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Bargaining Failure and Freedom to Operate: Re-evaluating the Effect of Patents on Cumulative Innovation

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ABSTRACT

We investigate the causal effect of patent rights on cumulative innovation, using large-scale data that approximate the patent universe in its technological and economic variety. We introduce a novel instrumental variable for patent invalidation that exploits personnel scarcity in post-grant opposition at the European Patent Office. We find that patent invalidation leads to a highly significant and sizeable increase of follow-on inventions. The effect is driven by cases where the removal of the individual exclusion right creates substantial freedom to operate for third parties. Importantly, our results suggest that bargaining failure between original and follow-on innovators is not limited to environments commonly associated with high transaction costs. (107 words)

KEYWORDS: cumulative innovation, patents, bargaining failure, freedom to operate, opposition.

JEL Classification: K41, L24, O31, O32, O33, O34

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1 Introduction

Inventions are rarely stand-alone achievements, but build to a large extent on previous discoveries – *cumulative innovation* has become a dominant characteristic of the modern industrial innovation apparatus. Technical progress may however be impeded if the cumulative nature of invention negatively interacts with patent rights.[1] While the invention's disclosure and the resulting knowledge spillovers are seen as facilitating cumulative innovation (Scotchmer and Green, 1990), exclusion rights on existing technologies require coordination between original and follow-on inventors (Scotchmer, 1991). In the absence of transaction costs, the involved parties should reach a licensing agreement such that cumulative innovation is not blocked. In the presence of transaction costs, however, such negotiations may fail or result in inefficient licensing outcomes that thwart subsequent inventive efforts. In this case, we would expect detrimental consequences for technical progress and, ultimately, for economic growth. This paper investigates the causal effect of patent rights on follow-on invention.[2] We employ a new instrumental variable and make use of a large-scale dataset which approximates the patent universe in its technological and economic variety, e.g., concerning patent value and competitive landscape. We find strong evidence supporting the notion that cumulative innovation is impeded by patents. Reconciling our results with those of previous studies, we suggest that patents likely block follow-on invention across all technology fields – the blocking effect is just easier to detect in some cases than in others.

The empirical investigation of whether and where patents block cumulative innovation calls for exogenous variation in patent protection (Furman et al., 2017), e.g., in the rejection of pending patents during examination or the invalidation of granted patents during litigation. For interpretation, scholars have implicitly relied on the assumption that patent-induced bargaining failure will be reflected in increases of follow-on invention by others when the upstream patent right is removed. We argue, however, that the absence of an exclusion right can only give rise to an increase in follow-on invention by others if *two* conditions are met: first, bargaining failure must have previously limited efficient licensing, e.g., due to high transaction costs; and second, the removal of the patent must create *freedom to operate*, i.e., the ability to efficiently commercialize a new invention in the technology or product market.[3] Hence, the absence of follow-on invention after the removal of a patent does not necessarily imply the absence of ex-ante bargaining failure. Quite to the contrary, freedom to operate may still be restricted after a particular patent right has been removed.

Concerning bargaining failure (BF), prior literature suggests that transaction costs will be particularly high where negotiations involve numerous patents and rights holders (Bessen and Maskin, 2009; Heller and Eisenberg, 1998; Lemley and Shapiro, 2007; Shapiro, 2001). BF is thus expected to be most prevalent where products comprise a multitude of patentable elements, i.e., in so-called complex technology areas (Cohen et al., 2000), and where strategic firm behavior promotes patent thickets and fences (Granstrand, 1999; Hall and Ziedonis, 2001; Harhoff et al., 2007; Ziedonis, 2004). Whether bargaining failure exists in discrete technology areas, where products are com-

[1] See Hall and Harhoff (2012) for a literature survey.
[2] We treat "cumulative innovation" and "follow-on invention" as synonyms in spite of subtle differences in meaning.
[3] See WIPO (2005) and Pardey et al. (2003) for similar definitions.

prised of one or few patentable elements, is largely an open question – one which we will address in this paper. The prevalence of BF may also differ depending on the size of the original and follow-on innovators. While holders of large patent portfolios may be able to reach cross-licensing deals for follow-on invention, small firms or entrants may lack the leverage to negotiate efficient licenses (Cockburn et al., 2010; Lanjouw and Schankerman, 2004). Generally, the relative burden of transaction costs is disproportionately large for small firms.

Concerning freedom to operate (FTO), a very different scenario prevails. When bundles of patents jointly protect (and block) a technology, the potential gain in FTO from removing one individual patent can be very limited. In contrast, for discrete and non-overlapping technologies, substantial gains in FTO may be attained when the individual patent right is revoked. The ability to obtain FTO also depends on the characteristics of the original and the follow-on innovator, e.g., concerning complementary assets to restrict market entry or to retain market power even in the absence of an exclusion right.[4] Unless the complementary assets to successfully commercialize the technology are available, the removal of the focal patent right will hardly attract investments into follow-on inventions.

This has immediate implications for the interpretation of the effect of patent removal. The marginal effect of patent invalidation (or patent rejection) is a direct function of FTO. But the cumulative innovation literature is interested in measuring the effect of having patent protection (not individual patent rights) removed. That would require removing all patent rights that limit post-removal FTO for a particular technology. This effect is not measurable, since we have no empirical setting with this kind of experiment.

We thus postulate that the marginal blocking effect of an individual patent will equal the cumulative innovation effect (and thus reflect the underlying bargaining failure) only when FTO is solely limited by the patent in question, e.g., for discrete technology areas and for small patent holders. In contrast, whenever FTO remains restricted after the removal of one patent right, as in patent thickets or fences, the marginal blocking effect can only be interpreted as a lower bound to the full blocking effect of patent protection on cumulative innovation.

To address the above challenges and to estimate the causal effect of existing patent rights on follow-on invention, we construct a new dataset of more than 33,000 post-grant oppositions at the European Patent Office (EPO) across all technology areas. The EPO provides a harmonized application procedure for patent protection and grants European patents for as many as 38 countries, with a population of more than 450 million and a total GDP of more than 20 trillion USD. In the first nine months after grant, third parties can challenge the validity of a European patent by filing an opposition against the EPO's granting decision.[5] The opposition procedure represents a low-cost opportunity to centrally invalidate a European patent before it is split into a bundle of national patent rights. Opposition is therefore a frequent event with a historical opposition rate of about 6%, which well exceeds litigation rates in Europe (Cremers et al., 2017) and the US (Bessen and Meurer,

[4] Such complementary assets could lie in competitive manufacturing, distribution channels, know-how, and marketing (Teece, 1986). Such characteristics are likely correlated with firm size.

[5] 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 during the first 9 months after grant without involvement of the judiciary.

2013; Lanjouw and Schankerman, 2004). Opposition is also less prone to settlements due to the short time horizon available for negotiations and due to the EPO's ability to pursue an invalidation even after the opponent's withdrawal. Fewer than 10% of all oppositions end without adjudication, while more than 90% of litigation cases in the US end in settlements (Harhoff and Graham, 2014).

To overcome 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 is primarily 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 follow-on invention, as measured by post-opposition forward citations. The effect is significant for citations by other parties, whereas the effect is insignificant for self citations. We find that the effect is most pronounced where patent invalidation should lead to a substantial gain in freedom to operate for others. This is true, in particular, for discrete technology areas such as chemistry, for technology fields without patent thickets, and for patents which are not protected by similar patents of the same rights holder (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 firms if the focal patent holder is large. This corresponds to the argument that large firms are more likely in possession of complementary assets that can compensate for the loss of the exclusion right. To summarize, we find a significant effect in those subsamples where the estimated marginal blocking effect should approximate the overall effect of patent rights on cumulative innovation. In our robustness tests, we can show that the impact of relative size, thickets, and fencing is visible even within technology subsamples. Our results therefore suggest that patents induce bargaining failure over cumulative innovation even where prior literature has argued that transaction costs are low.

Recent empirical work has studied the existence of patent-induced impediments to cumulative innovation in settings that differ with respect to the source and the scope of variation in patent rights.[6] Murray and Stern (2007) use difference-in-differences estimation models on a sample of 169 biotech patent-paper pairs. Likewise, Huang and Murray (2009) use 1,279 gene patent-paper pairs. Both studies exploit the grant of patent protection as variation over time. They conclude that patent protection impedes subsequent research based on the underlying discovery.[7] Sampat and Williams (2019) further investigate the relationship of patent rights on follow-on invention in human genes by comparing citations to 1,545 successful and unsuccessful patent applications filed at the USPTO. Their instrumental variable regressions do not show a blocking effect of human gene patents

[6] Table B-1 in the Appendix provides an overview of recent studies.

[7] Corroborating these findings, 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.

on follow-on invention. Galasso and Schankerman (2015) investigate the effect of 1,357 patent invalidations by the US Court of Appeals for the Federal Circuit (CAFC) on follow-on invention. They address the endogeneity of the patent invalidation event by exploiting the randomized allocation of judges at the CAFC to identify judge fixed effects.[8] In their study, patent invalidation by the CAFC results in an increase of follow-on invention in technology areas that are largely considered complex, such as computers, electronics, and medical instruments. Moreover, they find that the strongest effect emerges when patents of large firms are invalidated. To explain their results, they point to the high transaction costs in complex technologies that make bargaining failure more likely. Arguably, their findings are specific to their highly selective sample of litigation cases at the appellate court for patent disputes, which makes an extrapolation to the patent population non-trivial. First, given that patent disputes at the appellate court involve millions of dollars in litigation costs, the *individual* patent rights in their sample must be very valuable. Hence, these patents are unlikely to be embedded into thickets, fences, or other complementary assets. Selection to the CAFC thus singles out those patents from an overall complex technology whose invalidation does result in FTO. Second, the discrete technology patents litigated at the CAFC overwhelmingly stem from the pharmaceutical sector. For these, invalidation is often pursued by generic companies to gain market approval for an existing drug, rather than to clear the way for follow-on inventions.[9] The combination of these effects may lead to the impression that bargaining failure is present only in complex technologies. We think that this conclusion may be misleading.

Our study makes several contributions to the literature on cumulative innovation with regard to identification and interpretation, empirical scope and measurement, and the geographic and institutional context. First, we present causal estimates of the effect of patents on cumulative innovation. For a consistent interpretation of our empirical findings, we conceptualize a new framework which incorporates the interplay of bargaining failure and freedom to operate. We point to cases where we expect the difference between the marginal and the overall blocking effect of patents to be particularly large. To operationalize our framework, we study the heterogeneity of the invalidation effect with respect to technology characteristics, firm size, and the patent landscape. Our findings challenge the established view that inefficient licensing is limited to the domain of complex technology areas. Instead, we find strong evidence that bargaining failure is also prevalent in discrete technologies. This result resonates strongly with the markets for technology literature, which has found pervasive impediments to efficient licensing across technologies (Agrawal et al., 2015; Arora and Gambardella, 2010; Gans and Stern, 2010).

Second, compared to previous work, our study stands out in the scope and scale of the underlying data. With more than 33,000 oppositions filed between 1993 and 2011, our sample of patents exceeds prior studies by more than an order of magnitude, despite the relatively short and recent time frame. Furthermore, the fine-grained EP citation data used in this study alleviate a key point of criticism concerning the use of forward citations as a proxy for cumulative innovation: strategic

[8]In a complementary study, Galasso and Schankerman (2018) use the same empirical setting to analyze the effect of patent invalidation on subsequent research activities of the focal patent holder.

[9]These validity challenges occur in the context of so-called Paragraph IV litigation (Higgins and Graham, 2009). Between 2002 and 2008 alone, the CAFC ruled on more than 220 unique drug patents (own calculations based on data from ParagraphFour.com).

and irrelevant citations (cf. Alcacer et al., 2009; Sampat, 2010). In contrast to the US patent system, citations in Europe are produced (or at least verified) by highly trained EPO personnel during the search and examination phase (Criscuolo and Verspagen, 2008). As a result, the average number of EPO patent citations is lower, but their technological relevance is higher (Breschi and Lissoni, 2004).

Lastly, concerning the geographic and institutional context, we are the first to provide a source of exogenous variation in patent rights at the European Patent Office. Given the economic significance of European patents, the EPO's decisions on patentability should be at least as important to the involved parties as the corresponding decisions by the USPTO. Nonetheless, the European context has so far been understudied. Concerning post-grant review, the literature has primarily focused 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 2 describes the institutional framework of patent opposition at the EPO. Section 3 provides details on the dataset, the dependent and independent variables, and shows descriptive statistics. Section 5 then presents the econometric analysis and a discussion of the results. Section 6 concludes.

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. As 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.[10]

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

[10] See Figure A-1 in the Appendix for a timeline of events for the average patent in our sample.

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 examining 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 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.

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 himself.[11] 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 par-

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

ties, 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.[12]

2.3 Appointment of examining 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 technology.[13] The examining division regularly consists of the previous search examiner as first member and two examiners appointed by the director as second member and chairman.[14]

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."

[12]According to our data (see Table B-2 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.

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

[14]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.

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.[15]

3 Data

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.

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.[16] 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.[17] We read out documents on the grant decision, the oral proceedings and the opposition decisions in order to extract the names of the examining division and opposition division members, since this information is not available from patent data providers.[18] We elaborate on our read-out and parsing efforts in Appendix F. 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.[19] Furthermore, the EPO PATSTAT Register

[15]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.

[16]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.

[17]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 on the day after the date of dispatch. Incoming communications become available once the filed document has been coded by the EPO.

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

[19]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.

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).

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 filing date within the DOCDB family of the citing patent. This is also 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).[20]

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, as US examiners add missing references, but do not mark applicant-generated references as relevant or not. The European-type search report provides that information.

[20] 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, 2019). 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. Our setting alleviates this issue. Prior studies have shown that EPO patent citations are of higher technological relevance than those produced by the USPTO (Breschi and Lissoni, 2004).

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 to be overruled in favor of the opponent than vice versa.[21] 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.[22]

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.[23] 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.[24] 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

[21] 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.

[22] 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.

[23] 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.

[24] 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.

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 in line with 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 clustered into 34 technology areas, each belonging to one of five main technological areas: (a) electrical engineering, (b) instruments, (c) chemistry, (d) mechanical engineering, and (e) other fields.

Measures for FTO: patent thickets and patent fences

We are interested in how the effect of patent invalidation is dependent on further restrictions to freedom to operate, in particular by other patent rights in the focal patent's periphery. To this end, we distinguish between *patent thickets* and *patent fences* and study corresponding subsamples. We measure the (time variant) density of patent thickets in the focal patent's technology area following the methodology of Von Graevenitz et al. (2011). They identify constellations in which three patent holders can mutually block each other. We expect that the more of these so-called *triples* exist in a technology area, the likelier it is that the gain in FTO from patent invalidation is highly limited. Besides thickets with mutual blocking potential between different holders, the focal patent may also be embedded into a patent fence of several similar patents held by the same owner. To measure similarity, we use a sophisticated semantic comparison of the patents' full texts (abstract, description, claims, and title; cf. Harhoff 2014). We then count the number of patents that are highly similar to the focal patent within the same holder's portfolio. If the invalidated patent is part of a such defined fence, we expect that the focal patent holder is more likely to maintain the ability to restrict FTO and to block follow-on invention.

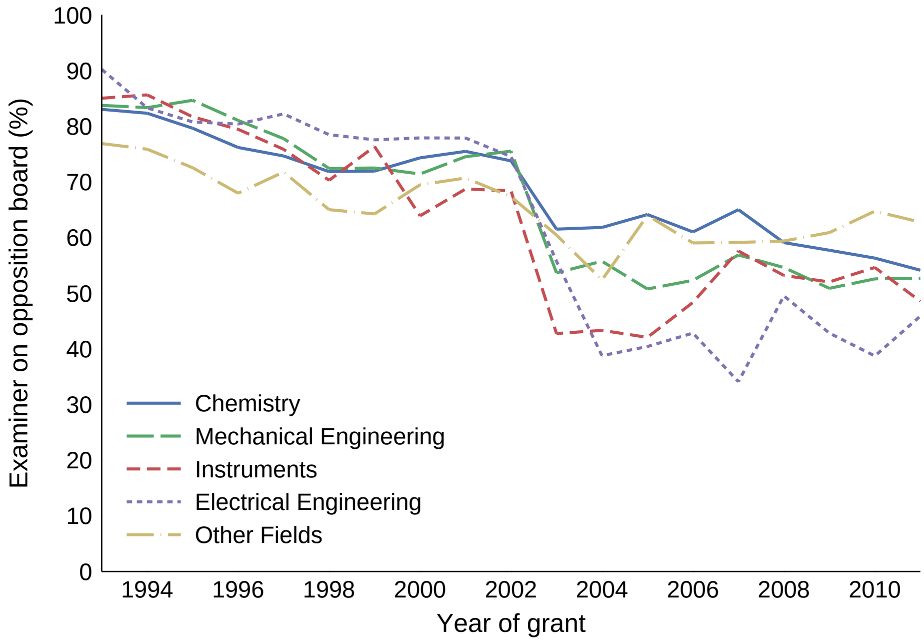
3.4 Instrumental variable

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 persons on the opposition board.[25] 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 continuous 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 found in the non-availability of other examiners with expertise in the particular technology area.

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

Figure 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.

If the number of substantive examiners relative to the technical unit's current workload 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 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.[26] Additionally, Table C-1 in the Appendix shows the relationship between the examiner participation rate and capacity constraints at the respective technical unit in panel regressions. Even when controlling for the full set of technical unit and time fixed effects, concurrent capacity constraints – measured by the share of patent applications whose search report was not completed before the first publication 18 months after priority filing (see Haeussler et al. (2014) for details) – are negatively associated with the examiner participation rate.[27] We hence conclude that the event "examiner participation in opposition proceeding" is plausibly exogenous to the focal patent and shows the necessary continuous variation within cohorts and technology areas to serve as an instrument.

[26]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.

[27]Notably, capacity constraints at the technical unit before (and after) the appointment of the opposition division have a considerably weaker effect on the examiner participation rate, which supports the notion that *temporal* staff shortages drive the decision to appoint the granting examiner to the opposition division (see Figure A-2a in the Appendix).

To further argue against potential endogeneity, we discuss the instrument's randomness and its adherence to the exclusion restriction. In Table C-2, 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.

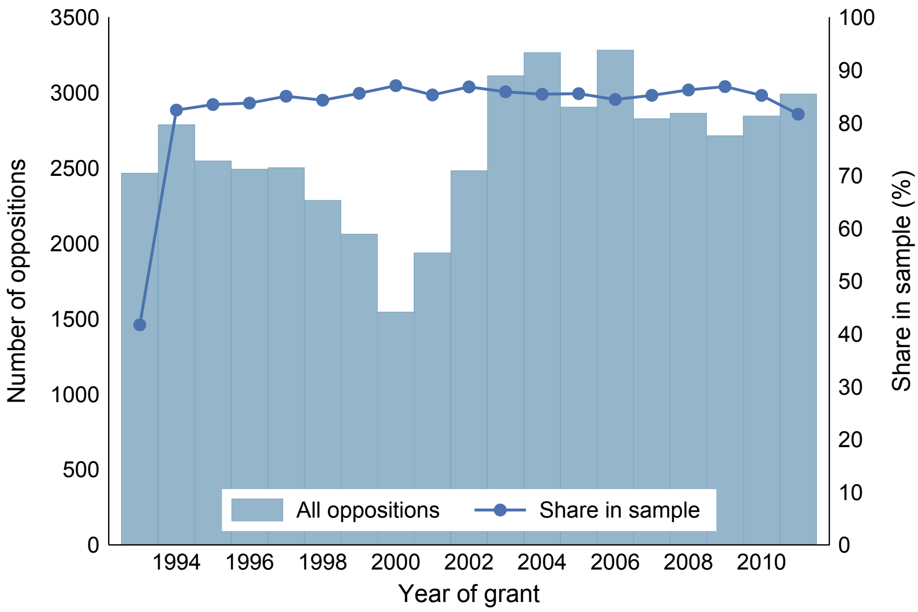
A random instrument could still violate the exclusion restriction if the outcome is affected through different ways than just the first stage. This would be the case if the applicant foresaw whether the examiner is part of the opposition proceeding before the decision on the patent's validity, providing him with enough time to adjust his 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.[28] 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 and at one. As can be seen from Figure A-2b, this concern is unfounded.

4 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

[28] 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 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.

involved in the grant and opposition decisions. For several reasons outlined in Table B-2, 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 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 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). Figure 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. 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 indepen-

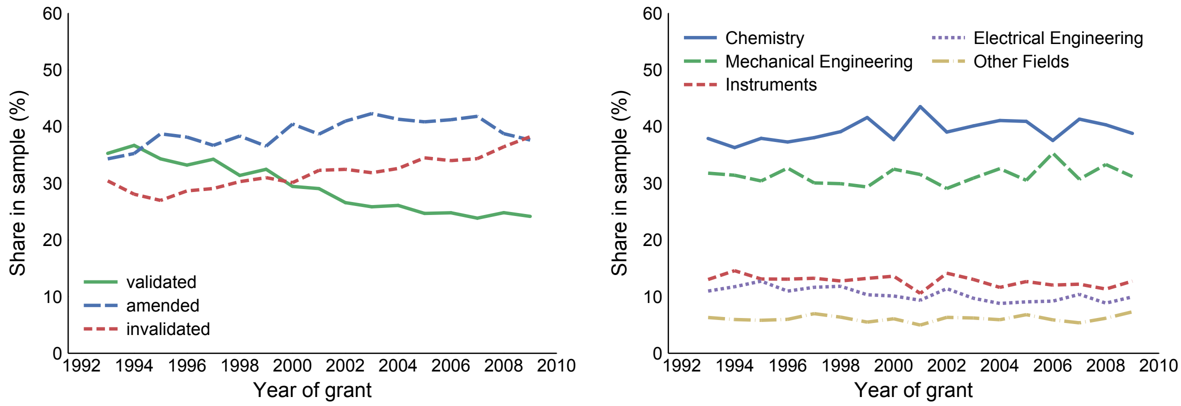
Table 1: Patent and procedural characteristics

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.

Figure 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.

dent 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 Figure A-3a).

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 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 Figure B-3).

Oppositions are mostly filed by corporations and directed at corporate patent holders. Table 3 shows that 94% of patent holders and 98% of opponents are companies with practically no involvement of parties from the academic or non-profit sector.[29] 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

[29]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 2: 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 citing patent holders or 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).

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.[30] As we are more interested in the size of all firms with follow-on invention 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 3, 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 himself than from an examiner.[31]

[30]For instance, oppositions are sometimes filed by law firms on behalf of an undisclosed third party.

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

Table 3: 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 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).

5 Empirical Analysis

5.1 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

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

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 invention, we would expect $\beta_1 \leq 0$. Vice versa, a finding of $\beta_1 > 0$ would suggest that patents block follow-on invention.

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 himself ("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 opposition outcome 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 (Sampat and Williams, 2019; Galasso and Schankerman, 2015). 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 $\boldsymbol{x}$,

$$\text{Prob}\,(\textit{Invalidated}_p) = \Phi\,(\gamma_1 \textit{Examiner participation}_p + \boldsymbol{\gamma x}_p) \\ \rightarrow \textit{Predicted probability of invalidation}_p \,. \tag{5.1}$$

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, [32]

$$\begin{aligned} \mathit{Invalidated}_p &= \alpha_1 \; \mathit{Predicted\ probability}_p + \boldsymbol{\alpha x}_p \; + u_p \\ \log\left(\mathit{Forward\ citations}_p\right) &= \beta_1 \; \widehat{\mathit{Invalidated}}_p \; + \boldsymbol{\beta x}_p \; + \; \epsilon_p \,. \end{aligned} \tag{5.2}$$

In Table 4, 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 C-2 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 C-3 and C-4 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.

[32] 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 4: 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^{***}	$\text{Yes}^{\dagger}$
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

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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

5.2 Results and discussion

In Table 5 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 himself. We find a weakly significant, positive effect of invalidation on the focal patent holder's follow-on inventive activity. Column (4) presents the results of the baseline specification on the total number of citations. In order to examine potential differences in the invalidation effect with respect to patent age and value, Table 6 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, whose invalidation triggers a statistically significant increase in forward citations by others.

The following four tables disentangle the average invalidation effect on other citations by environments that should differ in their prevalence of bargaining failure and in the gain in freedom to operate after patent removal. We first split our sample by technology area and by the complexity of the focal patent's technology field. Afterwards, we distinguish between the sizes of both the focal and the citing patent holder. Finally, we group patents by the presence of patent thickets in their field and by whether the patent is part of a patent fence, i.e., a portfolio of very similar patents.

First, Table 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.

Table 5: 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

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 himself 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table 6: 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

Notes: This table explores 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table 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

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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Second, given that the fairly large standard errors for "Electrical Engineering" and "Instruments" hint at potential heterogeneity in the invalidation effect, we now split the sample by the nature of the underlying technology and by the size of the focal patent holder. In Table 8 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 positive invalidation effect. These results go hand in hand with the common perception of differences between complex and discrete technologies. While the protection of an invention in discrete technologies is concentrated in a single patent, resulting in considerable gain in FTO for others in the case of an invalidation, inventions in complex technologies are typically spread across two or more patents, diminishing the implications of an invalidation for FTO. We further explore this channel in Table 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 in line with the argument that large firms are more likely to hold complementary assets that allow to keep up market entry barriers. In contrast, small (and medium-sized) firms are less able to compensate for the loss of the exclusion right. In turn, invalidation may create FTO for potential market entrants.

Third, motivated by our findings on patent holder size, in Table 9 we further explore the heterogeneity of the invalidation effect with respect to the differences in size between the owner of the citing patent (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 follow-on invention by large and small patent holders, respectively. While the coefficient for large follow-on patent holders is marginally significant and positive, the coefficient for small (and medium-sized) patent holders 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 small owner, we find highly significant coefficients. More specifically, the effect on small other parties appears stronger than the one for large other parties. These results imply an ordering with regard to the marginal blocking effect in the context of further entry barriers that may limit FTO. The observed effect on follow-on innovation is most pronounced for small focal patent holders and small follow-on innovators (4), significant for small 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 small subsequent applicants (2). This is consistent with intuition: While small firms may struggle to efficiently negotiate a path for follow-on invention 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 complementary assets (2). Although this logic may apply to large focal patent holders facing small follow-on innovators, it seems to be less applicable for those faced with a large competitor, where the invalidation shows a marginally significant positive effect (1). Finally, although small patent holders 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 are more capable of building on an

Table 8: Impact of invalidation on EP/WO citations – technology and patent holder size

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExaPost5...)	Other	Other	Other	Other
Subsample	Complex	Discrete	Large	Small
Invalidated (d)	0.097	0.369***	0.086	0.378***
	(0.134)	(0.092)	(0.140)	(0.088)
log(No of claims)	0.067***	0.039***	0.045***	0.054***
	(0.008)	(0.008)	(0.010)	(0.007)
log(CitEPExaPre3Other)	0.153***	0.105***	0.111***	0.135***
	(0.009)	(0.008)	(0.010)	(0.008)
log(CitEPExaPre3Self)	0.031*	0.017†	0.019†	0.032**
	(0.014)	(0.010)	(0.012)	(0.012)
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	78.0	135.5	63.9	171.0
Weak identification test	191.1	313.3	147.1	350.9
Observations	14,946	18,129	11,038	22,037

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 small (non-large) patent holders. 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

invalidated patent when the original applicant is small (1 vs 3).

Fourth, to further inquire into the findings for complex technologies (Table 8), we discuss the invalidation effect in the presence of patent thickets and patent fences in Table 10. In columns (1) and (2) the sample is split into technology fields with high and low prevalence of patent thickets, respectively. Consistent with intuition, we do not find a significant effect of invalidation in fields with thickets, i.e., with a high number of mutually blocking relationships of at least three patent holders. In contrast, we find a positive and significant effect for those technology fields without extensive thickets. 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 in the focal patent holder's portfolio. In contrast, there is a strong and highly significant effect if patent fences are absent.

Table 9: Impact of invalidation on EP/WO citations – by sizes of focal and citing patent holders

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExa...Post5Other)	Large	Small	Large	Small
Patent holder subsample	Large	Large	Small	Small
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

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 small (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 small 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table 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

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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

5.3 Robustness tests

Robustness across main technology area subsamples

To verify that the results reported in Tables 9 and 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 D-1 to D-4, finding qualitatively very similar coefficients.

Exclusion of particular cases

Table D-5 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.

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 invention. The results are very similar to the ones in our main section (see Table D-6).

Bootstrapped standard errors

In analogy to Table 5, Table D-7 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 D-8 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 5.

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 D-9 and D-10).

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 D-11). Due to resulting data restrictions we have to limit the sample to patents with an application filing year $\geq$ 2001. Despite a substantial reduction in the number of observations and in the citation count, the results closely resemble those of Table 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.

US citations

Tables US-4 to US-10 demonstrate that all findings are qualitatively similar when using US citations. This alternative measure of follow-on invention results in a dependent variable with much higher variation and more non-zero observations (see Figure A-3b 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

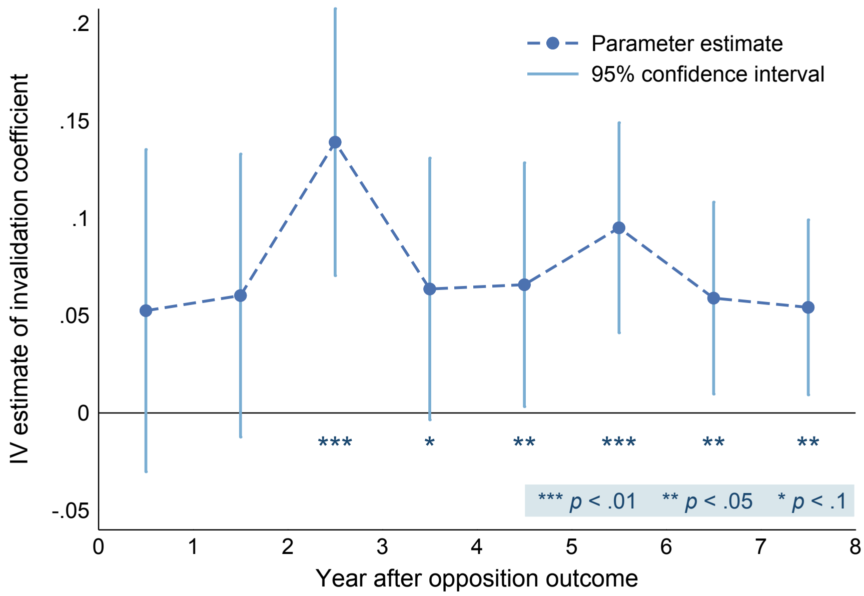
Figure 4 provides some insights into the timing of the invalidation effect. For each year after the opposition outcome, we run IV regressions with a dummy dependent citation variable indicating whether or not a patent has been cited in the respective time span.

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 follow-on invention 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-4a and A-4b 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 C-5 and C-6 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.

Figure 4: Timing of the invalidation effect



Notes: 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 parameter estimate.

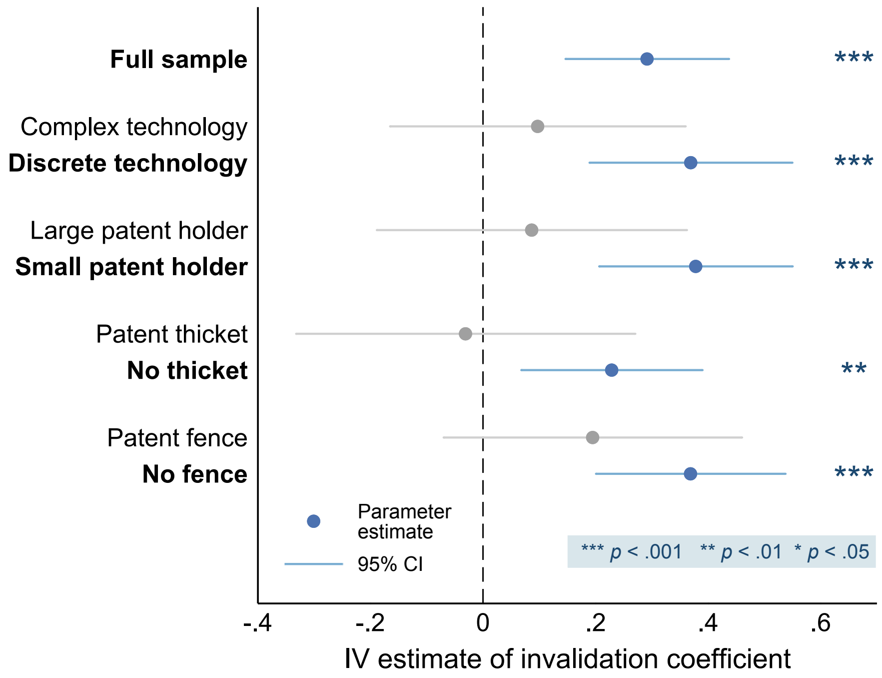
5.4 Discussion

Figure 5 summarizes our empirical findings. Our baseline model shows that patent invalidation on average leads to a highly significant increase of about 30% in forward citations. Hence, our results show that patent removal opens the path for follow-on inventions. This suggests patent rights actually block cumulative innovation and that upstream and downstream inventors systematically fail to reach necessary licensing agreements.

Our results indicate that bargaining failure also exists in environments that are typically associated with low transaction costs, but for which one can expect a large gain in freedom to operate from invalidation, e.g., chemistry patents. Vice versa, we can relate the lack of a significant invalidation effect in environments typically associated with high transaction costs (which are especially prone to bargaining failure) to persistent restrictions in freedom to operate that result from the context of the focal patent, e.g., closely related patents in fences or thickets.

The factors that impede successful licensing negotiations and the factors that limit the gain in freedom to operate are unlikely to be perfectly independent of each other. For example, bargaining failure due to high transaction costs should be particularly likely where many patents jointly block a given technological trajectory and where size asymmetries disfavor market entrants. In such a case, FTO is likely to be severely limited even after invalidation. The divergence between the general blocking effect and the *marginal* blocking effect in the context of further barriers limiting FTO is thus context-specific. The marginal blocking effect will approximate the overall effect of establishing

Figure 5: Overview of baseline and main subsample results



Notes: Blue (gray) points depict the coefficients of invalidation resulting from IV regressions on subsamples as indicated. All coefficients originate from regressions presented in Table 5 (full sample), Table 8 (discrete vs complex technologies; small vs large patent holders) and Table 10 (patent thickets and patent fences). Error bars show the corresponding lower and upper 95% confidence limits. The significance levels are indicated by stars next to each parameter estimate.

complete FTO only if the opposed patent is the sole determinant of FTO. In this case, the observed effect should reflect the underlying bargaining failure. In contrast, where FTO remains restricted in the absence of the patent right, the marginal blocking effect will merely constitute a lower bound of the actual blocking effect.

In our study, the observed marginal effect of removing a given patent approximates the overall effect of removing patent protection only in very specific subsamples (e.g., for small patent holders without complementary assets, or in the absence of thickets and fences). For these cases, our findings are in line with other studies that exploit large-scale variation in IP rights based on historic as well as more recent case studies. Moser and Voena (2012) and Watzinger et al. (2017) each focus on events where a set of patent rights became *de facto* ineffective in excluding others due to compulsory licensing. Moser and Voena (2012) find an increase in US innovation after 130,000 German-owned chemistry patents jointly became subject to compulsory licensing. Watzinger et al. (2017) study Bell Labs patents and find that compulsory free licensing increased follow-on inventions. However, as the authors state, these inventions occurred outside of the telecommunications industry, where Bell did not control crucial complementary assets. Furthermore, the results of Williams (2013) suggest that the release of a large set of previously IP protected genes led to an increase in subsequent scientific research and product development. In their sample a single firm held a large set of exclusion rights, which were practically all removed within a very short period of time. In fact, one reason why Sampat and Williams (2019) are not able to replicate the effect on gene follow-on invention previously found by Williams (2013) may lie in their study's focus on variation in gene protection at the individual patent level.

Galasso and Schankerman (2015) obtain somewhat different results despite a similar identification strategy. In their regression results, the invalidation of patents in discrete technologies by the CAFC does not result in an increase of forward citations, while they do find such an effect for patents in complex technologies. Moreover, they find that the strongest effect emerges when patents of large firms are invalidated. We argue that the findings for their sample of litigation cases at the appellate court for patent disputes cannot be extrapolated to the patent population in a simple fashion. First, US litigation cases are typically the consequence of an infringement allegation, which in turn suggests that the underlying technology has reached (or is close to) market maturity. Second, ending up at the appellate court, these cases are both particularly valuable and particularly uncertain, to the extent that the parties could not reach some form of settlement beforehand. These selection mechanisms substantially determine the sample composition with respect to a variety of both observable and unobservable characteristics beyond the commercial value of the patent. After all, our reasoning does not contradict their finding that patents negatively affect cumulative innovation in environments with considerable transaction costs. However, our findings indicate that the blocking effect of patents extends beyond the regimes that can be identified in highly selective litigation settings such as theirs. The patents selected for litigation at the highest court are simply no longer representative for the population in their respective technology area.

6 Conclusion

In this study, we investigate the causal effect of patent invalidation on follow-on inventions. The opposition procedure at the European Patent Office constitutes an ideal empirical setting. Opposition allows a central, low-cost invalidation of patents, before they are converted into a bundle of national patent rights in up to 38 signatory states. Opposition is hence a relatively frequent event with about 6% of all granted patents being attacked, which allows us to compile a sample of more than 33,000 opposed patents across all technology areas. Besides, the settlement rate is negligible, since private settlement does not terminate the opposition proceeding.

Our study contributes to the literature in several ways: it introduces a new instrument for identifying the causal effects of patent invalidation, it outlines a coherent framework for the interpretation of the empirical findings, it provides the first causal insights for the European institutional context, and it enlarges the previously accessible empirical scope by more than an order of magnitude.

Our baseline model shows that patent invalidation leads – on average – to a highly significant increase of about 30% in forward citations by other parties. Scholars have argued that patent-induced bargaining failure exists *to the extent that follow-on invention increases* when patent rights are removed. However, this empirical conclusion is contingent on an important premise: namely, that freedom to operate is restored if the patent in question is removed. We address this issue by distinguishing regimes where the blocking of follow-on invention is more or less dependent on the focal patent right.

Our empirical analysis produces two major results: First, follow-on innovation increases after invalidation in discrete technology areas. This result may sound surprising to some readers. The literature has conveyed the notion that in discrete technologies – where single patented inventions allow innovators to protect one product – automatically amounts to low bargaining costs. While it is probably true that for discrete technologies the subject matter of licensing agreements between original and follow-on inventors is more clear-cut, this does not mean that bargaining failure cannot occur. In fact, the reasons for bargaining failure in technology trade are manifold (see Arora and Gambardella (2010) for an overview). For instance, licensing contracts are not necessarily renegotiation-proof, which increases the uncertainty for both sides. The licensee may fear hold-up if the licensor contests the licensing contract in court. Vice versa, the licensee may behave opportunistically, lowering the licensor's expected value from licensing. Furthermore, commercial uncertainty makes ex ante licensing agreements incomplete. The most profitable application of an invention (be it the original or the follow-on invention) may only emerge long after the contracts have been signed. These difficulties are present across technology fields. Hence, we consider it unlikely that – even with discrete technologies – an efficient licensing contract can always be found ex ante.

Second, in circumstances where freedom to operate remains restricted after invalidation, follow-on invention does not increase significantly. This confirms our conjecture that both ex-ante bargaining failure and a gain in freedom to operate are necessary preconditions for patent invalidation to enhance cumulative innovation. We argue that our focus on FTO is important, and that its implications go considerably beyond the study of cumulative innovation. First, we note that this concept, which has received little academic attention, acknowledges a simple fact: patents are not only vertically related (as studied explicitly in the cumulative innovation literature), there are also horizontal relationships that limit the effect of removing a single patent right. These stem from managerial practice: "fencing an invention" by filing multiple patent applications is a commonly known, but rarely analyzed patenting behavior. Patent thickets – as an intentional or unintentional consequence of patent filing strategies – also limit the role of individual patents. For such contexts, the removal of an individual patent will hardly result in an increase of FTO. These real-world phenomena have to be taken into account when studying the impact of patents and their removal on invention and product market activities.

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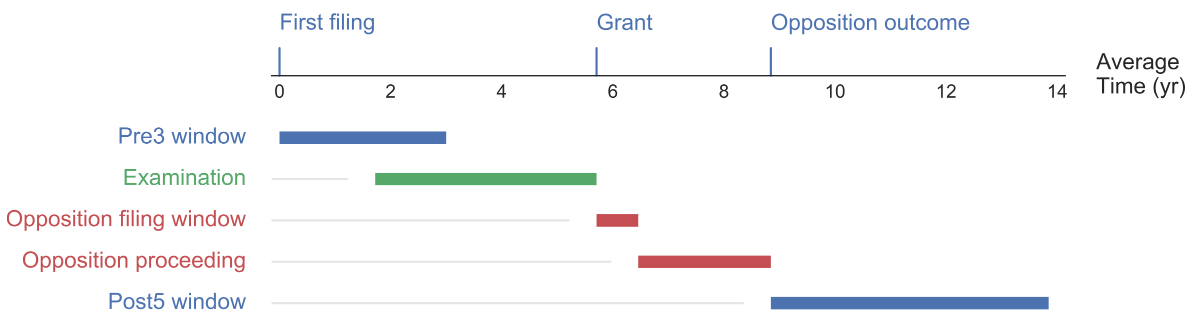
A Appendix: Figures

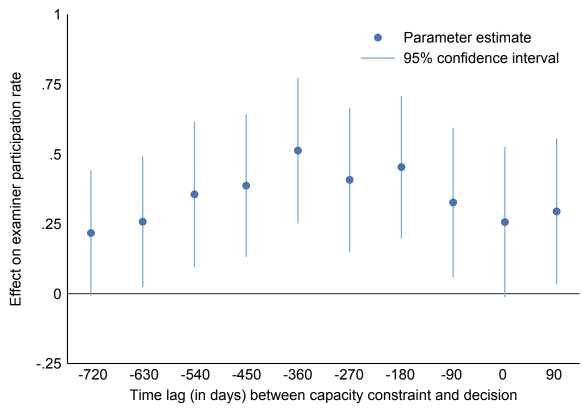
Figure A-1: Timeline for the average opposed patent in our sample



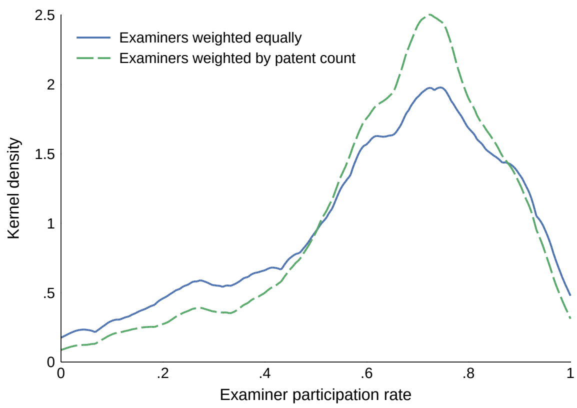
Notes: The Pre3 citation window covers the first three years after filing, the Post5 citation window covers the five years after the opposition outcome.

Figure A-2: Examiner participation

(a) Capacity constraints and examiner participation



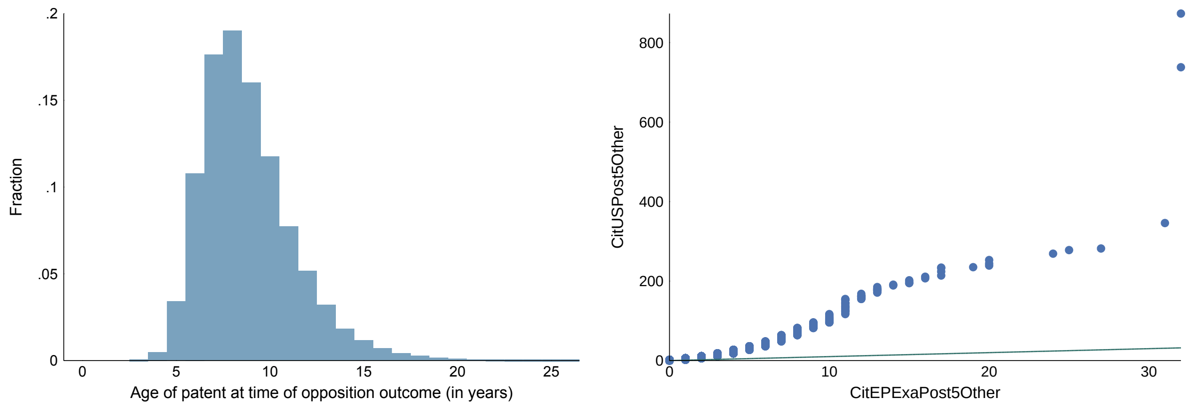
(b) Examiner-specific participation rates



Notes: The left graph depicts the effect of capacity constraints on examiner participation at technical unit level. Blue points depict the coefficients from OLS regressions of the respective technical unit's average examiner participation rate on concurrent capacity constraints for different quarters relative to the opposition outcome. Each regression includes non-parametric controls for technical unit and time, as in Table C-1, Column (3). Error bars show the corresponding lower and upper 95% confidence limits. The right graph shows the densities of participation rates at examiner level (simple and weighted). Examiners with fewer than 10 observations excluded.

Figure A-3: Distribution of patent age and forward citations

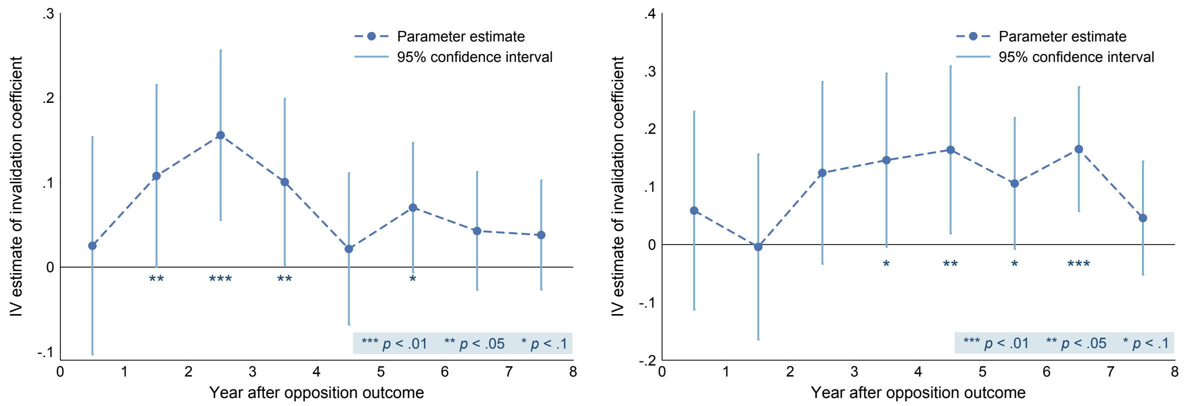
(a) Distribution of patent age (b) EP/WO examiner citations vs US citations



Notes: The left graph depicts the distribution of patent age at the time of opposition outcome. This graph includes all opposition proceedings which are part of our main sample of analysis. The right graph depicts the distribution of EP/WO examiner citations and US citations by other parties in the form of a quantile-quantile plot.

Figure A-4: Timing of the invalidation effect in technology subsamples

(a) Chemistry (b) Electr. Engineering / Instruments



Notes: These figures are in direct analogy to Figure 4 in the main text, but with the sample restricted to chemistry (Electr. Engineering and Instruments) 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.

B Appendix: Descriptives

Table B-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 patents
Huang and Murray (2009)	Scientific citations	DiD estimation	Biotech	1,279 patents
Sampat and Williams (2019)	Scientific/patent citations	IV (examiner fe)	Biotech	1,545 patents
Patent invalidation				
Galasso and Schankerman (2015)	Patent citations	IV (judge fe)	All	1,357 patents
Compulsory licensing				
Moser and Voena (2012)	Patents	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).

Table B-2: 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 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 B-3: 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 B-4: 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

C Appendix: Instrumental Variable and Complier Analysis

Table C-1: Regressions of instrumental dummy variable “Examiner participation in opposition proceeding” on technical unit capacity constraints

	(1)	(2)	(3)	(4)
Estimation method		OLS	OLS	OLS
Dependent variable	Exam. part. rate	Exam. part. rate	Exam. part. rate	Exam. part. rate
Capacity constraint	−0.098	0.526***	0.513***	0.462*
	(0.066)	(0.110)	(0.133)	(0.224)
– 4 quarter lag				−0.101
				(0.177)
– 3 quarter lag				−0.079
				(0.217)
– 2 quarter lag				0.159
				(0.229)
– 1 quarter lag				−0.023
				(0.217)
– 1 quarter lead				−0.057
				(0.247)
– 2 quarter lead				0.298
				(0.257)
– 3 quarter lead				−0.076
				(0.251)
– 4 quarter lead				−0.095
				(0.257)
– 5 quarter lead				0.043
				(0.205)
Tech unit effects	No	Yes***	Yes***	Yes***
Time effects	No	No	Yes***	Yes***
Model degrees of freedom	1	32	74	83
Adjusted R^2	0.001	0.186	0.289	0.287
Observations	1,245	1,245	1,245	1,245

Notes: This table explores the relationship between concurrent capacity constraints and examiner participation at the technical unit level. The level of observation is the technical unit (32 in total) over time (calendar year quarters). Capacity constraints are captured by the share of patent applications whose search report was not completed before the first publication 18 months after priority filing (see Haeussler et al. (2014) for details). We link the measure of capacity constraints to the quarter one year prior to the oral proceeding and opposition decision – the time when the technical unit's director typically allocates the opposition file to the opposition division (see p. 26 of the EPO's Quality Report 2016). Columns (1) to (3) show the effect of the concurrent capacity constraints on the examiner participation rate. Column (4) shows the effect of the capacity constraints variable with a set of lags/leads. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table C-2: 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†	−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†	0.003†
		(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

Notes: This table shows probit regressions of the "Examiner participation" dummy on the other exogenous variables not shown in Table 4. 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table C-3: 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

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. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table C-4: 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

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. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table C-5: LATE discussion – Complier shares

	Exam. part.	$\hat{p}(\text{Inv}) < q(.25)$	$\hat{p}(\text{Inv}) < q(.5)$	$\hat{p}(\text{Inv}) < q(.75)$
		Binary instrument		
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. (5.2) 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 C-6: LATE discussion – Complier characteristics

Binary characteristic x	$E[x]$	$E[x \mid \text{complier}]$	$E[x \mid \text{complier}]$ / $E[x]$		$p(\text{Ratio} = 1)$
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 $E[x] = P(x = 1)$ of patents with $x = 1$ in the entire population, the second column indicates the corresponding share $E[x \mid \text{complier}]$ 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 parentheses 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 C-5.

D Appendix: Robustness

Table D-1: Impact of invalidation on EP/WO citations – by 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	Small	Large	Small
Patent holder subsample	Large	Large	Small	Small
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

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 small (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 small 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table D-2: 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

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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table D-3: Impact of invalidation on EP/WO citations – by 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	Small	Large	Small
Patent holder subsample	Large	Large	Small	Small
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

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 small (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 small 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table D-4: 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

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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table D-5: 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

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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table D-6: 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

Notes: This table is analogous to Table 5, but counts only one forward citation per unique follow-on applicant in the respective time frames. The results thus indicate the effect of invalidation on the extensive margin of follow-on invention. 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † $p<0.1$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table D-7: 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

Notes: Analogous to Table 5 in the main text, but showing bootstrapped standard errors in parentheses (500 iterations). 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 B-4 in the Appendix. All bootstrapped standard errors are quantitatively very similar to the robust standard errors in Table 5, resulting in identical significance levels for the invalidation coefficient. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table D-8: 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

Notes: This table is analogous to Table 5, but has all citation variables replaced with the corresponding dummies indicating at least one citation. 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table D-9: 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

Notes: This table is analogous to Table 5, 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 himself 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table D-10: Impact of invalidation on EP/WO citations – technology and size – alternative treatment of "amended" patents

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitEPExaPost5...)	Other	Other	Other	Other
Subsample	Complex	Discrete	Large	Small
Invalidated (d)	0.070	0.247**	0.080	0.302***
	(0.166)	(0.077)	(0.127)	(0.087)
log(No of claims)	0.072***	0.053***	0.049***	0.070***
	(0.008)	(0.006)	(0.008)	(0.006)
log(CitEPExaPre3Other)	0.154***	0.108***	0.112***	0.140***
	(0.010)	(0.008)	(0.010)	(0.008)
log(CitEPExaPre3Self)	0.031*	0.016†	0.020†	0.031**
	(0.014)	(0.010)	(0.011)	(0.012)
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	21.4	85.4	28.2	76.9
Weak identification test	75.9	386.0	96.9	345.8
Observations	14,946	18,129	11,038	22,037

Notes: This table is analogous to Table 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 small (non-large) patent holders. 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table D-11: 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†	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†
	(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

Notes: While in close analogy to Table 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 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

E Appendix: US Citations

Note: The numbering of the tables is analogous to the one for EP/WO citations in the main text.

Table US-3: 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 US-4: 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†	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

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 B-4 in the Appendix.

Table US-5: 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

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 himself 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table US-6: Impact of invalidation on US citations – patent age and value

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitUSPost5...)	Other	Other	Other	Other
Subsample	Younger	Older	Smaller family	Larger family
Invalidated (d)	0.448*	0.265	0.137	0.256
	(0.182)	(0.172)	(0.149)	(0.170)
log(No of claims)	0.094***	0.078***	0.077***	0.100***
	(0.012)	(0.013)	(0.011)	(0.013)
log(CitUSPre3Other)	0.454***	0.420***	0.457***	0.397***
	(0.011)	(0.010)	(0.011)	(0.010)
log(CitUSPre3Self)	0.167***	0.153***	0.109***	0.183***
	(0.015)	(0.014)	(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	93.7	129.7	38.3	155.3
Weak identification test	182.5	257.7	206.7	249.4
Observations	16,981	16,094	17,188	15,880

Notes: This table explores the differences of the invalidation effect on US forward citations 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table US-7: 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†	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

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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table US-8: Impact of invalidation on US citations – technology and size

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitUSPost5...)	Other	Other	Other	Other
Subsample	Complex	Discrete	Large	Small
Invalidated (d)	0.308	0.389*	0.202	0.484***
	(0.192)	(0.152)	(0.215)	(0.139)
log(No of claims)	0.087***	0.091***	0.086***	0.081***
	(0.013)	(0.012)	(0.016)	(0.011)
log(CitUSPre3Other)	0.510***	0.359***	0.395***	0.448***
	(0.011)	(0.010)	(0.012)	(0.009)
log(CitUSPre3Self)	0.163***	0.157***	0.172***	0.161***
	(0.017)	(0.013)	(0.015)	(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	78.2	136.4	64.4	172.2
Weak identification test	191.2	314.7	149.2	351.3
Observations	14,946	18,129	11,038	22,037

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 small (non-large) patent holders. 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table US-9: Impact of invalidation on US citations – by sizes of focal and citing patent holders

	(1)	(2)	(3)	(4)
Estimation method	IV	IV	IV	IV
Dep var: log(CitUS...Post5Other)	Large	Small	Large	Small
Patent holder subsample	Large	Large	Small	Small
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

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 small (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 small 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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table US-10: 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

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 B-4 in the Appendix. Robust standard errors presented in parentheses. Significance levels: † p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

F Technical Appendix: Construction of the Examiner Participation Indicator Variable

As explained in section 5, we use the presence or absence of the primary examiner on the opposition board as an instrument to allow for causal inference concerning follow-on invention 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.[33] 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.

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