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Causal Evidence From European Patent Opposition

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ABSTRACT

We study the causal impact of invalidating marginally valid patents during post-grant opposition at the European Patent Office on affected inventors' subsequent patenting. We exploit exogenous variation in invalidation by leveraging the participation of a patent's original examiner in the opposition division as an instrument. We find a disciplinary effect of invalidation: Affected inventors file 20% fewer patent applications in the decade after the decision. This effect is entirely driven by a reduction in low-quality filings, i.e., filings that examiners associate with prior art that threatens the application's novelty or inventive step. We do not observe shifts into national patenting.

KEYWORDS: Inventors, marginal patents, patent invalidation, patent opposition, post-grant review, EPO, innovation

JEL Classification: O31, O34

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1 Introduction

Marginally valid patents are a prime concern for the patent system. By definition at the edge of patentability, these patents are privately valuable, but socially detrimental. For instance, they may deter competitors from innovating and cause tremendous litigation costs that run in the billions of dollars every year (e.g., Bessen and Meurer, 2012; Hall and Harhoff, 2012; Gaessler et al., 2017). Following the unprecedented growth in patenting over the past decades, this problem has become increasingly severe (Hall and Harhoff, 2004; de Rassenfosse and Jaffe, 2018).

To alleviate the negative consequences of marginally valid patents (marginal patents, from here), many patent systems rely on centralized opposition procedures, so called post-grant reviews. In contrast to litigation, which easily generates costs in the millions of dollars per case in the US (Bessen and Meurer, 2005; American Intellectual Property Law Association, 2017), post-grant review costs in Europe range between 7,500 and 45,000 euros (MacDougall and Hamer, 2009). The European Patent Office (EPO) has been using a post-grant review process for a long time already. In the United States, the America Invents Act of 2011 has established a post-grant review process following the calls of various scholars (e.g. Lemley et al., 2005; Farrell and Shapiro, 2008).

For policymakers, the level of stringency during post-grant review is key. The impact of increased stringency on patent quality is theoretically ambiguous. On the one hand, if the invalidation propensity in these processes increases, this may ensure the quality of disclosed ideas as inventors shy away from filing low-quality applications (Hall et al., 2004). On the other hand, a higher propensity of invalidation may deter inventors from filing patents for high-quality ideas as well (Galasso and Schankerman, 2018). Empirical evidence on the consequences of more stringent post-grant review still remains scarce.

In this paper, we analyze how the invalidation of marginal patents during post-grant review influences affected inventors' subsequent supply of ideas to the patent system. We show that following invalidation, affected inventors file fewer patent applications. Our results suggest a disciplinary effect of post-grant review: Invalidation only decreases future applications that search examiners associate with prior art that threatens their novelty or inventive step ("novelty-threatening", from here). This suggests that invalidation deters applications of questionable patentability. Therefore, post-grant review may ensure the quality of patent applications in the long run.

The post-grant review process at the EPO constitutes a unique setting for our analysis. In the first nine months after a patent grant, any third party can challenge the validity of an EPO patent by filing opposition against the decision. Opposition thus occurs early in the patent's lifetime, in contrast to court proceedings previously used for identification (e.g., Galasso and Schankerman, 2015, 2018). The post-grant review procedure is relatively inexpensive and is the only centralized possibility to invalidate EPO patents on a transnational level.[1] As a result, with a rate of around 6%, opposition is a frequent event: Our sample contains around 60,000 inventors first involved in around 30,000 oppositions filed between 1994 and 2010.[2] An "opposition division" comprising three qualified patent examiners decides on the outcome of the opposition proceeding. According to Art. 19(2) EPC, the examiner who granted the patent initially may be part of this committee.

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

We exploit the random allocation of the original examiner to the opposition division as an instrumental variable for the invalidation of opposed patents, as first suggested by Gaessler et al. (2017). We therefore estimate local average treatment effects: The invalidation coefficients reflect differences in subsequent patenting for inventors whose opposition outcome is shifted by the instrument. The corresponding patents are at the very margin of patentability because the participation of the original examiner in the opposition division alone determines their invalidation.[3] This makes the variation particularly policy relevant as the estimates reflect the impact of marginally shifting the threshold of invalidation during post-grant review on subsequent patent filings. The instrument provides a strong first stage: When the granting examiner is part of the opposition division, the likelihood of invalidation decreases by around 6 percentage points. Importantly, the allocation of examiners to opposition divisions is as good as random. Participation of the original examiner is primarily driven by the availability of *other* suitable examiners.[4] Besides, neither the patent holder nor the opponent can influence the composition of the opposition division.

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

[2]In comparison to prior work, this should make our sample less selective regarding patent quality and, in particular, patent value. For example, in comparison to the litigation setting studied by Galasso and Schankerman (2015, 2018), the EPO's post-grant review process is also less prone to unobserved settlements (i) because of the short time frame for filing an opposition and (ii) because the EPO can continue the proceeding on its own motion, independently of the party that initially filed opposition.

[3]Again, this does not imply that these patents are not valuable. In fact, if marginal patents were not valuable, they would not pose a problem for cumulative innovation or the patent system.

[4]This is corroborated by the substantial decrease in the rate of granting examiner participation after an EPO initiative promoted search-only examiners to substantive examiners (see Figure A-1). Only the latter are eligible as members of the opposition division.

Invalidation in opposition could impact subsequent patenting for several reasons. First, losing a patent has been shown to adversely affect firm success, especially for small ventures (Wagner and Cockburn, 2010; Farre-Mensa et al., 2017; Gaule, 2018; Galasso and Schankerman, 2018). Second, inventors or their firms and patent attorneys may adjust their filing strategy. For instance, patenting could be shifted to substitute authorities such as the national patent offices or the World Intellectual Property Organization (WIPO) to avoid centralized opposition at the EPO. More importantly, inventions could be kept secret instead of being disclosed in a patent application. However, secrecy is differently viable across technology areas (Hall et al., 2014) and may only be a worthwhile alternative to patenting for substantial technological advances, where competitors would learn much from disclosure (Anton and Yao, 2004). Third, invalidation may serve as a signal at the inventor or the invention level (cf. Azoulay et al., 2015, 2017). If invalidation is informative about inventor or idea quality, firms may allocate resources towards other inventors or technology areas.[5] Finally, post-grant review may induce learning about the likelihood of opposition or invalidation in opposition, about the screening efforts of competitors, or about the competitive landscape in the respective technology space in general.

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

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

[5] Invalidation may also impact inventor mobility. Melero et al. (2017) show that inventors respond to patent grants by becoming less mobile, especially between firms in the same technology area. Mobility decisions may in turn affect subsequent productivity (Hoisl, 2007, 2009). Similar effects may arise from changes to the inventors' stream of income (Harhoff and Hoisl, 2007; Toivanen and Vaeaenaenen, 2012) following invalidation.

an invalidation in their expert area show comparable effects to those with an invalidation outside their central field of expertise. Third, the effects are somewhat more pronounced in "complex" technology fields such as Electrical Engineering, where products are comprised of numerous patentable elements (Cohen et al., 2000), than in "discrete" fields such as Chemistry. The heterogeneity of effects across fields is however limited. Fourth, using median splits along several *applicant* characteristics such as the size of the patent portfolio, revenue, and profitability, we do not find significant differences in effect sizes. Fifth, using median splits along several *inventor* characteristics such as tenure, the number of prior applications, and the prior number of technology areas in which applications were filed, we do not find strong heterogeneities either. If anything, the effects seem to be less pronounced for inventors with fewer prior applications and applications in fewer technology areas.

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

This paper contributes to the nascent literature analyzing the impacts of post-grant review. Although these procedures have gained substantial interest, there is little empirical evidence about the consequences of establishing such institutions. Most of the literature has outlined potential costs and benefits theoretically (e.g., Hall and Harhoff, 2004). Empirically, Harhoff and Reitzig (2004) show that patents in the EPO's post-grant review system are associated with higher measures of patent value, such as forward citations.[6] Graham and Harhoff (2014) show that for patents that are litigated in the US, the European counterparts are often revoked or amended in the EPO's post-grant process. Overall, there is a lack of empirical evidence as to how post-grant reviews affect innovation.

This paper also contributes to an emerging literature investigating the impact of patent

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

invalidation on subsequent innovation and productivity, which has so far mostly focused on firm outcomes. Galasso and Schankerman (2018) use the random allocation of judges to committees deciding on the invalidation of patents to find that small firms decrease their inventive activity in response to an invalidation. Gaule (2018) and Farre-Mensa et al. (2017) use prior examiner leniency and find that venture-capital backed start-ups fare substantially better when being granted a patent.[7] Implications of patent grants for firms' follow-on innovation, firm behavior, and firm success have thus been studied to some extent. From an innovation viewpoint, it is however important to know whether *inventors* stop patenting altogether or whether they just continue inventing for other companies.[8] In light of this, it is surprising just how little is known about whether and how patents affect the performance of individual inventors. To the best of our knowledge, we are the first to show that patent invalidation affects the subsequent patent filings of *individual* inventors.

In summary, this paper contributes to a better understanding of the consequences of the patent system's institutions: Invalidation in post-grant review may help to ensure the quality of patent applications in the long run.

2 Setup, Data, and Empirical Strategy

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

2.1 Patent Opposition at the EPO

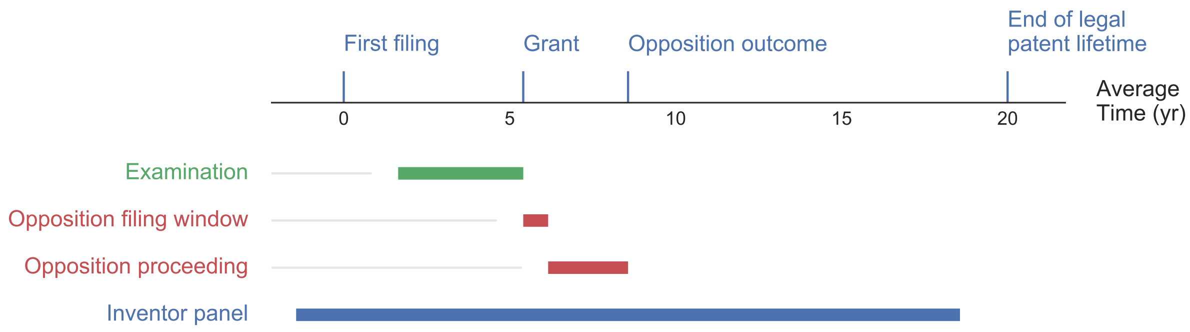
The EPO provides a harmonized application procedure for patent protection in one or more member states of the European Patent Convention (EPC).[9] Patent applications granted by the EPO disperse into a bundle of national patent rights, each entering the patent system of the respective member state. Thus,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

[7] There is an ongoing discussion about the identifying assumption behind using patent examiner leniency for identification (cf. Sampat and Williams, 2019; Righi and Simcoe, 2019).

[8] The relevance of inventor-level output is corroborated by the recent finding that firm heterogeneity only explains around 3-5% of the variance in inventors' patenting performance. In contrast, inventor fixed effects explain 23-29% of innovative performance, with inventor productivity being highly correlated over time (Bhaskarabhatla et al., 2017).

[9] This section is shortened from Gaessler et al. (2017).

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



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

opposition procedure, the outcome of which is binding for all designated states, represents the only option to invalidate a patent right covering multiple European jurisdictions in a single, relatively inexpensive step.[10] Because it is a centralized, low-cost procedure, it is a frequent event. In total, around 6% of all granted patents are opposed before the EPO. Constructing a sample based on oppositions thus compares favorably with similar, more selective litigation setups such as the one by Galasso and Schankerman (2015, 2018). Figure 1 displays the timeline for the average opposed patent in our sample.

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

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

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

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

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

The opposition division consists of a first examiner, a minute writer, and a chairman. The director of the patent's technical art unit appoints the members of the opposition division under consideration of the technical qualifications relevant to the patent.[15] As substantive examiners with the necessary technical qualification, the members of the examination division are natural candidates for the opposition division.[16] Concerning the participation of the grant examiners in the opposition proceeding, Article 19(2) of the European Patent Convention states that at least two of the members of the opposition division must not have taken part in the original examination and that the original examiner may not be the chairman of the opposition division. Gaessler et al. (2017) show that the primary examiner frequently participates in the opposition proceeding of the same patent. Case law has established that patent holder and opponent cannot object to the director's decision regarding the appointment of a particular examiner to the opposition division.[17]

2.2 Data and Summary Statistics

We build a panel data set of opposed inventors' patenting activity using the European Patent Office's 2018 spring release of PATSTAT. Our panel of individual inventors covers 10 years before and after their first opposition decision at the EPO. Because we observe the universe of patent applications, we assign a value of zero patents to years in which inventors do not appear in the data. We identify inventors in two separate ways: (a) by their *doc_std_name*,

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

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

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

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

[17]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 (see Gaessler et al. 2017).

correcting obvious errors using string similarity metrics, and (b) using the disambiguation provided by Morrison et al. (2017) for robustness. For our primary dataset, we obtain information on 65,415 inventors associated with 29,009 first oppositions filed between 1994 and 2010. Our data on oppositions is largely based on Gaessler et al. (2017). They 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 patent granted by the EPO, they first observe in the EPO PATSTAT Register database whether an opposition was filed within the statutory period of nine months after the grant date. They subsequently extract opposition outcomes and the names of the examination and the opposition division members. For full information on the data construction process of the instrumental variable, see Gaessler et al. (2017).

Our main dependent variable is the number of patent applications that inventors file.[18] We further construct a dummy variable indicating whether inventors patent in a given year and compute the log of the number of patent applications in our main analysis to account for outliers.[19] We also provide evidence on the impact of patent invalidation on the quality of subsequent patent applications. To this end, we use citation-weighted patent applications.

We additionally distinguish subsequent patents with and without novelty-threatening prior art, as indicated by so-called X-, Y-, and E-references in the EPO search reports. The reports classify prior art by their relevance for the patentability of the focal application. Simply put, applications with X-, Y-, or E-references can be thought of as patents of lower quality, in the sense that their patentability is questionable: According to the EPO's examination guidelines (EPO, 2017), X-references indicate prior documents that are "such that when taken alone, a claimed invention cannot be considered novel or cannot be considered to involve an inventive step". Analogously, category Y indicates threats to patentability due to a combination of prior documents. Finally, category E labels prior patent documents that may conflict with the application, but were not disclosed at the time of filing.[20] This detailed information about the content of patent applications is an important advantage of using EPO data over data from other jurisdictions that do not contain reference types: We have an additional and interesting measure for the quality of subsequent patent filings.

The decision of the opposition division may have three mutually exclusive results for the opposed patent: "opposition rejected" (patent valid as is), "valid in amended form", and

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

[19]In addition, we distinguish subsequent applications by their technology area (same vs. different area than the invalidated patent) and split the sample by whether the invalidation occurred in the inventor's field of expertise (defined as the area in which she has filed most patents prior to her first opposition outcome). Besides, we analyze whether there has been a shift to national patenting or to WIPO applications.

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

Table 1: Summary statistics

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

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

"invalid". Following the prior literature (Galasso and Schankerman, 2015, 2018; Gaessler et al., 2017), we classify the outcomes "invalid" and "valid in amended form" as an invalidation.[21] Following Gaessler et al. (2017), we construct our analysis around the first decision of the opposition division, not the final outcome of a potential appeal.[22]

Table 1 shows the summary statistics of our sample. The upper panel shows descriptive statistics on the inventor level. At the date of the opposition outcome, the mean inventor

[21] Results are robust to only coding "invalid" as an invalidation. Results are available on request.

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

in our data has been patenting at the EPO for more than ten years, filing a yearly average of 0.6 applications in 0.4 technology areas and working with 1.6 co-inventors per year. Inventors in opposition are therefore among the more productive. For over three quarters of inventors we observe the first opposition in the technology area they are most active in, which we refer to as the inventor's "expert area". The bottom panel contains descriptive statistics on the level of the opposed application. In over two thirds of oppositions, the original examiner is in the opposition division. Around 70 percent of opposed patents are invalidated during the proceeding. The average DOCDB patent family comprises around 10 applications, the mean application filing year is 1996. The year of the first outcome of the opposition is 2004 on average, reflecting an average time period of around 7-8 years between application and opposition outcomes.

We additionally retrieve data on financial characteristics and on the size of applicant firms from Bureau van Dijk's Orbis database by matching to the assignees of the opposed patents in our sample. We use leverage, profitability, and R&D intensity to explore effect heterogeneity along applicant financial characteristics in Tables E-1 and E-2. They are defined as total liabilities per total assets, EBITDA per total assets, and R&D expenses per total assets, respectively. As proxies for firm size, we extract the number of employees and revenues. Revenues are deflated by the US GDP deflator provided in the World Bank's World Development Indicators database.

2.3 Econometric Specification

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

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

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

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

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

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

where i denotes the inventor index, t the index for the year relative to the opposition outcome, and a_t the corresponding year effects. t_{af} is the year of application filing relative to opposition outcome and $b_{t-t_{\text{af}}}$ are the corresponding year effects.[23] Table 2 demonstrates that the original examiner's participation in the opposition division significantly decreases the opposed patent's likelihood of invalidation by around 4-7 percentage points. This corresponds to decrease of about 10% relative to the average rate of invalidation. Heteroskedasticity-robust first stage F-statistics are substantially above the common thresholds for weak instruments (Kleibergen and Paap (2006) Wald $F = 77.5$). Thus, the instrument meets the relevance condition.

The exogeneity condition is by definition untestable. However, there are a number of reasons why we believe that it holds. First and most importantly, the presence of the original examiner in the opposition division is mostly driven by the availability of *other* potential members with expertise in the particular technology. Thus, staffing at the EPO seems to be the primary driver of the original examiners' participation in the opposition division. Gaessler et al. (2017) confirm this in interviews conducted with EPO officials. Figure A-1 in the appendix presents further evidence, showing the likelihood of examiner participation over time: After the EPO introduced the "BEST" initiative to increase the number of available patent examiners, the likelihood of having the original examiner in the oppo-

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

Table 2: First stage

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

Standard errors in parentheses

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

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

sition division decreased substantially.[24] Second, the associated parties do not know the composition of the opposition division until the oral proceedings, i.e., the day of the decision on the opposition outcome. Therefore, lobbying in some direction is difficult. Third, attributes of the opposed application or the inventor have no explanatory power for examiner participation in our data: Table C-2 in the appendix shows that conditional on grant year, outcome year, and technology fixed effects, examiner participation in the opposition division is unrelated to a number of important application and inventor characteristics.

In summary, the participation of the original examiner in the opposition division is likely exogenous to the patenting activity of inventors. Our estimates can be interpreted as causal if conditional on inventor fixed effects and time period specific effects, the allocation of original patent examiners to the opposition division is exogenous to the productivity of inventors. For the reasons outlined above, we believe this assumption holds.

3 Results and Discussion

In this section, we present and discuss our results. We start by providing evidence on the impact of patent invalidation on future patent applications of affected inventors. In this context, we also test for substitution of patenting to other authorities. We then assess the impact of invalidation on the quality of these applications. Subsequently, we investigate changes in the direction of patenting activities by using alternative dependent variables. Finally, we assess the heterogeneity of our results through splits by applicant and inventor characteristics. In each case, we discuss in how far our results are compatible with potential underlying mechanisms.

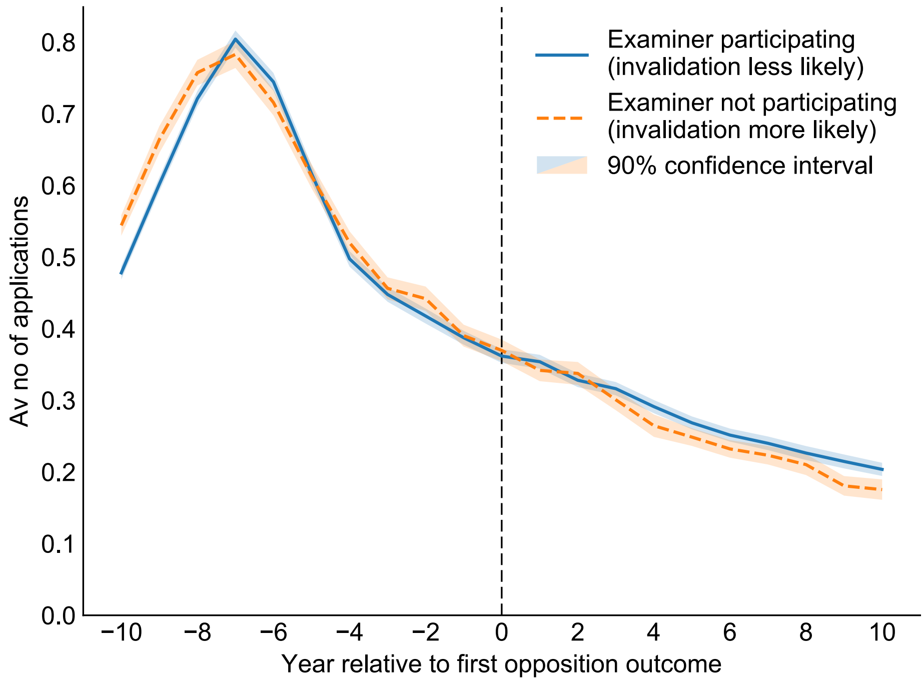
3.1 Patent Counts

Table 3 displays the regression results of the impacts of invalidation on subsequent patenting. Without instrumenting the invalidation decision, Column (1) shows the partial correlation of patent invalidation and the number of subsequent patent applications. The inventor fixed effects regression returns a negative, significant coefficient of patent invalidation.

Because of the potential endogeneity of the invalidation decision, we use the examiner participation instrumental variable in all subsequent columns. In a first step, Column (2) shows the reduced form coefficient: The presence of the original examiner (lower likelihood of invalidation) increases subsequent patent applications. Figure 2 shows this result in a time series of inventor productivity, split by whether the original examiner of the patent

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

Figure 2: Inventor patenting around the outcome of opposition, by examiner participation



Notes: The figure shows the average number of patent applications in the years around the outcome of an inventor's first opposition. The blue solid line indicates inventors with opposition divisions that include the original examiner, the orange dashed line represents examiners with divisions that do not. Absence of the original examiner in the opposition division makes an invalidation more likely (cf Table 2). Shaded areas indicate 90% confidence intervals around the mean.

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

Column (3) of Table 3 presents the instrumented coefficient of invalidation of our preferred specification. It shows that the magnitude of the effect is substantial: On average, the local average treatment effect implies that inventors file half a patent less per year. The sizeable difference to the coefficient in Column (1) indicates that the main source of endogeneity is time-varying and cannot be controlled for by individual fixed effects. This is in line with the findings of Galasso and Schankerman (2015, 2018) and indicates that inventors may indeed file more applications over time, which are however also more likely to be invalidated if in opposition.

Column (4) shows that our results are robust to using the log number of applications to account for the skewness of the dependent variable. Following invalidation due to examiner

Table 3: Effect of invalidation: Number of applications

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

Standard errors clustered at the opposition level in parentheses

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

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

(non-)participation, inventors file around 20% fewer patents. To get a sense of whether the productivity effects are driven by the extensive or the intensive margin, Column (5) shows the effect on the probability of filing a patent application at all in a given year. Having a patent invalidated in opposition reduces the likelihood of subsequently filing a patent by 15 percentage points.

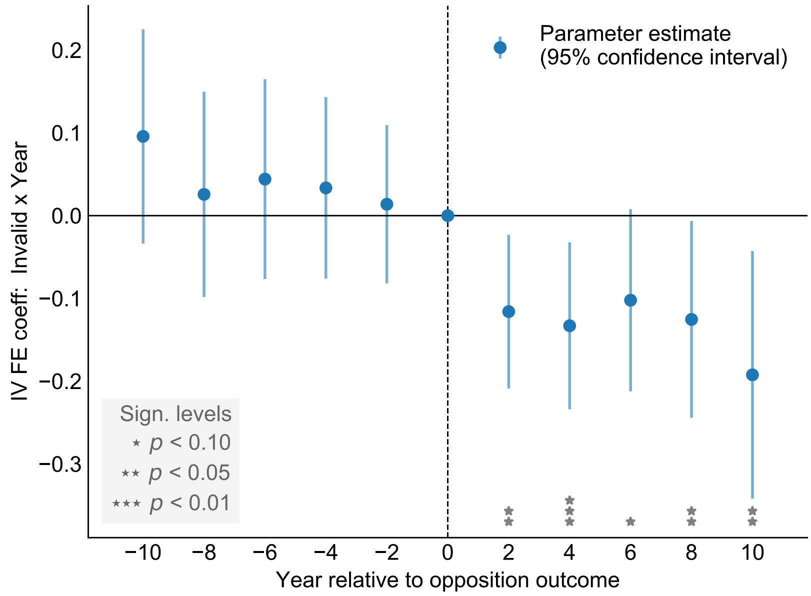
In principle, the decrease in patent applications after invalidation could be independent of innovative activities and merely reflect a change in filing strategies. Inventors, their firms, or their patent attorneys could steer patenting away from the EPO and instead patent directly at the desired national patent offices, avoiding a potential centralized opposition procedure. To investigate this channel, Column (6) uses the number of patent families with (European) national patent applications as the dependent variable (not counting patent families that contain EPO or WIPO applications). We find no change in national patenting. Alternatively, innovators could substitute EPO patenting with WIPO's centralized application procedure. To investigate this possibility, the dependent variable in Column (7) counts patent families containing a WIPO, but no EPO application. While the point estimate is positive, it is not significantly different from zero. Besides, its magnitude is substantially smaller than our main effects. Our results therefore reflect an actual decrease in patent filings rather than a shift to substitute patent authorities.

In the appendix, we show that our main productivity results are robust to excluding outliers (such as the top 5% of inventors with respect to prior filings and technology areas) and to restricting the sample to inventors who patent both before and after the opposition outcome (Table C-1). In Table D-1, we also show that our results are unaffected by using the alternative inventor disambiguation by Morrison et al. (2017). Finally, in Tables D-2 and D-3 we show that findings are very similar for European and non-European inventors.

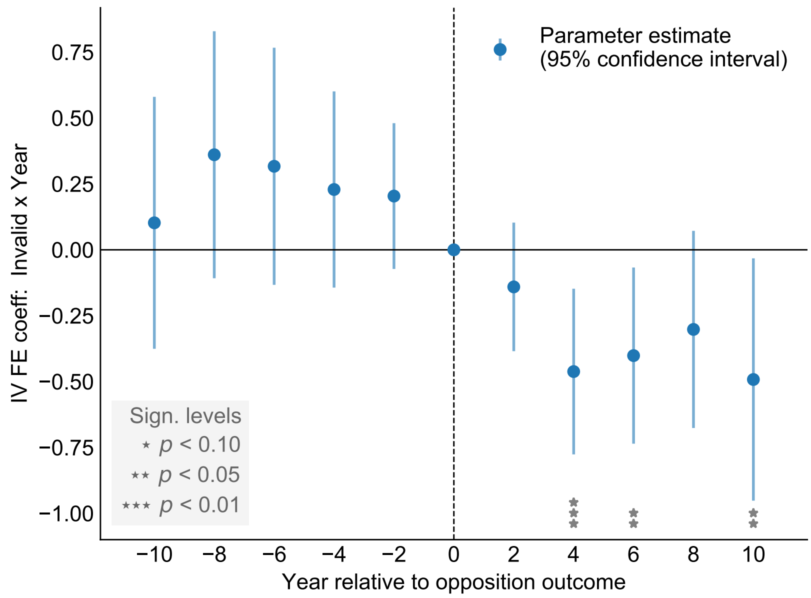
We next investigate the dynamic effects of invalidation in Figure 3. Because of the high variance of patenting, we average effects over two years. Panel (a) shows the instrumented impact of patent invalidation on the likelihood of filing for a patent. In line with our identification assumption, there is no differential application propensity in the years prior to the outcome of opposition. In response to the outcome, inventors whose patent was invalidated due to the absence of the original examiner in the opposition division are significantly less likely to file patent applications. The same picture arises in Panel (b) which uses the number of applications as the dependent variable. In line with the prior graph, "unlucky" inventors whose patent was invalidated due to the original examiner not taking part in the opposition division subsequently file fewer patent applications. The effect materializes after around four years, starting a bit later than in Panel (a). In line with the identification assumption, there are no statistically significant differences in patent filings before the decision of the opposition division.

Figure 3: Dynamic effects of invalidation

(a) Likelihood of filing an application



(b) Number of applications



Notes: Coefficient estimates of invalidation for year pairs relative to opposition outcome from an instrumental variable (2SLS) fixed effects regression on (inventor, year relative to opposition outcome)-level using Schaffer (2010). In Panel (a), the dependent variable is the dummy variable $y_{it} = 1(N_{\text{App},it} > 0)$, indicating whether inventor i has filed a patent application in period t. In Panel (b), the dependent variable $y_{it} = N_{\text{app},it}$ counts the number of applications on DOCDB family level which inventor i has filed in period t. The corresponding specification is given by $y_{it} = \sum_{\tau=-5,\tau\neq 0}^{5} \beta_{2\tau}\, \mathbf{1}(\text{Invalidated}_i)\, \mathbf{1}(t = 2\tau \mid t = 2\tau - 1) + a_t + b_{t-t_{\text{af}}} + c_i + \epsilon_{it}$. i and t are the indices for the inventor and the year relative to opposition outcome, respectively; fixed effects are described in the main text. The interactions are instrumented with $z_{i,t}^{2\tau} = \mathbf{1}(\text{Examiner participation}_i)\, \mathbf{1}(t = 2\tau \mid t = 2\tau - 1)$, where $\tau = -5, \ldots, -1, 1, \ldots, 5$. Error bars indicate the respective coefficient's 95% confidence interval. Stars at the bottom of each panel indicate the significance levels of the coefficients.

Given that we instrument invalidation by the presence of the original examiner in the opposition division, our estimates reflect local average treatment effects. To explore whether compliers differ from the overall population of patents in opposition, in Appendix B we follow Angrist and Pischke (2009) and document the relative incidence of certain applicant and inventor characteristics among compliers. Note that in our context, compliers are inventors whose application was invalidated *because* the original patent examiner did not participate in the opposition division. Table B-1 shows the complier share, which lies at around 7% on average. Table B-2 examines the characteristics of complier applications relative to the general population of patents in opposition. On average, applications whose opposition outcome changes with the examiner's presence in the opposition division are less likely to have more than two inventors and to receive above median citations. Their family size is larger, but this is at the margin of statistical significance. Table B-3 conducts an analogous comparison for inventor characteristics. Inventors of complier patents are more likely to have below median tenure and to have filed patents in a lower number of technology areas before the invalidation. They have also filed fewer patents before the opposition, but the difference is insignificant. In summary, however, complier patents do not differ substantially from the average patent in opposition.

3.2 Patent Quality

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

Overall, this table shows that while invalidation in opposition decreases subsequent patent filings, this effect is driven by a decrease in applications with novelty-threatening

Table 4: Effect of invalidation: Quality of applications

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

Standard errors clustered at the opposition level in parentheses

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

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

prior art. This sheds a favorable light on the opposition procedure at the EPO: Following an invalidation, inventors decrease applications that are at risk of being invalidated because of a lack of novelty or the absence of an inventive step. This finding is in line with a positive impact of invalidation in opposition on the average quality of subsequent filings. The effects for non-XYE-referenced applications are ambiguous, given that the number of such applications increases significantly while we do not find a positive impact on their forward-citations.[25]

In principle, shifts from patenting to secrecy could be driving our results, since private incentives for nondisclosure may differ for applications at the margin of patentability.[26] Generally, firms and inventors will prefer to keep inventions secret if the expected benefit from filing compares unfavorably with disclosure and the risk of invalidation. Applications with X, Y, or E search report references are likely less novel and insightful than the average patent (Harhoff and Wagner, 2009). On the one hand, they will thus be subject to a higher risk of invalidation. On the other hand, filing such applications will reveal little technological information to competitors. Besides, as a signal about future firm strategy they should not be more informative than the average patent application. Hence, secrecy should be more attractive for inventions that constitute a substantial technical advance (cf. Anton and Yao, 2004; Zaby, 2010). Given that the decrease after invalidation is concentrated in applications of questionable novelty, it seems implausible that a shift to secrecy is the main driver of the effect.

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

3.3 Direction of Patenting

In Table 5, we explore in how far our results can be explained by changes to the direction of patenting. Inventors may shift their efforts to other technology areas in response to an invalidation. Inventors could also only frame their patents differently to steer applications to examiners from other EPO technology units. In Columns (1) and (2) of Table 5 we split subsequent patent applications by whether they were filed in the same area than the invalidated patent or another area. We find similar effects for both.

Galasso and Schankerman (2018) find that after an invalidation of litigated patents, firms decrease patenting especially when the invalidated patent was in their core technology area. In Columns (3) and (4) we thus split our sample by whether the invalidation occurred

[25] These findings are again identical when using the disambiguation by Morrison et al. (2017). Our findings are also similar for European and non-European inventors. All results are available on request.

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

Table 5: Effect of invalidation: Direction

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

Standard errors clustered at the opposition level in parentheses

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

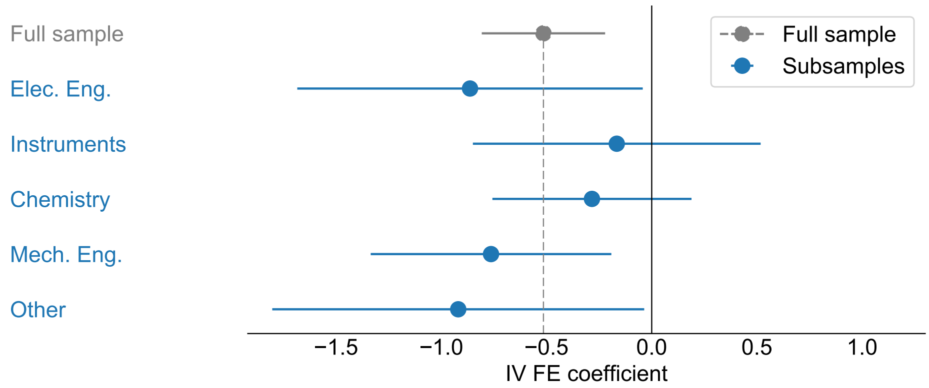
Notes: Columns (1) and (2) present the effect of invalidation on the number of applications in the same and other technology areas as the opposed patent, respectively. Column (3) shows the invalidation effect for inventors who experience their first opposition outside their area of expertise, i.e., outside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

in the inventor's expert technology area. We find very similar effects for both, although the estimates are imprecise when the invalidation occurs in a different area than the inventor's expert technology. In line with the findings of Galasso and Schankerman (2018), the effects for invalidations in the expert area are mostly attributable to fewer filings in the same technology area (Column 5), which is also where most filings occur. However, we also find significant effects for subsequent applications in other areas (Column 6).[27]

Finally, we also analyze the heterogeneity of our results with respect to the field of the invalidated patent. Figure 4 shows these estimates as well as our baseline result. The effects

[27] These findings are again identical when using the disambiguation by Morrison et al. (2017). Our findings are also similar for European and non-European inventors. All results are available on request.

Figure 4: Effect of invalidation on the number of applications by field of opposed patent



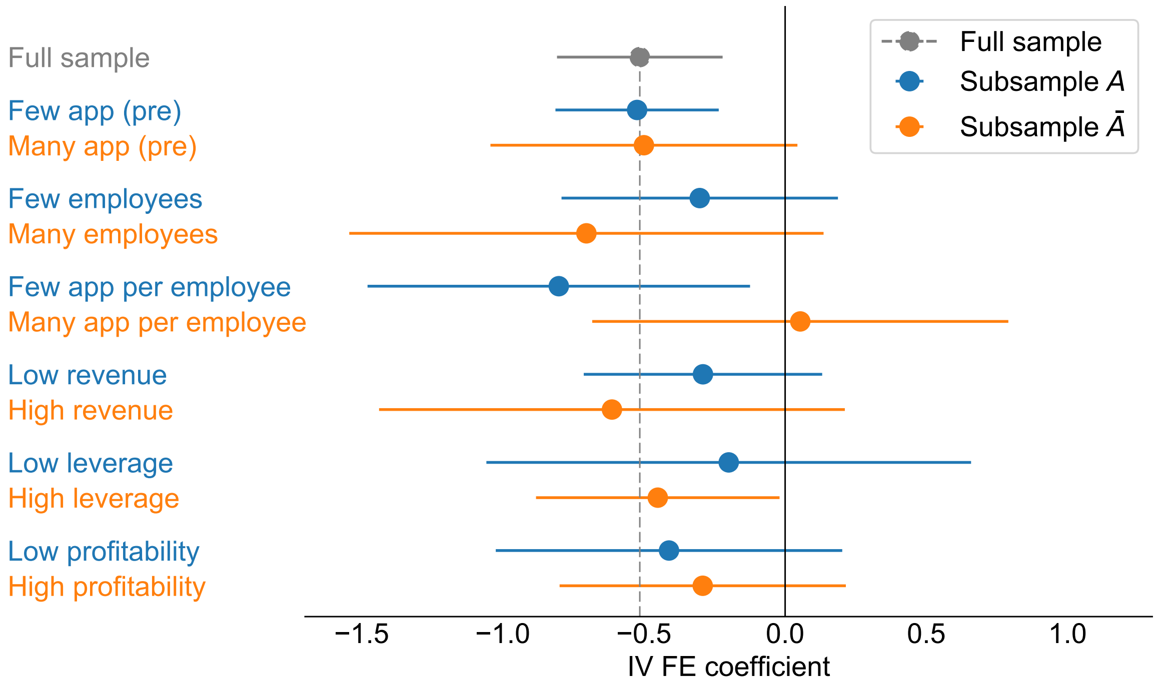
Notes: Coefficient estimates of invalidation from instrumental variable (2SLS) fixed effects regressions on (inventor, year relative to opposition outcome)-level using Schaffer (2010). The baseline regression on the full sample is shown in gray, together with a dashed line for the ease of comparison. The subsamples are defined by the field of the invalidated patent, as indicated in the figure. The dependent variable is in each case $y_{it} = N_{\text{App},it}$. Error bars indicate the respective coefficient's 95% confidence interval.

are somewhat more pronounced and statistically significant for "complex" fields such as Electrical Engineering, in which products are comprised of numerous separately patentable elements (Cohen et al., 2000). In "discrete" fields such as Chemistry, where products are comprised of a single or few patentable elements, the effects are weaker than the main impact and statistically insignificant. However, confidence bounds generally overlap, such that the heterogeneity of effects with respect to the field of the invalidated patent seems weak.

3.4 Applicant and Inventor Heterogeneity

To assess the heterogeneity of the invalidation effect on subsequent patent filings, we split our samples by applicant and inventor characteristics. Figure 5 shows how results differ with respect to patent applicants. As can be seen from the figure, the confidence bounds of all subsamples overlap with the point estimate of the overall sample. If anything, those firms with above median patent applications per employee are less affected than those below the median, unlike in Galasso and Schankerman (2018). An absence of substantial effect heterogeneity along applicant characteristics would be surprising if the impact of invalidation on subsequent filing behavior was a function of the effect on the firm. Therefore, explanations proposed in the literature, such as impacts on firm survival (Farre-Mensa

Figure 5: Effect of invalidation on number of applications: Applicant heterogeneity



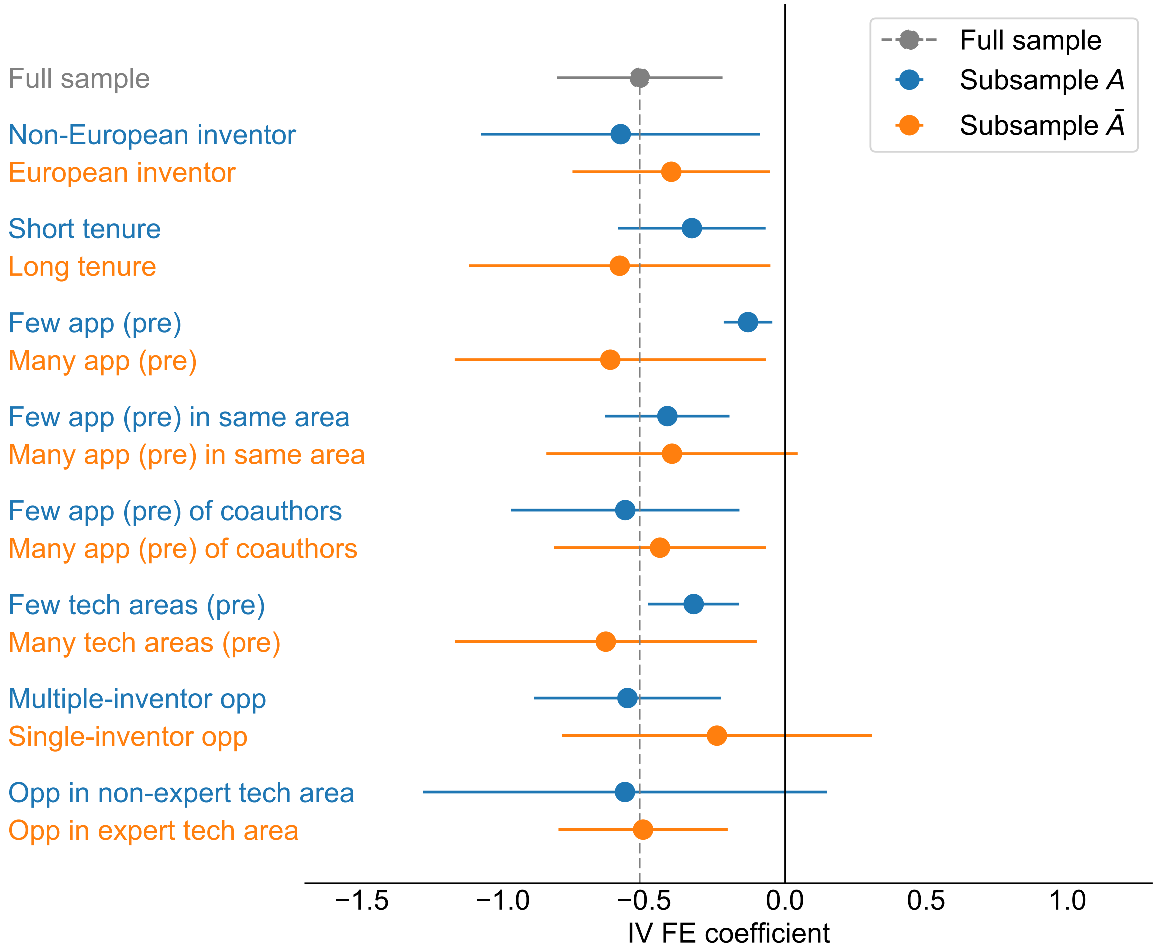
Notes: Coefficient estimates of invalidation from instrumental variable (2SLS) fixed effects regressions on (inventor, year relative to opposition outcome)-level using Schaffer (2010). The baseline regression on the full sample is shown in gray, together with a dashed line for the ease of comparison. Pairs of blue and orange markers indicate coefficients in complementary subsamples. For each pair, the sample is split at the median of an applicant characteristic: the prior number of applications, the number of employees, the number of applications per employee, revenue (deflated), leverage (defined as total liabilities over total assets), and profitability (defined as ebitda over total assets). The dependent variable is in each case $y_{it} = N_{\text{App},it}$. Error bars indicate the respective coefficient's 95% confidence interval. For the corresponding regression table, see Table E-1 in the online appendix.

et al., 2017; Gaule, 2018), are unlikely to drive our effects.[28] However, our results complement the finding that firm heterogeneity only accounts for around 3-5% of the variance in inventors' innovative performance (Bhaskarabhatla et al., 2017).

In addition to applicant characteristics, we explore the invalidation effect's heterogeneity with respect to inventor characteristics. Figure 6 displays the results of this exercise. Here, differences between subsamples are somewhat more pronounced. Inventors with a below median number of patent filings before the opposition are less impacted than those with above median applications. Analogously, those who filed patents in a below median number of technology areas before the opposition are less affected by an invalidation. Con-

[28]Note that due to data availability and the matching process between Patstat and Orbis, sample sizes are considerably smaller for some of the regressions, going along with weaker first-stage F statistics (cf. Table E-1). Undocumented regressions show that inventors who work for firms with available data belong to a slightly more impacted subsample.

Figure 6: Effect of invalidation on number of applications: Inventor heterogeneity



Notes: Analogous to Figure 5, but using inventor instead of applicant characteristics. The IV FE coefficient of $\mathbf{1}(\text{Invalidated}_i)\,\mathbf{1}(\text{Post}_t)$ is shown for the full sample (gray, dashed gray line), and for sample splits by inventor origin, tenure, number of applications, number of applications in the same technology area as the opposed patent, co-inventor patenting experience, number of technology areas in prior applications, and by whether the opposition occurred in the inventor's area of expertise, i.e., the area in which she has filed most patents prior to opposition outcome. The dependent variable is in each case $y_{it} = N_{\text{App},it}$. Error bars indicate the respective coefficient's 95% confidence interval. For the corresponding regression table, see Table E-2 in the online appendix.

sistently, those having below median tenure (defined as the time since their first patent application) are less impacted as well, even though this difference is smaller. These results do not support explanations proposed in the literature, such as inventors receiving information about the quality of their ideas (Chan et al., 2014; Azoulay et al., 2015, 2017), changes in inventor income streams (Harhoff and Hoisl, 2007; Toivanen and Vaeaenaenen, 2012), or other impacts on inventor careers such as labor mobility (Melero et al., 2017). If any of these explanations were true, we would expect larger effects for young and inexperienced inventors who are still uncertain about their productivity and who still have their careers ahead of them. However, if anything, our results point towards these inventors being less affected by invalidations.

4 Conclusion

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

Our results show that inventors file fewer patents in response to an invalidation. Invalidation in particular decreases subsequent applications associated with novelty-threatening prior art. It thus appears unlikely that a shift towards secrecy fully explains the results. Neither is the effect driven by patenting shifts to national authorities or the WIPO. These findings apply broadly throughout our sample, without strong heterogeneities along fields or along inventor or applicant characteristics. Being one of the first to provide evidence on the consequences of patent invalidation for *individual* inventors, this paper complements recent research by Galasso and Schankerman (2018).

Importantly, this paper contributes to understanding the consequences of post-grant review. Despite having gained substantial interest, empirical evidence on the impacts of opposition procedures remains scarce. While invalidations in opposition seem to decrease the quantity of inventors' subsequent applications, we find that the effect is concentrated in low-quality filings. From this angle, post-grant review at the EPO appears to benefit the patent system.

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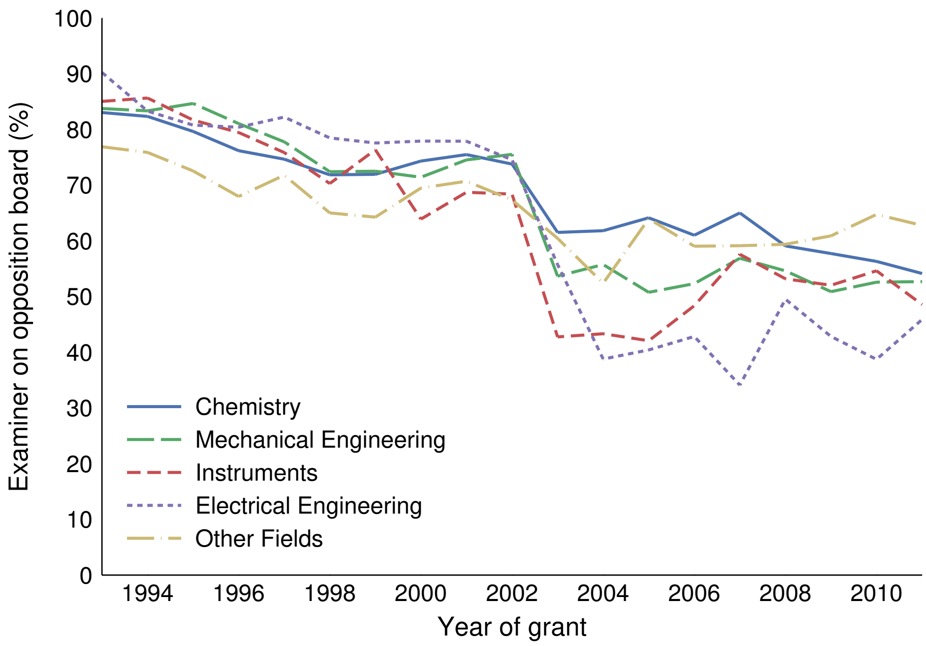
A Appendix: Figures

Figure A-1: Examiner participation in opposition proceeding over time



Notes: Share of oppositions with the original examiner present in the opposition division by main technology area. The underlying data includes oppositions with outcomes after 2011 and oppositions which are not the first of an inventor. Reproduced from Gaessler et al. (2017).

B Appendix: Complier Analysis

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

Table B-1: LATE discussion – Complier shares

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

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

Table B-2: LATE discussion – Complier application characteristics

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

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

Table B-3: LATE discussion – Complier inventor characteristics

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

Notes: Analogous to the application-level analysis in Table B-2, this table explores in how far the complier inventor subpopulation differs from the full sample of first-opposition inventors with respect to a series of inventor characteristics (cf first column). The second column shows the number of inventors included in our baseline sample. On a 10% level, we find that significantly smaller shares of complier inventors with tenure above 9 years and with prior patenting in more than two technology areas. Standard errors indicated in parantheses are clustered on the opposition level.

C Appendix: Tables – Robustness & Instrumental Variable

Table C-1: Effect of invalidation on number of applications: Robustness

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

Standard errors clustered at the opposition level in parentheses

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

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

Table C-2: Regressions of instrumental variable on application and inventor characteristics

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

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

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

D Appendix: Tables – Baseline Specification

Table D-1: Effect of invalidation: Number of applications (Morrison et al. (2017) inventor disambiguation)

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

Standard errors clustered at the opposition level in parentheses

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

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

Table D-2: Effect of invalidation: Number of applications (European inventors)

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

Standard errors clustered at the opposition level in parentheses

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

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

Table D-3: Effect of invalidation: Number of applications (foreign inventors)

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

Standard errors clustered at the opposition level in parentheses

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

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

E Appendix: Tables – Effect Heterogeneity - For Online Publication

Table E-1: Effect of invalidation on number of applications: Applicant heterogeneity

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

Cluster(appln_id)-robust standard errors in parentheses

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

Notes: Table corresponding to Figure 5, displaying heterogeneity of the invalidation effect for sample splits by applicant characteristics. All columns present results from instrumental variable (2SLS) fixed effects regressions on (inventor, year relative to opposition outcome)-level. Column (1) indicates the coefficient of 1(Invalidated) × 1(Post) for the full sample. Columns (2)-(15) show the coefficients for the subsamples split by the applicant's patent portfolio, number of employees, number of patent applications per employee, revenue (deflated), leverage (defined as total liabilities over total assets), and profitability (defined as ebitda over total assets). In each case, the sample is split at the median of the respective variable. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).

Table E-2: Effect of invalidation on number of applications: Inventor heterogeneity

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

Cluster(appln_id)-robust standard errors in parentheses

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

Notes: Table corresponding to Figure 6, displaying heterogeneity of the invalidation effect for sample splits by inventor characteristics. All columns present results from instrumental variable (2SLS) fixed effects regressions on (inventor, year relative to opposition outcome)-level. Columns (1)-(16) display the coefficients for the subsamples split by inventor origin, by tenure, i.e., by the time since the first EPO application, by the number of applications prior to opposition outcome, by the number of applications in the same area as the opposed patent, by the number of applications of the inventor's coauthors, by the number technology areas in prior filings, by whether the opposed patent lists multiple inventors, and by whether the opposed patent falls into the inventors technology area of expertise, i.e., the area in which she has filed most patents prior to opposition outcome. For the continuous and the count variables, the sample is split at the respective median. All variables are counted on the DOCDB family level. The post period is defined as the time window from 0 to 10 years after opposition. Standard errors are clustered at the opposition level. The underidentification and weak identification tests are the heteroskedasticity-robust Kleibergen and Paap (2006) rk LM and Wald F statistics, respectively, as reported by the xtivreg2 Stata command (Schaffer, 2010).