et al. (2017) inventor disambiguation)

	(1)	(2)	(3)	(4)
Estimation method	IV FE	IV FE	IV FE	IV FE
Dependent variable	$N_{\text{app}}^{\text{XYE}}$	$N_{\text{app}}^{\text{non-XYE}}$	$N_{\text{app}}^{\text{cit5}}$	$N_{\text{app}}^{\text{cit5, non-XYE}}$
1(Invalidated) × 1(Post)	−0.577***	0.059	−1.007	−0.366
	(0.159)	(0.077)	(0.982)	(0.284)
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes***
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***
Underidentification test	39.8	39.8	12.7	12.7
Weak identification test	40.1	40.1	12.7	12.7
Number of oppositions	21,324	21,324	12,514	12,514
Number of inventors	47,419	47,419	27,419	27,419
Observations	909,521	909,521	508,518	508,518

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Analogous to Table 2.4 in the main text, but using the Morrison et al. (2017) inventor disambiguation. Column (1) shows the causal effect of invalidation on the number of applications which receive an X-, Y-, or E-reference in the EPO examiner's search report. Such references are indicative of novelty-threatening prior art and hence constitute a proxy for subsequent failure to receive a patent grant. Column (2) presents regression results for the number of applications which do not receive such a reference. While the number of XYE-cited applications significantly decreases, the number of patent families, which are more likely to receive a grant, increases. Column (3) displays the effect on the number applications weighted by the forward citations they receive in a five-year window after filing. Column (4) uses the number of non-XYE-cited applications, weighted by the five-year forward citation number, as the dependent variable. The citation-weighted variables in Column (3) and (4) are winsorized at the 99th percentile to mitigate noise introduced by outliers. Without winsorizing, we obtain coefficients of very similar magnitude, but larger standard errors. To allow for a full observation of the citation window, the sample is truncated five years earlier, resulting in fewer observations. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

Table B.10: Effect of invalidation: Quality of applications (European inventors)

	(1)	(2)	(3)	(4)
Estimation method	IV FE	IV FE	IV FE	IV FE
Dependent variable	$N_{\text{app}}^{\text{XYE}}$	$N_{\text{app}}^{\text{non-XYE}}$	$N_{\text{app}}^{\text{cit5}}$	$N_{\text{app}}^{\text{cit5, non-XYE}}$
1(Invalidated) × 1(Post)	-0.533^{***}	0.130^{*}	-1.183	-0.191
	(0.145)	(0.071)	(0.807)	(0.235)
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes**
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***
Underidentification test	53.5	53.5	17.3	17.3
Weak identification test	53.9	53.9	17.4	17.4
Number of oppositions	18,553	18,553	11,776	11,776
Number of inventors	37,618	37,618	23,687	23,687
Observations	731,366	731,366	451,662	451,662

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Analogous to Table 2.4 in the main text, but using the subsample of European inventors. Column (1) shows the causal effect of invalidation on the number of applications which receive an X-, Y-, or E-reference in the EPO examiner's search report. Such references are indicative of potentially novelty destroying prior art and hence constitute a proxy for subsequent failure to receive a patent grant. Column (2) presents regression results for the number of applications which do not receive such a reference. While the number of XYE-cited applications significantly decreases, the number of patent families, which are more likely to receive a grant, increases. Column (3) displays the effect on the number applications weighted by the forward citations they receive in a five-year window after filing. Column (4) uses the number of non-XYE-cited applications, weighted by the five-year forward citation number, as the dependent variable. The citation-weighted variables in Column (3) and (4) are winsorized at the 99th percentile to mitigate noise introduced by outliers. Without winsorizing, we obtain coefficients of very similar magnitude, but larger standard errors. To allow for a full observation of the citation window, the sample is truncated five years earlier, resulting in fewer observations. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

Table B.11: Effect of invalidation: Quality of applications (foreign inventors)

	(1)	(2)	(3)	(4)
Estimation method	IV FE	IV FE	IV FE	IV FE
Dependent variable	$N_{\text{app}}^{\text{XYE}}$	$N_{\text{app}}^{\text{non-XYE}}$	$N_{\text{app}}^{\text{cit5}}$	$N_{\text{app}}^{\text{cit5, non-XYE}}$
1(Invalidated) × 1(Post)	-0.734^{***}	0.152^{**}	-2.098	-0.309
	(0.236)	(0.071)	(1.277)	(0.280)
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***
Underidentification test	28.2	28.2	12.0	12.0
Weak identification test	28.4	28.4	12.1	12.1
Number of oppositions	11,383	11,383	7,501	7,501
Number of inventors	27,797	27,797	18,703	18,703
Observations	545,363	545,363	359,344	359,344

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Analogous to Table 2.4 in the main text, but using the subsample of non-European inventors. Column (1) shows the causal effect of invalidation on the number of applications which receive an X-, Y-, or E-reference in the EPO examiner's search report. Such references are indicative of potentially novelty destroying prior art and hence constitute a proxy for subsequent failure to receive a patent grant. Column (2) presents regression results for the number of applications which do not receive such a reference. While the number of XYE-cited applications significantly decreases, the number of patent families, which are more likely to receive a grant, increases. Column (3) displays the effect on the number applications weighted by the forward citations they receive in a five-year window after filing. Column (4) uses the number of non-XYE-cited applications, weighted by the five-year forward citation number, as the dependent variable. The citation-weighted variables in Column (3) and (4) are winsorized at the 99th percentile to mitigate noise introduced by outliers. Without winsorizing, we obtain coefficients of very similar magnitude, but larger standard errors. To allow for a full observation of the citation window, the sample is truncated five years earlier, resulting in fewer observations. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

B.6 Tables – Direction

Table B.12: Effect of invalidation: Direction (Morrison et al. (2017) inventor disambiguation)

	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE
Dependent variable	$N_{\text{app}}^{\text{same ar}}$	$N_{\text{app}}^{\text{other ar}}$	N_{app}	N_{app}	$N_{\text{app}}^{\text{same ar}}$	$N_{\text{app}}^{\text{other ar}}$
Subsample	Full	Full	Non-Expert	Expert	Expert	Expert
1(Invalidated) × 1(Post)	−0.359**	−0.159	−0.204	−0.618***	−0.439**	−0.179**
	(0.144)	(0.102)	(0.421)	(0.221)	(0.178)	(0.072)
Year effects (rel to oppo)	Yes***	Yes***	Yes**	Yes***	Yes**	Yes***
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Underidentification test	39.8	39.8	14.6	33.9	33.9	33.9
Weak identification test	40.1	40.1	14.7	34.1	34.1	34.1
Number of oppositions	21,324	21,324	6,275	18,732	18,732	18,732
Number of inventors	47,419	47,419	9,554	37,865	37,865	37,865
Observations	909,521	909,521	181,739	727,782	727,782	727,782

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Analogous to Table 2.5 in the main text, but using the Morrison et al. (2017) inventor disambiguation. Columns (1) and (2) present the effect of invalidation on the number of applications in the same and other technology areas as the opposed patent, respectively. Column (3) shows the invalidation effect for inventors who experience their first opposition outside their area of expertise, i.e., outside the area in which they have filed most patents prior to opposition outcome. Columns (4)-(6) show the effect for the complimentary subsample of inventors whose first opposition is in their expert technology area. Column (4) presents the effect on the all applications, Columns (5) and (6) present the effects on applications in the same and other areas as the opposed patent, respectively. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

Table B.13: Effect of invalidation: Direction (European inventors)

	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE
Dependent variable	$N_{\text{app}}^{\text{same ar}}$	$N_{\text{app}}^{\text{other ar}}$	N_{app}	N_{app}	$N_{\text{app}}^{\text{same ar}}$	$N_{\text{app}}^{\text{other ar}}$
Subsample	Full	Full	Non-Expert	Expert	Expert	Expert
1(Invalidated) × 1(Post)	−0.211*	−0.192*	−0.552	−0.371**	−0.264*	−0.107
	(0.122)	(0.104)	(0.495)	(0.180)	(0.143)	(0.070)
Year effects (rel to oppo)	Yes***	Yes*	Yes	Yes***	Yes***	Yes**
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Underidentification test	53.5	53.5	12.8	51.0	51.0	51.0
Weak identification test	53.9	53.9	12.9	51.4	51.4	51.4
Number of oppositions	18,553	18,553	5,823	15,968	15,968	15,968
Number of inventors	37,618	37,618	8,356	29,262	29,262	29,262
Observations	731,366	731,366	161,160	570,206	570,206	570,206

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Analogous to Table 2.5 in the main text, but for the subsample of European inventors. Columns (1) and (2) present the effect of invalidation on the number of applications in the same and other technology areas as the opposed patent, respectively. Column (3) shows the invalidation effect for inventors who experience their first opposition outside their area of expertise, i.e., outside the area in which they have filed most patents prior to opposition outcome. Columns (4)-(6) show the effect for the complimentary subsample of inventors whose first opposition is in their expert technology area. Column (4) presents the effect on the all applications, Columns (5) and (6) present the effects on applications in the same and other areas as the opposed patent, respectively. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

Table B.14: Effect of invalidation: Direction (foreign inventors)

	(1)	(2)	(3)	(4)	(5)	(6)
Estimation method	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE
Dependent variable	$N_{\text{app}}^{\text{same ar}}$	$N_{\text{app}}^{\text{other ar}}$	N_{app}	N_{app}	$N_{\text{app}}^{\text{same ar}}$	$N_{\text{app}}^{\text{other ar}}$
Subsample	Full	Full	Non-Expert	Expert	Expert	Expert
1(Invalidated) × 1(Post)	-0.359^{**}	-0.223	-0.420	-0.647^{**}	-0.464^{**}	-0.183^{*}
	(0.161)	(0.159)	(0.513)	(0.273)	(0.217)	(0.110)
Year effects (rel to oppo)	Yes***	Yes**	Yes**	Yes***	Yes***	Yes
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Underidentification test	28.2	28.2	15.0	22.1	22.1	22.1
Weak identification test	28.4	28.4	15.1	22.2	22.2	22.2
Number of oppositions	11,383	11,383	4,237	9,791	9,791	9,791
Number of inventors	27,797	27,797	6,691	21,106	21,106	21,106
Observations	545,363	545,363	129,923	415,440	415,440	415,440

Standard errors clustered at the opposition level in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Analogous to Table 2.5 in the main text, but for the subsample of non-European inventors. Columns (1) and (2) present the effect of invalidation on the number of applications in the same and other technology areas as the opposed patent, respectively. Column (3) shows the invalidation effect for inventors who experience their first opposition outside their area of expertise, i.e., outside the area in which they have filed most patents prior to opposition outcome. Columns (4)-(6) show the effect for the complimentary subsample of inventors whose first opposition is in their expert technology area. Column (4) presents the effect on the all applications, Columns (5) and (6) present the effects on applications in the same and other areas as the opposed patent, respectively. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

B.7 Tables – Effect Heterogeneity

Table B.15: Effect of invalidation on number of applications: Applicant heterogeneity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Estimation method	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE
	Full sample	App (pre)		Employees		App per employee		Revenue		Leverage		Profitability	
		Few	Many	Few	Many	Few	Many	Low	High	Low	High	Low	High
Dependent variable	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}
1(Invalidated) × 1(Post)	−0.515***	−0.524***	−0.500*	−0.302	−0.704	−0.802**	0.054	−0.291	−0.613	−0.200	−0.451**	−0.411	−0.292
	(0.150)	(0.148)	(0.277)	(0.250)	(0.429)	(0.346)	(0.376)	(0.215)	(0.421)	(0.438)	(0.220)	(0.313)	(0.259)
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes***	Yes**	Yes**	Yes***	Yes*	Yes**	Yes***	Yes**	Yes*	Yes**
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Underidentification test	76.9	55.1	26.7	24.5	14.1	15.3	19.0	35.5	14.0	13.9	31.9	18.8	32.6
Weak identification test	77.5	55.8	26.8	24.8	14.2	15.4	19.1	36.1	14.0	14.0	32.4	18.9	33.3
Number of oppositions	29,009	14,451	14,483	5,795	5,795	5,733	5,733	6,092	6,096	6,003	6,007	5,264	5,264
Number of inventors	65,415	29,172	36,088	12,189	14,185	13,046	13,121	12,749	15,065	13,721	13,445	11,811	12,236
Observations	1,276,729	572,604	701,151	228,326	273,946	254,861	243,392	240,915	290,765	261,790	260,285	224,684	236,926

Cluster(appln_id)-robust standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Table corresponding to Figure 2.5, displaying heterogeneity of the invalidation effect for sample splits by applicant characteristics. All columns present results from instrumental variable (2SLS) fixed effects regressions on (inventor, year relative to opposition outcome)-level. Column (1) indicates the coefficient of 1(Invalidated) × 1(Post) for the full sample. Columns (2)-(15) show the coefficients for the subsamples split by the applicant's patent portfolio, number of employees, number of patent applications per employee, revenue (deflated), leverage (defined as total liabilities over total assets), and profitability (defined as ebitda over total assets). In each case, the sample is split at the median of the respective variable. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

Table B.16: Effect of invalidation on number of applications: Inventor heterogeneity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Estimation method	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE	IV FE
	Inventor origin		Tenure		App (pre)		App (pre) same area		App (pre) coauthors		Tech areas (pre)		Inventors in opp		Opp tech area	
	Non-Eur	European	Short	Long	Few	Many	Few	Many	Few	Many	Few	Many	Multiple	Single	Non-exp	Expert
Dependent variable	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}	N_{app}
1(Invalidated) × 1(Post)	−0.582**	−0.403**	−0.330**	−0.586**	−0.131***	−0.619**	−0.417***	−0.401*	−0.566***	−0.443**	−0.324***	−0.635**	−0.558***	−0.241	−0.567	−0.503***
	(0.252)	(0.179)	(0.133)	(0.272)	(0.044)	(0.281)	(0.112)	(0.227)	(0.206)	(0.192)	(0.082)	(0.273)	(0.169)	(0.280)	(0.365)	(0.153)
Year effects (rel to oppo)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes	Yes***	Yes***
Year effects (rel to appl)	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Underidentification test	28.2	53.5	55.1	41.9	54.1	47.2	42.4	54.4	56.6	50.8	57.9	45.6	60.5	32.6	26.5	68.4
Weak identification test	28.4	53.9	55.6	42.2	54.6	47.6	42.7	54.9	56.9	51.2	58.4	45.9	61.0	32.7	26.7	68.9
Number of oppositions	11,383	18,553	17,642	18,773	18,028	19,517	15,262	21,047	22,192	16,576	17,338	20,228	20,925	8,084	9,915	25,090
Number of inventors	27,797	37,618	32,688	32,727	31,399	34,016	26,568	38,847	31,044	34,371	29,205	36,210	57,331	8,084	15,047	50,368
Observations	545,363	731,366	646,594	630,135	618,680	658,049	522,135	754,594	608,904	667,825	575,046	701,683	1,117,227	159,502	291,083	985,646

Cluster(appln_id)-robust standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Table corresponding to Figure 2.6, displaying heterogeneity of the invalidation effect for sample splits by inventor characteristics. All columns present results from instrumental variable (2SLS) fixed effects regressions on (inventor, year relative to opposition outcome)-level. Columns (1)-(16) display the coefficients for the subsamples split by inventor origin, by tenure, i.e., by the time since the first EP application, by the number of applications prior to opposition outcome, by the number of applications in the same area as the opposed patent, by the number of applications of the inventor's coauthors, by the number technology areas in prior filings, by whether the opposed patent lists multiple inventors, and by whether the opposed patent falls into the inventors technology area of expertise, i.e., the area in which she has filed most patents prior to opposition outcome. For the continuous and the count variables, the sample is split at the respective median. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

C

Appendix to Chapter 3

Selection of Patents for Litigation

C.1 Analytical Results

This appendix shows analytical results necessary for the numerical evaluation of model predictions and hence the fit of the model. Subsections C.1.1 to C.1.4 present general expressions, Subsection C.1.5 derives results for the specific distributional assumptions of Section 3.4.1. In the following, probability density functions (pdf) will be denoted with f, cumulative distribution functions (cdf) with F. Random variables will be indicated with a hat.

C.1.1 Probability Density and Cumulative Distribution Functions

This section lists probability density and cumulative distribution functions for a selection of relevant distributions.

Normal distribution $\hat{x} \sim \mathcal{N}(\mu, \sigma^2)$ of mean $\mu \in \mathbb{R}$ and standard deviation $\sigma \in \mathbb{R}^+$:

$$\begin{aligned} f(x) &= \frac{1}{\sqrt{2\pi}\sigma} e^{-(x-\mu)^2/2\sigma^2} = \frac{1}{\sigma}\varphi\left(\frac{x-\mu}{\sigma}\right) \\ F(x) &= \frac{1}{2}\left(1+\operatorname{erf}\left(\frac{x-\mu}{\sqrt{2}\sigma}\right)\right) = \Phi\left(\frac{x-\mu}{\sigma}\right), \end{aligned} \tag{C.1}$$

where $x \in \mathbb{R}$ and where φ and Φ are the standard normal pdf and cdf, respectively. Most programming languages provide fast implementations for the exponential function exp, the error function erf and often even the standard normal cdf Φ. Besides, numerous analytical results exist for integrals containing φ and Φ in their integrands (Bronstein et al., 2008; Owen, 1980).

Log-normal distribution $\ln(\hat{x}) \sim \mathcal{N}(\mu, \sigma^2)$ with parameters $\mu \in \mathbb{R}$ and $\sigma \in \mathbb{R}^+$:

$$\begin{aligned} f(x) &= \frac{1}{\sqrt{2\pi}\sigma x} e^{-(\ln(x)-\mu)^2/2\sigma^2} \\ F(x) &= \frac{1}{2}\left(1+\operatorname{erf}\left(\frac{\ln(x)-\mu}{\sqrt{2}\sigma}\right)\right) = \Phi\left(\frac{\ln(x)-\mu}{\sigma}\right), \end{aligned} \tag{C.2}$$

where $x \in \mathbb{R}^+$.

Exponential distribution $\hat{x} \sim \mathrm{Exp}(\lambda)$ with parameter $\lambda \in \mathbb{R}^+$:

$$\begin{aligned} f(x) &= \lambda e^{-\lambda x} \\ F(x) &= 1 - e^{-\lambda x}, \end{aligned} \tag{C.3}$$

where $x \in \mathbb{R}$.

C.1.2 Joint, Conditional, and Derived Distributions

The cumulative distribution function of $\hat{\imath}_p = \hat{\imath} + \hat{\varepsilon}_p$ is given by

$$\begin{aligned} F_{i_p}(i_p) &= \int_{-\infty}^{\infty} di\, f_i(i) \int_{-\infty}^{\infty} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) \mathbb{1}_{i+\varepsilon_p \leq i_p} \\ &= \int_{-\infty}^{\infty} di\, f_i(i) \int_{-\infty}^{i_p - i} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) \\ &= \int_{-\infty}^{\infty} di\, f_i(i) F_{\varepsilon_p}(i_p - i) . \end{aligned} \tag{C.4}$$

Hence, the probability density function is given by

$$f_{i_p}(i_p) = \frac{\partial}{\partial i_p} F_{i_p}(i_p) = \int_{-\infty}^{\infty} di\, f_i(i) f_{\varepsilon_p}(i_p - i) . \tag{C.5}$$

Analogous expressions hold for $\hat{\imath}_d = \hat{\imath} + \hat{\varepsilon}_d$.

The joint distribution of $\hat{\imath}_p$ and $\hat{\imath}_d$ can be written as

$$\begin{aligned} f(i_p, i_d) &= \int_{-\infty}^{\infty} di f_i(i) \int_{-\infty}^{\infty} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) \int_{-\infty}^{\infty} d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d) \delta(i + \varepsilon_p - i_p) \delta(i + \varepsilon_d - i_d) \\ &= \int_{-\infty}^{\infty} di f_i(i) f_{\varepsilon_p}(i_p - i) f_{\varepsilon_d}(i_d - i) , \end{aligned} \tag{C.6}$$

where δ denotes the Dirac delta function.

The distribution of $\hat{\imath}_p$ conditional on $\hat{\imath}_d$ is given by

$$f_{i_p}(i_p \mid i_d) = \frac{f(i_p, i_d)}{f_{i_d}(i_d)} \tag{C.7}$$

and the corresponding cumulative distribution function by

$$\begin{aligned} F_{i_p}(i_p \mid i_d) &= \int_{-\infty}^{i_p} di'_p f_{i_p}(i'_p \mid i_d) \\ &= \ldots = \frac{1}{f_{i_d}(i_d)} \int_{-\infty}^{\infty} di f_i(i) F_{\varepsilon_p}(i_p - i) f_{\varepsilon_d}(i_d - i) \end{aligned} \tag{C.8}$$

Analogous results hold for the distribution of $\hat{\imath}_d$ conditional on $\hat{\imath}_p$.

For the joint distribution of $\hat{\imath}_p$ and $\hat{\varepsilon}_p$ one obtains

$$\begin{aligned} f(i_p, \varepsilon_p) &= f_{\varepsilon_p}(\varepsilon_p) \int_{-\infty}^{\infty} di f_i(i) \delta(i + \varepsilon_p - i_p) \\ &= f_i(i_p - \varepsilon_p) f_{\varepsilon_p}(\varepsilon_p) . \end{aligned} \tag{C.9}$$

The joint distribution of $\hat{\imath}$, $\hat{\imath}_p$ and $\hat{\imath}_d$ is

$$f(i,i_d,i_p) = f_i(i) f_{\varepsilon_d}(i_d - i) f_{\varepsilon_p}(i_p - i)\,. \tag{C.10}$$

C.1.3 Model Mechanics

The probability that a patent is invalid given d's information is independent of $\hat{v}$,

$$\begin{aligned}\mathbb{P}(\text{invalid} \mid \hat{\imath}_d) &= \mathbb{P}(\text{invalid} \mid \hat{\imath}_d, \hat{v}) \\ &= \int_{-\infty}^{\infty} d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d) \mathbb{1}_{\hat{\imath}=\hat{\imath}_d-\varepsilon_d<i_0} \\ &= \int_{\hat{\imath}_d-i_0}^{\infty} d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d) = 1 - F_{\varepsilon_d}(\hat{\imath}_d - i_0)\end{aligned} \tag{C.11}$$

The probability that a patent is valid given p's information is the ratio

$$\mathbb{P}(\text{valid} \mid \hat{\imath}_p, \hat{v}, \text{entry}) = \frac{\mathbb{P}(\text{valid, entry} \mid \hat{\imath}_p, \hat{v})}{\mathbb{P}(\text{entry} \mid \hat{\imath}_p, \hat{v})}\,, \tag{C.12}$$

the denominator of which is given by

$$\mathbb{P}(\text{entry} \mid \hat{\imath}_p, \hat{v}) = \int_{-\infty}^{\infty} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) \int_{-\infty}^{\infty} d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d) \mathbb{1}_{\mathbb{E}[\pi_d|\hat{\imath}_d=\hat{\imath}_p-\varepsilon_p+\varepsilon_d,\hat{v},\text{entry}]>0}\,.$$

Note that through the sharp decision at zero expected profits, which enters through the indicator function, the integrand is discontinuous. To simplify this expression further and to make it accessible to numerical integration I define

$$i_d^{\max}(\hat{v}):\ \mathbb{E}[\pi_d \mid \hat{\imath}_d = i_d^{\max}(\hat{v}), \hat{v}, \text{entry}] = \mathbb{E}[\pi_d \mid \text{no entry}] = 0\,. \tag{C.13}$$

Under the assumption that $\mathbb{E}[\pi_d \mid \hat{\imath}_d, \hat{v}, \text{entry}]$ is a monotonous function of $\hat{\imath}_d$ that is strictly decreasing in its root $i_d^{\max}(\hat{v})$ (the root consequently being unique), the following are equivalent:

$$\mathbb{E}[\pi_d \mid \hat{\imath}_d, \hat{v}, \text{entry}] > 0 \iff \hat{\imath}_d < i_d^{\max}(\hat{v})\,. \tag{C.14}$$

One can thus write

$$\begin{aligned}\mathbb{P}(\text{entry} \mid \hat{\imath}_p, \hat{v}) &= \int_{-\infty}^{\infty} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) \int_{-\infty}^{\infty} d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d) \mathbb{1}_{\hat{\imath}_d=\hat{\imath}_p-\varepsilon_p+\varepsilon_d<i_d^{\max}(\hat{v})} \\ &= \int_{-\infty}^{\infty} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) F_{\varepsilon_d}(i_d^{\max}(\hat{v}) - \hat{\imath}_p + \varepsilon_p)\,.\end{aligned} \tag{C.15}$$

The numerator in Eq. (C.12) is given by

$$\begin{aligned}\mathbb{P}(\text{valid, entry} \mid \hat{\imath}_p, \hat{v}) &= \int_{-\infty}^{\infty} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) \int_{-\infty}^{\infty} d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d) \mathbb{1}_{\hat{\imath}_d = \hat{\imath}_p - \varepsilon_p + \varepsilon_d < i_d^{\max}(v)} \mathbb{1}_{\hat{\imath} = \hat{\imath}_p - \varepsilon_p > i_0} \\ &= \int_{-\infty}^{\hat{\imath}_p - i_0} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) F_{\varepsilon_d}(i_d^{\max}(\hat{v}) - \hat{\imath}_p + \varepsilon_p) \end{aligned} \tag{C.16}$$

and thus

$$\mathbb{P}(\text{valid} \mid \hat{\imath}_p, \hat{v}, \text{entry}) = \frac{\int_{-\infty}^{\hat{\imath}_p - i_0} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) F_{\varepsilon_d}(i_d^{\max}(\hat{v}) - \hat{\imath}_p + \varepsilon_p)}{\int_{-\infty}^{\infty} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) F_{\varepsilon_d}(i_d^{\max}(\hat{v}) - \hat{\imath}_p + \varepsilon_p)} . \tag{C.17}$$

Auxiliary results for d's expected profits

The probability that the patent would enter litigation in the case of entry, i.e. the probability that the asking price is above the bidding price, given d's information, is given by

$$\begin{aligned}&\mathbb{P}(A(\hat{\imath}_p, \hat{v}) > B(\hat{\imath}_d, \hat{v}) \mid \hat{\imath}_d, \hat{v}) \\ &\quad = \int_{-\infty}^{\infty} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) \int_{-\infty}^{\infty} d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d) \mathbb{1}_{A(\hat{\imath}_d - \varepsilon_d + \varepsilon_p, \hat{v}) > B(\hat{\imath}_d, \hat{v})}\end{aligned} \tag{C.18}$$

Note that I do not write $\mathbb{P}(\text{litigation, valid} \mid \hat{\imath}_d, \hat{v})$ here, since with "litigation" I usually mean "entry" *and* "$A > B$". Here however, the probability of "entry" does not make sense, since this probability is precisely used to determine whether entry occurs. In that sense, "entry" does not contain any additional information beyond $\hat{\imath}_d$.

To move the indicator function to the integration borders, I define

$$i_p^{\min}(\hat{\imath}_d, \hat{v}) := \min\{i_p : A(i_p, \hat{v}) > B(\hat{\imath}_d, \hat{v})\} . \tag{C.19}$$

If $A(i_p, \hat{v}) \leq B(\hat{\imath}_d, \hat{v}) \, \forall \, i_p$ given $(\hat{\imath}_d, \hat{v})$, I set $i_p^{\min}(\hat{\imath}_d, \hat{v}) = \infty$, so that the probability of A being larger than B is consistently zero, $\mathbb{P}(A(\hat{\imath}_p, \hat{v}) > B(\hat{\imath}_d, \hat{v})) = \mathbb{P}(\hat{\imath}_p > i_p^{\min}(\hat{\imath}_d, \hat{v})) = 0$. Under the assumptions that $A(\hat{\imath}_p, \hat{v})$ and $B(\hat{\imath}_d, \hat{v})$ are strictly increasing functions in $\hat{\imath}_p$ and $\hat{\imath}_d$, respectively, this leads to the equivalence relation

$$A(\hat{\imath}_p, \hat{v}) > B(\hat{\imath}_d, \hat{v}) \iff \hat{\imath}_p > i_p^{\min}(\hat{\imath}_d, \hat{v}) , \tag{C.20}$$

which one can use to rewrite Eq. (C.18) to obtain

$$\mathbb{P}(A(\hat{\imath}_p, \hat{v}) > B(\hat{\imath}_d, \hat{v}) \mid \hat{\imath}_d, \hat{v}) = \int_{-\infty}^{\infty} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) F_{\varepsilon_d}(\hat{\imath}_d - i_p^{\min}(\hat{\imath}_d, \hat{v}) + \varepsilon_p) \tag{C.21}$$

or, equivalently,

$$\mathbb{P}(A(\hat{\imath}_p,\hat{v}) > B(\hat{\imath}_d,\hat{v}) \mid \hat{\imath}_d,\hat{v}) = \int_{-\infty}^{\infty} d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d)\big[1 - F_{\varepsilon_p}(i_p^{\min}(\hat{\imath}_d,\hat{v}) - \hat{\imath}_d + \varepsilon_d)\big].$$

Clearly, for the opposite event,

$$\mathbb{P}(A(\hat{\imath}_p,\hat{v}) \leq B(\hat{\imath}_d,\hat{v}) \mid \hat{\imath}_d,\hat{v}) = 1 - \mathbb{P}(A(\hat{\imath}_p,\hat{v}) > B(\hat{\imath}_d,\hat{v}) \mid \hat{\imath}_d,\hat{v}).$$

The probability that a patent is valid and would enter litigation in the case of entry given d's information follows from a reasoning similar to the one above, again using Def. (C.19),

$$\begin{aligned}
&\mathbb{P}(A(\hat{\imath}_p,\hat{v}) > B(\hat{\imath}_d,\hat{v}), \text{valid} \mid \hat{\imath}_d,\hat{v}) \\
&\quad = \int_{-\infty}^{\infty} d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) \int_{-\infty}^{\infty} d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d) \mathbb{1}_{A(\hat{\imath}_d-\varepsilon_d+\varepsilon_p,\hat{v})>B(\hat{\imath}_d,\hat{v})} \mathbb{1}_{\hat{\imath}_d-\varepsilon_d>i_0} \\
&\quad = \int_{-\infty}^{\hat{\imath}_d-i_0} d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d)\big[1 - F_{\varepsilon_p}(i_p^{\min}(\hat{\imath}_d,\hat{v}) - \hat{\imath}_d + \varepsilon_d)\big]. \qquad \text{(C.22)}
\end{aligned}$$

The probability of a patent potentially entering litigation and being invalid follows directly from the two previous results,

$$\begin{aligned}
&\mathbb{P}\big(A(\hat{\imath}_p,\hat{v}) > B(\hat{\imath}_d,\hat{v}), \text{invalid} \mid \hat{\imath}_d,\hat{v}\big) \\
&\quad = \mathbb{P}\big(A(\hat{\imath}_p,\hat{v}) > B(\hat{\imath}_d,\hat{v}) \mid \hat{\imath}_d,\hat{v}\big) - \mathbb{P}\big(A(\hat{\imath}_p,\hat{v}) > B(\hat{\imath}_d,\hat{v}), \text{valid} \mid \hat{\imath}_d,\hat{v}\big). \qquad \text{(C.23)}
\end{aligned}$$

C.1.4 Model Predictions

Outcome and validity rates

The probability that a random patent is invalid is simply given by

$$\mathbb{P}(\text{invalid}) = \int_{-\infty}^{i_0} di f_i(i) = F_i(i_0) \qquad \text{(C.24)}$$

The probability that no entry occurs can be simplified using the definition of $i_d^{\max}$ in Eq. (C.13),

$$\begin{aligned}
\mathbb{P}(\text{no entry}) &= \int_0^{\infty} dv f_v(v) \int_{-\infty}^{\infty} di_d f_{i_d}(i_d) \mathbb{1}_{i_d > i_d^{\max}(v)} \\
&= \int_0^{\infty} dv f_v(v)\big[1 - F_{i_d}(i_d^{\max}(v))\big] \qquad \text{(C.25)}
\end{aligned}$$

The probability of litigation can be derived as

$$\begin{aligned}
\mathbb{P}(\text{litigation}) &= \mathbb{P}(\text{entry}, A(\hat{\imath}_p, \hat{v}) > B(\hat{\imath}_d, \hat{v})) \\
&= \int_0^\infty dv f_v(v) \int_{-\infty}^\infty d_{i_d} f_{i_d}(i_d) \int_0^\infty d_{i_p} f_{i_p}(i_p \mid i_d) \\
&\qquad \underbrace{\mathbb{1}_{i_d \leq i_d^{\max}(v)}}_{\Rightarrow \text{entry}} \underbrace{\mathbb{1}_{i_p \geq i_p^{\min}(i_d, v)}}_{\Rightarrow A > B} \underbrace{\mathbb{1}_{i_p^{\min}(i_d,v)<\infty}}_{\text{can be added since } i_p < \infty\ \mathbb{P}\text{-a.s.}} \\
&= \int_0^\infty dv f_v(v) \int_{-\infty}^{i_d^{\max}(v)} d_{i_d} f_{i_d}(i_d) \left[1 - F_{i_p}(i_p^{\min}(i_d, v) \mid i_d)\right] \mathbb{1}_{i_p^{\min}(i_d,v)<\infty}
\end{aligned} \tag{C.26}$$

Note that $i_p^{\min} = \infty$ causes a discontinuity in the integrand, forcing it to 0 due to $F_{i_p}(i_p^{\min}(i_d, v) \mid i_d) = 1$, which is why I have introduced the additional indicator function as a reminder above. To circumvent resulting issues during numerical integration, I define

$$i_d^\infty(v) := \max\{i_d \in \mathbb{R} : i_p^{\min}(i_d, v) < \infty\}, \tag{C.27}$$

which can efficiently be determined to an arbitrarily high precision numerically. The probability of litigation is thus given by

$$\mathbb{P}(\text{litigation}) = \int_0^\infty dv f_v(v) \int_{-\infty}^{\min\{i_d^{\max}(v), i_d^\infty(v)\}} d_{i_d} f_{i_d}(i_d) \left[1 - F_{i_p}(i_p^{\min}(i_d, v) \mid i_d)\right] \tag{C.28}$$

The probability of settlement follows directly from the above,

$$\mathbb{P}(\text{settlement}) = 1 - \mathbb{P}(\text{no entry}) - \mathbb{P}(\text{litigation}), \tag{C.29}$$

since it is the only remaining outcome.

Conditional outcome and validity rates

The probability that a patent is valid, given that no entry occurs, is given by

$$\mathbb{P}(\text{valid} \mid \text{no entry}) = \frac{\mathbb{P}(\text{valid, no entry})}{\mathbb{P}(\text{no entry})} \tag{C.30}$$

where the numerator is given by

$$\begin{aligned}
\mathbb{P}(\text{valid, no entry}) &= \int_{i_0}^\infty di f_i(i) \int_0^\infty dv f_v(v) \int_{-\infty}^\infty d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d) \mathbb{1}_{i_d = i + \varepsilon_d > i_d^{\max}(v)} \\
&= \int_{i_0}^\infty di f_i(i) \int_0^\infty dv f_v(v) \left[1 - F_{\varepsilon_d}(i_d^{\max}(v) - i)\right].
\end{aligned} \tag{C.31}$$

The probability that a patent is valid, given that it is subject to litigation, is the ratio

$$\mathbb{P}(\text{valid} \mid \text{litigation}) = \frac{\mathbb{P}(\text{valid, litigation})}{\mathbb{P}(\text{litigation})} \tag{C.32}$$

where the numerator is given by

$$\begin{aligned}\mathbb{P}(\text{valid, litigation}) = \int_{i_0}^{\infty} di f_i(i) \int_0^{\infty} dv f_v(v) \int_{-\infty}^{\infty} d\varepsilon_d f_{\varepsilon_d}(\varepsilon_d) \\ \left[1 - F_{\varepsilon_p}(i_p^{\min}(i+\varepsilon_d, v) - i)\right].\end{aligned} \tag{C.33}$$

Note that this is different from the result in Eq. (C.22), which is conditional on d's information.

Finally, the probability that a patent is valid, given a settlement outcome, is given by

$$\mathbb{P}(\text{valid} \mid \text{settlement}) = \frac{\mathbb{P}(\text{valid, settlement})}{\mathbb{P}(\text{settlement})} \tag{C.34}$$

where the numerator follows directly from previous results,

$$\mathbb{P}(\text{valid, settlement}) = \mathbb{P}(\text{valid}) - \mathbb{P}(\text{valid, no entry}) - \mathbb{P}(\text{valid, litigation}). \tag{C.35}$$

Outcome probabilities conditional on validity follow immediately from the above results,

$$\mathbb{P}(\text{outcome} \mid \text{valid}) = \frac{\mathbb{P}(\text{valid, outcome})}{\mathbb{P}(\text{valid})}. \tag{C.36}$$

Expected patented invention values

The expected patented invention value for an arbitrary patent from the population is

$$\mathbb{E}[v] = \int_0^{\infty} dv f_v(v) v = e^{\mu_v + \sigma_v^2/2}, \tag{C.37}$$

by the standard result for the log-normal distribution.

The expected patented invention values conditional on an outcome can be calculated in direct analogy to the corresponding outcome probabilities. In each case, the numerator differs only by the additional v in the integrand. Hence, the expected patented invention value given that no entry occurs can be derived as

$$\begin{aligned}\mathbb{E}[v \mid \text{no entry}] &= \frac{1}{\mathbb{P}(\text{no entry})} \int_0^{\infty} dv f_v(v) v \int_{-\infty}^{\infty} di_d f_{i_d}(i_d) \mathbb{1}_{i_d > i_d^{\max}(v)} \\ &= \frac{1}{\mathbb{P}(\text{no entry})} \int_0^{\infty} dv f_v(v) v \left[1 - F_{i_d}(i_d^{\max}(v))\right].\end{aligned} \tag{C.38}$$

The expected patented invention value given litigation is

$$\mathbb{E}[v \mid \text{litigation}] = \frac{1}{\mathbb{P}(\text{litigation})} \int_0^\infty dv f_v(v) v \int_{-\infty}^\infty di_d f_{i_d}(i_d) \int_{-\infty}^\infty di_p f_{i_p}(i_p)$$
$$\mathbb{1}_{i_d \leq i_d^{\max}(v)} \mathbb{1}_{i_p \geq i_p^{\min}(i_d, v)} \mathbb{1}_{i_p^{\min}(i_d,v) < \infty}$$
$$= \int_0^\infty dv f_v(v) v \int_{-\infty}^{\min\{i_d^q \max(v), i_d^\infty(v)\}} d_{i_d} f_{i_d}(i_d) \left[1 - F_{i_p}(i_p^{\min}(i_d, v) \mid i_d)\right]. \tag{C.39}$$

Finally, the expected patented invention value given that parties settle follows immediately from the previous results,

$$\mathbb{E}[v \mid \text{settlement}] = \frac{\mathbb{E}[v] - \mathbb{P}(\text{no entry})\mathbb{E}[v \mid \text{no entry}] - \mathbb{P}(\text{litigation})\mathbb{E}[v \mid \text{litigation}]}{1 - \mathbb{P}(\text{no entry}) - \mathbb{P}(\text{litigation})}. \tag{C.40}$$

C.1.5 Explicit Results for the Distributional Assumptions of Section 3.4.1

This subsection lists analytical results for the distributional assumptions of Section 3.4.1. Results for the expressions of the previous subsections which are not explicitly spelled out follow trivially or in close analogy. First, let me define and solve two definite integrals that will be useful in several of the derivations below.

Integral I_1 is defined as

$$I_1(b, c) := \int_{-\infty}^b d\varepsilon_p f_{\varepsilon_p}(\varepsilon_p) F_{\varepsilon_d}(c + \varepsilon_d)$$
$$= \begin{cases} 0 \quad \text{if} \quad b \leq 0 \ \vee \ b \leq -c \\ e^{-\lambda_p \max\{0,-c\}} - e^{-\lambda_p b} - \frac{\lambda_p}{\lambda_p + \lambda_d} e^{-\lambda_d c}\left(e^{-(\lambda_p+\lambda_d)\max\{0,-c\}} - e^{-(\lambda_p+\lambda_d) b}\right) & \text{otherwise} \end{cases} \tag{C.41}$$

Note that $\lim_{\hat{\imath}_p \to \infty} I_1(\hat{\imath}_p - i_0, i_d^{\max}(\hat{v}) - \hat{\imath}_p) = 0$.

Integral I_2 is defined as

$$I_2(\lambda, b) := \int_{-\infty}^b di\, f_i(i) e^{\lambda i} = \frac{1}{\sigma} \int_{-\infty}^b di\, \varphi\left(\frac{i - \mu_i}{\sigma_i}\right) e^{\lambda i}. \tag{C.42}$$

By substituting with $x = \frac{i-\mu_i}{\sigma_i}$, one obtains

$$= e^{\lambda \mu_i} \int_{-\infty}^{(b-\mu_i)/\sigma_i} dx'\, \varphi(x') e^{\lambda \sigma_i x' + \lambda \mu_i},$$

which is a tabulated integral (Bronstein et al., 2008), evaluating to

$$= e^{\lambda\mu_i} e^{\lambda^2\sigma_i^2/2}\, \Phi\left(\frac{b-\mu_i}{\sigma_i} - \lambda\sigma_i\right).$$

In the numerical implementation, it is advisable to calculate this expression as

$$= \exp\left(\lambda\mu_i + \frac{\lambda^2\sigma_i^2}{2} + \ln\Phi\left(\frac{b-\lambda\sigma_i^2-\mu_i}{\sigma_i}\right)\right) \tag{C.43}$$

to avoid arithmetic overflow. In Python's `scipy` library, the logarithm of the Gaussian cumulative distribution function, $\ln\Phi$, is implemented as `scipy.special.log_ndtr`.

Using these definitions, I can rewrite the cumulative distribution function of i_p as

$$F_{i_p}(i_p) = F_i(i_p) - e^{-\lambda_p i_p}\, I_2(\lambda_p, i_p) \tag{C.44}$$

and, by applying the product rule, the probability density function as

$$f_{i_p}(i_p) = \frac{\partial}{\partial i_p} F_{i_p}(i_p) = \lambda_p e^{-\lambda_p i_p} I_2(\lambda_p, i_p)\,. \tag{C.45}$$

Of course, analogous results hold for i_d.

The joint probability density of i_p and i_d of Eq. (C.6) becomes

$$f(i_p, i_d) = \lambda_p\lambda_d e^{-\lambda_p i_p - \lambda_d i_d}\, I_2(\lambda_p+\lambda_d, \min\{i_p, i_d\})\,. \tag{C.46}$$

The conditional cumulative distribution function of i_p given i_d of Eq. (C.8) is then

$$F_{i_p}(i_p \mid i_d) = \Big(e^{-\lambda_d i_d}\, I_2(\lambda_d, \min\{i_p, i_d\}) - e^{-\lambda_p i_p - \lambda_d i_d}\, I_2(\lambda_p+\lambda_d, \min\{i_p, i_d\})\Big)/f_{i_d}(i_d)\,. \tag{C.47}$$

Analogous results hold for $F_{i_d}(i_d \mid i_p)$.

Concerning probabilities, Eq. (C.17) becomes

$$\mathbb{P}(\text{valid} \mid \hat{\imath}_p, \hat{v}, \text{entry}) = \frac{I_1(\hat{\imath}_p - i_0,\ \hat{\imath}_d^{\max}(\hat{v}) - \hat{\imath}_p)}{I_1(\ \infty\ \ ,\ \hat{\imath}_d^{\max}(\hat{v}) - \hat{\imath}_p)} \tag{C.48}$$

It can be shown that for $\hat{\imath}_p > i_d^{\max}(\hat{v}) > i_0$, the expression for $\mathbb{P}(\text{valid} \mid \hat{\imath}_p, \hat{v}, \text{entry})$ is independent of $\hat{\imath}_p$. Further, for Eq. (C.22),

$$\mathbb{P}(A(\hat{\imath}_p, \hat{v}) > B(\hat{\imath}_d, \hat{v}), \text{valid} \mid \hat{\imath}_d, \hat{v}) = I_1(\infty, \hat{\imath}_d - i_p^{\min}(\hat{\imath}_d, \hat{v}))\,. \tag{C.49}$$

Eq. (C.31) can be rewritten as

$$\mathbb{P}(\text{valid, no entry}) = \int_0^\infty dv \Big(1 - F_i(i_d^{\max}(v)) + e^{-\lambda_d i_d^{\max}(v)} \big[I_2(\lambda_d, i_d^{\max}(v)) - I_2(\lambda_d, i_0)\big]\Big). \tag{C.50}$$

From Eq. (C.33), I know that

$$\mathbb{P}(\text{valid, litigation}) = \int_0^\infty dv\, f_v(v) \int_{i_p^{\min}(i_d,v)}^\infty di_p \int_{-\infty}^{i_d^{\max}(v)} di_d\, H(i_p, i_d), \tag{C.51}$$

where

$$\begin{aligned} H(i_p, i_d) &:= \int_{i_0}^\infty di\, f_i(i) f_{\varepsilon_p}(i_p - i) f_{\varepsilon_d}(i_d - i) \\ &= \int_{i_0}^\infty di\, f_i(i) \lambda_p \lambda_d e^{-\lambda_p (i_d - i)} e^{-\lambda_d (i_d - i)} \mathbb{1}_{i_d \geq i} \mathbb{1}_{i_p \geq i} \\ &= f_{\varepsilon_p}(i_p) f_{\varepsilon_d}(i_d) \int_{i_0}^{\bar{\imath}(i_p, i_d)} di\, f_i(i) e^{(\lambda_p + \lambda_d) i} \\ &= f_{\varepsilon_p}(i_p) f_{\varepsilon_d}(i_d) \big(I_2(\lambda_p + \lambda_d, \bar{\imath}(i_p, i_d)) - I_2(\lambda_p + \lambda_d, i_0)\big) \end{aligned} \tag{C.52}$$

where $\bar{\imath}(i_p, i_d) := \max\{\min\{i_p, i_d\}, i_0\}$. In order to carry out the i_p-integration,

$$H'(i_d) = \int_{i_p^{\min}(i_d,v)}^\infty di_p f_{\varepsilon_p}(i_p) \big[I_2(\lambda_p + \lambda_d, \bar{\imath}(i_p, i_d) —) - I_2(\lambda_p + \lambda_d, i_0)\big], \tag{C.53}$$

I split the integral at $i_p = i_d$ and make a distinction by case. If $i_p^{\min}(i_d, v) = \infty$,

$$H'(i_d) = 0. \tag{C.54}$$

If instead, $i_d < i_p^{\min}(i_d, v)$, then $i_d < i_p \Rightarrow \bar{\imath} = \max\{i_d, i_0\}$ and

$$H'(i_d) = \big[1 - F_{\varepsilon_p}(i_p^{\min}(i_d, v))\big]\big[I_2(\lambda_p + \lambda_d, \max\{i_d, i_0\}) - I_2(\lambda_p + \lambda_d, i_0)\big]. \tag{C.55}$$

Finally, if $i_d > i_p^{\min}(i_d, v)$, then

$$H'(i_d) = \int_{i_p^{\min}(i_d,v)}^{i_d} di_p\, f_{\varepsilon_p}(i_p)\left[I_2(\lambda_p+\lambda_d, \max\{i_p, i_0\}) - I_2(\lambda_p+\lambda_d, i_0)\right] + \underbrace{\int_{i_d}^{\infty} di_p\, f_{\varepsilon_p}(i_p)}_{=1-F_{\varepsilon_p}(i_d)}\left[I_2(\lambda_p+\lambda_d, \max\{i_d, i_0\}) - I_2(\lambda_p+\lambda_d, i_0)\right]. \tag{C.56}$$

The terms in square brackets vanish if $i_p \leq i_0$ and $i_d \leq i_0$, respectively. Since the latter is independent of i_p, the evaluation of the corresponding integral is trivial.

The remaining integrations over i_p, i_d and v are carried out numerically. To move discontinuities in the v and the i_d-integration (due to $i_p^{\min} = \infty$) to the integration borders, it is helpful to introduce

$$i_d^{\infty}(v) := \max\{i_d : i_p^{\min}(i_d, v) < \infty\} \tag{C.57}$$

and

$$v^{\infty}(i_d) := \min\{v : i_p^{\min}(i_d, v) < \infty\}, \tag{C.58}$$

which is constant for $i_d \leq i_0$ and smaller than at any $i_d > i_0$, i.e., $v^{\infty}(i_{d1}) = v_0^{\infty} < v^{\infty}(i_{d2})\ \forall\ i_{d1} \leq i_0 < i_{d2}$. The expressions for i_d^{∞} and v^{∞} can efficiently be evaluated numerically. The short algorithm I have developed for this purpose first searches for the "abyss" in an exponentially increasing interval, then identifies the respective cut-off by bisections, thus converging exponentially fast.

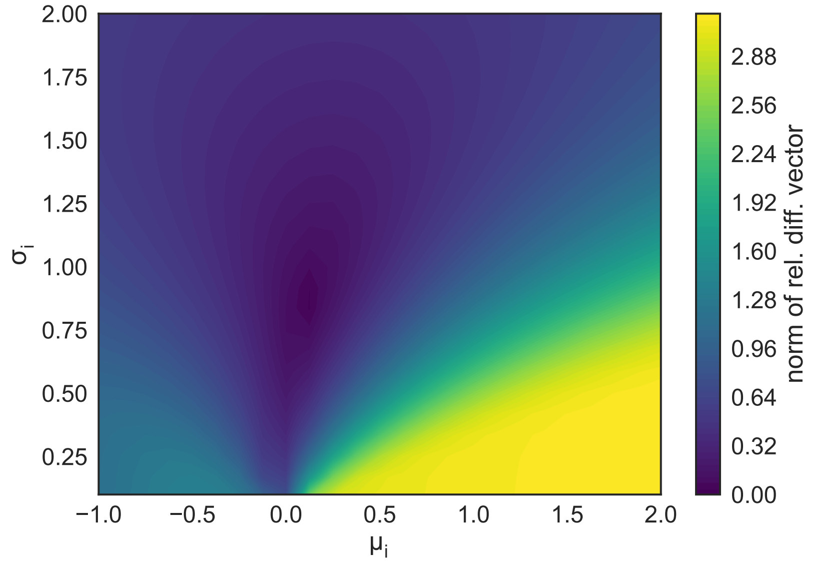
Using these cut-offs, the integration borders in the expressions for $\mathbb{P}$(litigation), $\mathbb{P}$(valid, litigation) and the corresponding expected patented invention values are modified to

$$\int_0^{\infty} dv \int_{-\infty}^{i_d^{\max}(v)} di_d\,(\ldots) \rightarrow \int_{v_0^{\infty}}^{\infty} dv \int_{-\infty}^{\min\{i_d^{\max}(v),\, i_d^{\infty}(v)\}} di_d\,(\ldots). \tag{C.59}$$

For better convergence of the quadrature algorithm, the i_d-integration is split at i_0 in the numerical implementation. For $\mathbb{P}$(valid, no entry), the numerical integration over v in Eq. (C.50) can be carried out without adjusting integration borders.

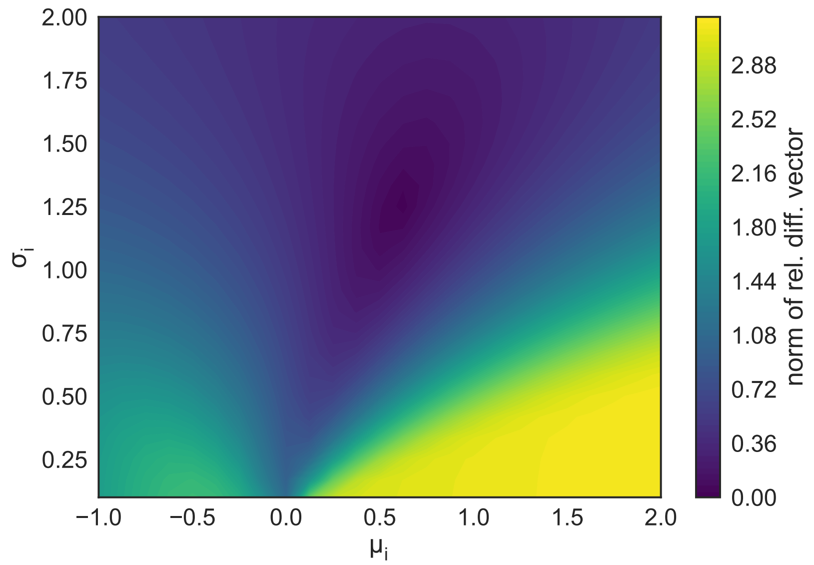
C.2 Figures

Figure C.1: Two-dimensional fitness landscape at $R_{\text{lit}} = 0$



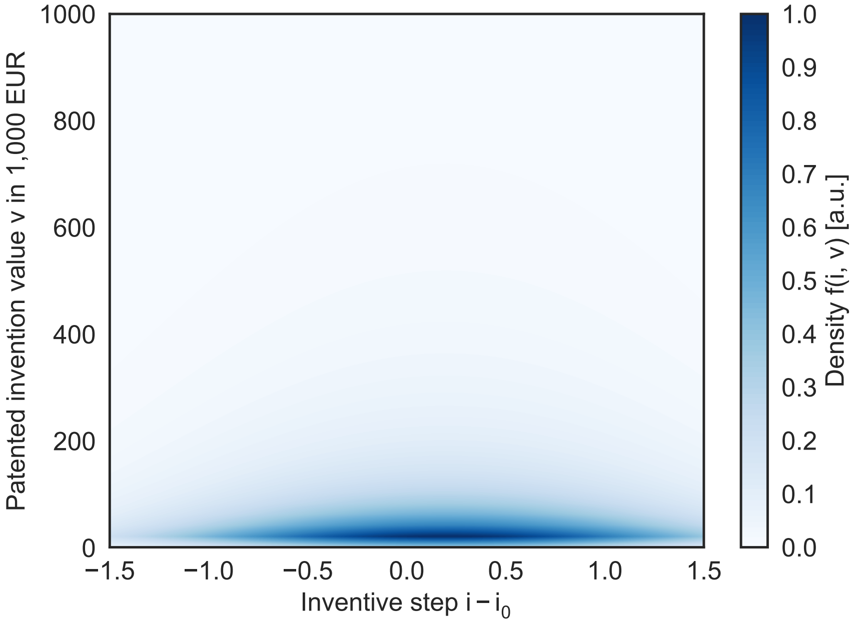
Notes: Value of the objective function g defined in Eq. (3.10) as a function of the model parameters μ_i and σ_i. The litigation reputation parameter is set to $R_{\text{lit}} = 0$, the remaining parameters are set the baseline values indicated in Table 3.1.

Figure C.2: Two-dimensional fitness landscape at $R_{\text{lit}} = 4$



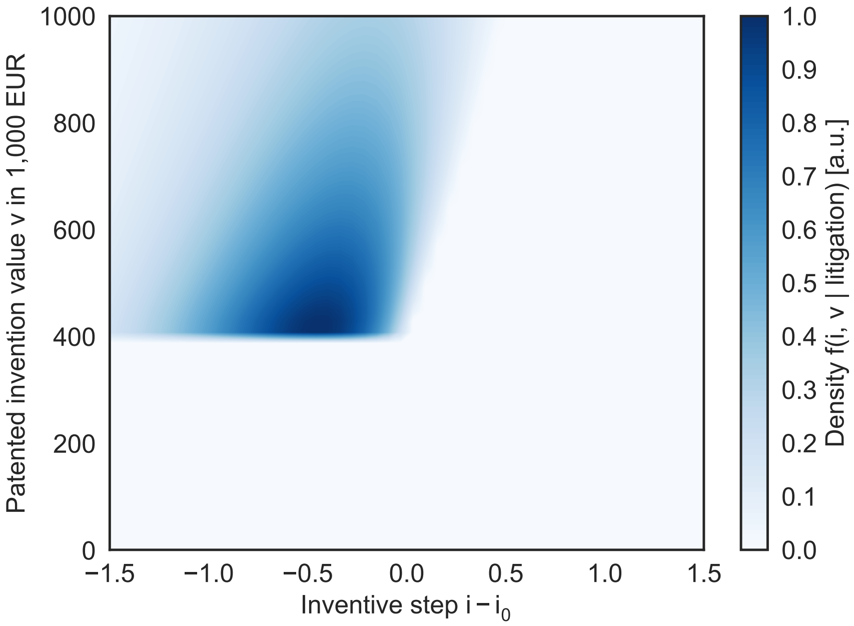
Notes: Analogous to Figure C.1, but for $R_{\text{lit}} = 4$.

Figure C.3: Joint probability density $f(i,v)$



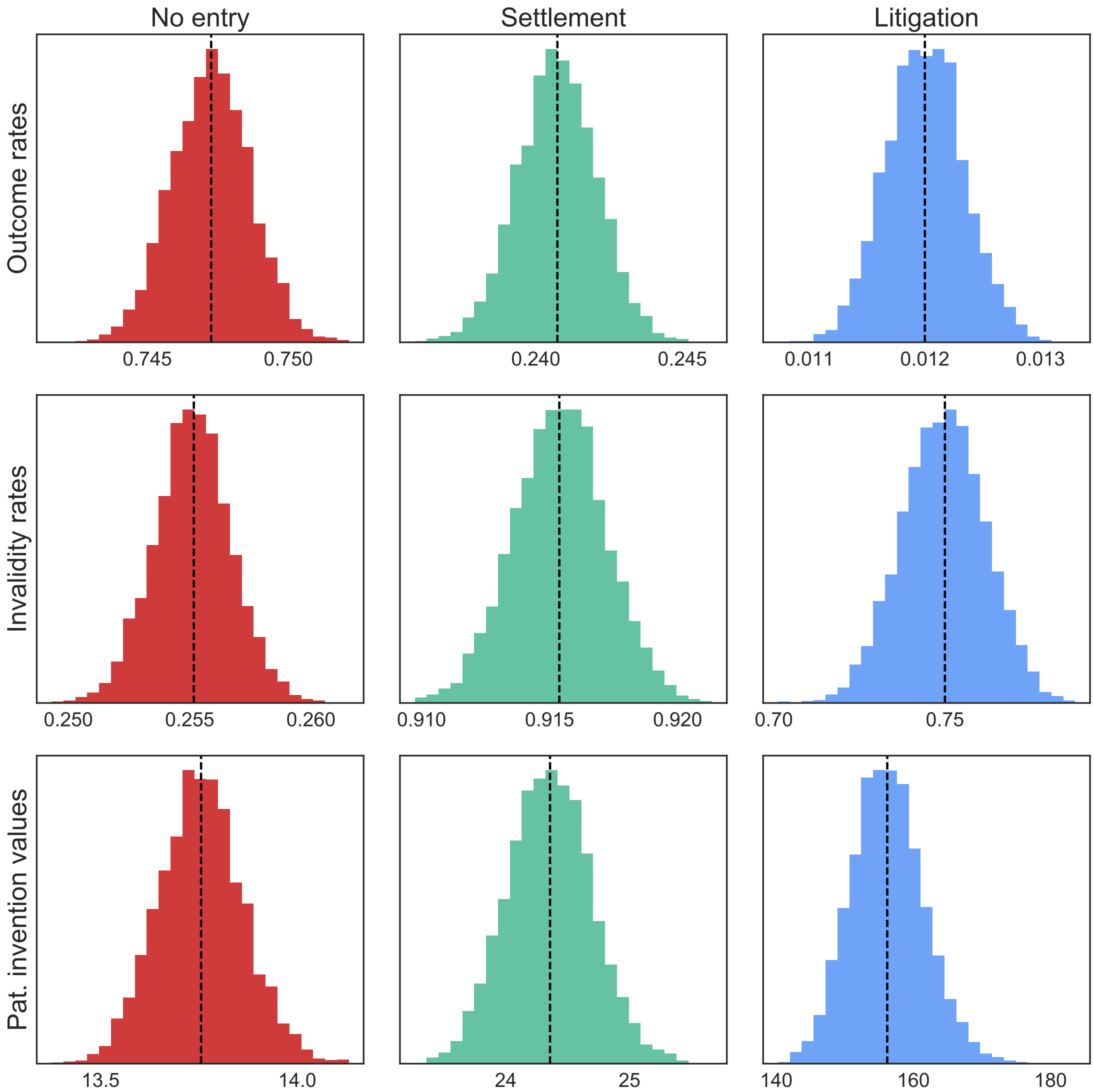
Notes: Joint probability density function $f(i,v)$ of inventive step $\hat{\imath}$ and patented invention value $\hat{v}$ for the patent population in the baseline calibration. By definition, $\hat{\imath}$ and $\hat{v}$ are independent and hence uncorrelated.

Figure C.4: Conditional joint probability density $f(i,v \mid \text{litigation})$



Notes: Joint probability density function $f(i,v \mid \text{litigation})$ of inventive step $\hat{\imath}$ and patented invention value $\hat{v}$ for litigated patents in the baseline calibration. Although $\hat{\imath}$ and $\hat{v}$ are independent random variables, among litigated patents they are positively correlated due to selection.

Figure C.5: Analytical results vs Monte-Carlo simulations



Notes: Analytical results (dashed vertical lines) vs Monte-Carlo simulations (histograms, based on 5,000 simulations of 10^5 patents each). The three columns represent the three outcomes “no entry”, “settlement”, and “litigation”. The rows indicate (i) the overall outcome rates, (ii) the invalidity rates conditional on the respective outcome, and (iii) the average patented invention values. In all cases, the simulations perfectly reproduce the exact results obtained through analytical and numerical integration within their respective precision. Due to the large simulated sample sizes, the integration results can be reproduced with an accuracy of less than 1% (no entry outcome rate) to less than 10% (value of litigated patented inventions).

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