The Causal Effect of Essential Patents on Follow-on Innovation Related to Technology Standards

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Abstract

This paper analyzes the causal effect of the inclusion of patented technology into a technology standard on follow-on innovation related to this standard. I analyze standards subject to declarations of potentially essential pending patent applications, and compare standards subject to successful applications with standards subject to declared patent applications which are eventually abandoned or rejected at the USPTO. I use the grant rate by examiner to instrument for the grant decision. I find a positive effect of the grant of the pending standard-essential patent (SEP) application on follow-on innovation as measured by patent citations to the technology standard. Distinguishing between types of follow-on innovation, I find that a patent grant has a positive effect on follow-on progress in the standard itself, and a negative effect on use of the standard by different, new technology standards. The positive effects of SEPs on patent citations and contributions to the further progress of the standard are not driven by patent applications or contributions of the SEP owner itself. Rather, the results suggest that the grant of the SEP induces other firms to increase their own efforts to secure patents related to the technology standard.

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Kewords: Standard-Essential Patents, Technology Standards, Cumulative Innovation, Ex-post effect of patents
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1 Introduction

This paper analyzes the causal effect of Standard-Essential Patents (SEPs) on the further technological progress and the adoption of technology standards. It is widely understood that the prospect of gaining SEPs is an important incentive to develop and contribute standard-related technology. The ex-post effect of SEPs on the further progress of standards is however controversially discussed in a substantial academic and practitioner literature. There are widespread concerns that the inclusion of patented technology into technology standards can produce adverse effects. Theoretical arguments point to the risks that the inclusion of SEPs into technology standards generates patent thickets (webs of overlapping patent rights) or threats of patent hold-up (exorbitant royalty requests after an industry is committed to a specific technological solution), which may stifle standard adoption. On the other hand, the inclusion of SEPs may also produce positive effects on the subsequent technological progress of standards, such as internalization effects, incentivizing the owners of existing SEPs to invest resources in the further development of technology standards in order to increase demand for the standard including their patented technology. While these theoretical arguments are widely discussed, they are currently not supported by causal empirical evidence.

The discussion of the effect of SEPs is however informed by an empirical literature on the more general ex-post effect of patents on follow-on technological innovation. This literature has produced heterogeneous results, and points to Information and Communication Technologies (ICT) as the technological area in which negative ex-post effects are most likely to arise. This finding is explained by the fact that ICT are often subject to fragmented patent ownership, which increases transaction costs and mitigates internalization benefits. In contrast to other patents in ICT, SEPs are subject to specific requirements, including the obligation to publicly disclose the existence of the SEP in a standardized database, and make available licenses on Fair, Reasonable and Non-Discriminatory (FRAND) terms. While there is wide agreement that the purpose of disclosure obligations and FRAND licensing policies is to mitigate potential adverse effects resulting from the inclusion of SEPs, there is currently no empirical evidence whether the negative effect of patents on follow-up innovation observed in ICT also characterizes SEPs.

Another open question relates to the fact that follow-on innovation could mean various things. In particular, it is important to distinguish between further improvements of the patented technology; and the use of the patented technology for different, new projects. Measures used in previous research projects (patent citations, academic citations, clinical trials) conflate the two forms of follow-on innovation. Finally, an important gap in the literature is the question how the marginal effect of a patent on follow-on innovation depends on the existence of other patents related to the same technology. This question is of paramount importance to complex technological systems like technology standards.

This paper fills these various gaps. I analyze a sample of pending US patent applications that were declared potentially essential to specific technology standards, and compare technology standards subject to declared patent applications that resulted in a granted US patent with standards subject to declared applications that were unsuccessful at the USPTO. Following Sampat and Williams (2015), I use the grant rate of USPTO examiners as instrumental variable to identify the causal effect of the patent grant.

I analyze the effect of the patent grant on five different outcome variables that provide complementary information on different aspects of follow-on innovation. First, I analyze the effect of the grant of the SEP application on normative and informative references from other standards to the standard including the patented technology. These references are a measure of the use of the standard in new, different technological applications. Second, I analyze new work items and change requests relating to the standard including the patented technology. These are direct measures of further improvements of the technology standard including the patented invention. Finally, I analyze patent citations to the standard as part of the non-patent literature (NPL) citations. These citations are a measure of the number of new inventions building upon the standard.

The instrumental variable regressions reveal contrasted effects. In particular, I find a positive effect of SEP grant on citations to the standard from new patent applications. I also find a positive effect of SEP grant on the number of new work items related to the standard, and a positive albeit only mildly significant effect on the number of change requests. I find a strongly significant negative effect of the SEP grant on the number of informative references, whereas the effect on normative references is not significant. Differentiating between references from different SSOs, I find a significant negative effect of the SEP grant on references from IETF standards, but no significant effect on references by other SSOs. IETF is among the few SSOs expressing a preference for non-patented technologies for their standards (Baron and Spulber, 2016).

The literature on the effect of patents in complex technologies has pointed to "patent thickets" or patent ownership fragmentation as a potential concern, but has so far provided no evidence how the effect of patents depends on the existence of complementary patents relating to the same technology. I analyze how the effect of the grant of SEP applications depends on whether the same firm already had declared other SEPs for the same standard before declaring this application, and whether other firms already had declared to own SEPs for the same standard. The evidence is contrasted, and does not indicate a clear-cut relationship between the effects of patent grant and the existence of complementary patents.

Furthermore, I distinguish between effects of SEP grant on follow-on innovation carried out by the owner of the SEP application, and innovation carried out by other firms. The SEP grant has no significant effect on contributions or patent citations from the owner of the SEP applications, but a mildly significant positive effect on contributions and a significant positive effect on patent citations from other firms. This counter-intuitive finding can potentially be explained by the fact that the SEP may induce other firms to more aggressively seek SEPs. Indeed, I find that the SEP grant has significant effects only on a relatively small category of change requests. These change requests are also much more likely to constitute patentable inventions, and may thus lead to a new SEP for their authors if accepted.

Overall, my findings suggest that SEPs induce an increase in standard-related patenting and in contributions to the further development of the technology standards, and a limited negative effect on the use of the standardized technology by other standards. The findings are difficult to reconcile with prevailing theories on the effects of patents, which focus on transaction costs and internalization effects. The negative effect of SEPs on the implementation of the standard in other technologies does not seem to reflect transaction costs, in particular because it does not depend on the number of complementary patents and is limited to SSOs that have specific policies discouraging the use of patented technologies. Furthermore, the positive effect of SEPs on patenting and contributions can better be explained by competition between firms rather than by internalization effects. Indeed, the SEP grant has a significant effect only on patenting and patentable contributions, and the effect is driven by other firms, not by the SEP owner itself.

The remainder of this article is organized as follows. In Section 2, I present the analytical framework and review the literature. In Section 3, I discuss the empirical methodology. In Section 4, I present the results of the Instrumental Variable regressions. Section 5 is a preliminary conclusion.

2 Analytical Framework

2.1 Effect of patents on follow-on innovation

An important strand of economic research investigates the effect of patents on technological innovation. Patents allow an inventor to exclude others from practicing the patented invention for a limited time, and thus may allow the inventor to earn supra-competitive returns. These returns in turn are an important reward for inventors, and can thus incentivize additional investments in research and development (R&D). The effect of the prospect of patent protection on the incentives to pursue R&D which may result in a patentable invention is called the ex-ante effect of patents on innovation.

Besides the ex-ante effect, patents may also have ex-post effects on technological innovation. Ex-post effects are all the effects of the grant of a patent on subsequent innovative activities, including the effects of patents on further improvements of the patented invention, or the invention of new applications for the patented technology. It is not straightforward whether the ex-post effect of patents on further innovation is positive or negative, or whether there is any effect at all. Green and Scotchmer (1995) argue that if transaction costs are sufficiently low, the grant of a patent should have no consequences on follow-on innovation. If however transaction costs are significant, these transaction costs may prevent some follow-on innovations from being developed. Patents can play a positive or negative role in this respect, and either encourage or discourage follow-on innovation.

On the one hand, in the presence of transaction costs, follow-on innovation may be stifled by bargaining failures between the owner of the existing patent and the potential follow-up inventor. Because of these bargaining failures, potential follow-on inventors may refrain from inventive activities, e.g. in order to avoid costly litigation on patent infringement (Bessen and Maskin, 2009). I will call this the transaction cost effect of patents on follow-on innovation.

On the other hand, transaction costs might also prevent beneficial follow-on innovation if the initial invention is not patented. Patent protection can facilitate knowledge transfers to follow-on inventors and overcome coordination problems in incremental innovation (Spulber, 2015). Another situation is that the benefits of the follow-on invention cannot be fully appropriated by the follow-on inventor (e.g. the follow-on innovation involves results that are not patentable). Once again, a patent on the initial invention can overcome this problem, because the patent owner internalizes the benefits of a follow-on invention improving his patented invention, and has an incentive to invest resources in incremental innovation or assign a research contract to a potential follow-on inventor (Kitch, 1977). I will call these various potential beneficial effects the internalization effects of patents on follow-on innovation. Galasso and Schankerman (2015b) study the effect of patent protection on follow-on innovation by the patent owner itself, and find that invalidation of the patent leads to a 50% decrease in the rate of citations to the invalidated patents from new patent applications by the owner of the first patent.

Whether the overall effect of patent on follow-on innovation is positive or negative is thus ultimately an empirical question. So far, two studies have investigated the causal effect of patents on follow-on innovation.[1] Sampat and Williams (2015) study the effect of the grant of patents related to human genomes on subsequent academic and commercial scientific research on this particular genome. They find no evidence for any significant effect. Galasso and Schankerman (2015a) investigate the effect of patents on follow-on innovation by studying the effect of patent invalidation in the courts. They find evidence for a significant negative effect of patents (a positive effect of patent invalidation) in the field of Information and Communication Technologies (ICT), whereas they find no evidence for significant effects in any other technological area. ICT are thus the focus of the debate on the effect of patents on follow-on innovation.

ICT are characterized by a high degree of technological complexity. Complex technologies are technologies consisting in a very large number of different patentable inventions that must all be jointly used in order to produce a desired outcome.[2] It is thus very frequent that follow-on innovation in ICT builds on large numbers of different patented inventions owned by multiple inventors. Such a situation, sometimes pejoratively referred to as patent thicket, is seen as particularly prone to the adverse effects of patents, because the transaction costs for negotiating the required licenses increase exponentially in the number of required patents (Llanes and Trento, 2012). Furthermore, the internalization benefits of patents are potentially less relevant in complex technologies, because each patent owner only internalizes a small part of the benefit of follow-up innovation improving or making use of the complex technology including his patented invention.

2.2 Standard-essential patents

The situation that complex technologies are subject to fragmented patent ownership is particularly frequent in the case of technology standards. Technology standards are common rules which define a particular technological design that various users of the standard must follow in order to ensure that their various products or services are interoperable. Standards often specifically address a large number of detailed technological choices. If the organization setting the standard decides to require users of the standard to use patented

[1] A larger number of studies have investigated the effect of other Intellectual Property Rights, e.g. Murray and Stern (2007) and Williams (2013)

[2] e.g. operating a phone call involves a large number of technical operations, such as digital coding of the speech data, encryption of the data for safety reasons, data transmission, routing the data through large networks towards the intended recipient of the communication, and decryption and decoding of the digital data at the other end of the call

technologies, this gives rise to SEPs. SEPs are patents that are necessarily infringed by any implementation of a technology standard. Patented inventions that are merely useful, but not necessary, for the implementation of a standard are not essential. Similarly, patents that protect a particular implementation of a standard, as opposed to an invention used by all implementations of a standard, are not SEPs. SEPs are thus a subset of patented inventions relating to technology standards.

While not all patents relating to standardized technology, SEPs have attracted a very large amount of attention in the academic literature and policy discussions (e.g. Shapiro (2001); Lemley and Shapiro (2013). On the one hand, many stakeholders believe that SEPs are problematic, because they may confer incremental market power to the owners of patents protecting the particular technology that has been chosen as a standard (Lerner and Tirole, 2015). This market power might allow a patent owner to exclude users from using a standard that an entire industry has agreed upon.

On the other hand, SEPs can be particularly valuable patents, and may provide significant financial returns to their owners (Rysman and Simcoe, 2008; Blind et al., 2015). SEPs may thus allow firms participating in the costly R&D effort of developing complex technology standards to recoup their investment through licensing revenue. The licensing revenue earned by SEP owners is often considered a necessary incentive for companies to invest in standard-related R&D, participate in standardization efforts, and make their technologies available for inclusion into technology standards.

In order to strike the balance between the benefits and potential risks of SEPs, many SSOs have adopted specific policies regulating the inclusion of patented technologies into their standards (Chiao et al., 2007; Bekkers and Updegrove, 2012). These policies generally include two aspects. First, most SSOs require that SSO members participating in standardization meetings disclose any Intellectual Property Rights (IPR) they own which they believe to be essential to a technology standard or a proposed standard under development. These disclosures are made publicly available on the website of the SSO. Neither SSOs nor any other third party makes any verification of the patent owner's claim that his patent is essential to the use of the standard. Both over- or under-declaration of patents can thus occur. Nevertheless, companies have strong legal and economic incentives to declare their SEPs accurately and to the best of their knowledge.[3]

Second, most SSOs require that a company declaring to own standard-essential IPR commits to offer licenses on Fair, Reasonable and Non-Discriminatory (FRAND) terms to all users of the technology standard. If a patent owner declines to make such a licensing promise, the SSO can set the standard such as not to include the patented technology. The precise interpretation of the terms fair, reasonable and non-discriminatory is heavily contentious (Layne-Farrar et al., 2007; Sidak, 2013).

[3]The failure to declare SEPs may result in serious adverse legal consequences. Antitrust authorities have investigated cases in which firms were accused to fail to declare their SEPs during standard development in order to later collect disproportionate royalty revenues on patent inventions that the SSO could have chosen not to include in the standard had it known of the existence of the patent. This strategy is called patent ambush, and has resulted in serious antitrust fines or remedies. On the other hand, over-declaration of patents is costly, because along with the disclosure companies agree to make their patents available on specific terms that are more advantageous to licensees than what a patent owner might request in the absence of the SSO obligation.

A common interpretation of the FRAND commitment is that FRAND is designed to mitigate two potential threats arising from the inclusion of patented technology into a standard which might develop into a disincentive to the adoption of technology standards. First, the implementation of a standard is often costly, and in particular necessitates substantial sunk investments by the future user of the standard. Potential users of the standard may be disinclined to incur these sunk costs in the implementation of a standard, if there are SEPs relating to this standard. There is at least a theoretical risk that owners of these SEPs might ask for exorbitant royalty rates after they observe that users have already incurred the sunk costs of standard implementation, and would have to forfeit on this sunk investment if they cannot secure a license to practicing the standard-essential technology. This is called hold-up (Lemley and Shapiro, 2007). Second, many standards include many SEPs, owned by multiple different patent owners. If these patent owners don't coordinate their royalty requests, there is a risk that the aggregate licensing cost for users of the standard is unviable, and eliminates demand for the use of the standard. This risk is called royalty stacking (Lemley and Shapiro, 2007).

Both the risk of hold-up and royalty stacking are frequently cited in the academic literature and by policy makers as motivating far-reaching regulatory intervention. Nevertheless, at the present stage, both the risk of hold-up and royalty stacking are only supported by an exclusively theoretical analysis. It has repeatedly been observed that there is to date no solid empirical evidence for the actual occurrence or empirical relevance of either of these risks (Galetovic et al., 2015).

Furthermore, while it is widely accepted that FRAND licensing commitments are intended to curb the risks of patent hold-up and royalty stacking, there is no reliable empirical evidence whether FRAND licensing policies are successful at mitigating the potential adverse effects of SEPs on standard adoption and follow-on innovation. On the balance, there are different views and contrasted evidence on how SEPs - subject to specific risks associated with essentiality, but also to specific policies - compare with other patents. On the one hand, Simcoe et al. (2009) find an increase in litigation rates after a patent is declared standard-essential. On the other hand, Wen et al. (2015) argue that standardization and SSO disclosure policies reduce transaction costs and reduce the extent of strategic patenting.

2.3 Patent applications and the examination process at the USPTO

SSOs usually require their members not only to disclose actual patents, but also pending applications which might result - if the application is granted - in SEPs.[4] Many SEPs relate to inventions that are made in the immediate context of standard development. It is therefore very common that SEP applications are still pending at the time when the SEP declaration is requested. Approximately half of the US patent numbers declared as potentially standard-essential to the various SSOs requiring SEP disclosure are application file numbers or application publication numbers.

[4] In an empirical analysis of ten SSO policies, Bekkers and Updegrove (2012) found that nine SSOs required the disclosure of pending applications. The other policy is the policy of the American National Standards Institute (ANSI), which only defines minimum requirements for the SSOs accredited by ANSI. The ANSI policy thus leaves it up to the accredited SSO to determine the specific scope of the disclosure obligation.

Not all applications result in the grant of a patent. The decision whether a patent application is granted is taken at the patent office by a patent examiner. At the USPTO and many other patent offices, patent examiners work in different art units according to their technical specialization. A patent application is assigned to an art unit according to the technological content and focus of the invention. Within the art unit, patent applications are randomly assigned to patent examiners by order of arrival.

In principle, all examiners use the same criteria in determining whether a patent application can be granted. In particular, the invention must be patentable subject matter, novel, non-obvious and useful. The precise definitions of these notions are determined by statutory requirements, a substantial body of case law, and the rules and procedures of the USPTO. In spite of the fact that all examiners are asked to enforce the same body of rules, there is ample evidence that different examiners can arrive at different decisions when facing the same application. Lemley and Sampat (2012) e.g. find that examiners become increasingly lenient in the course of their career path. Frakes and Wasserman (2016) explain that the amount of time that an examiner has to process a patent application depends on career stages, and show that examiners having less available time are less likely to decide to reject an application. Most significantly, Sampat and Williams (2015) find a very significant "examiner fixed effect". Independently of their experience and career stage, some examiners are significantly stricter or more lenient than others.

The fact that patent applications are randomly assigned to examiners who are more or less lenient in the examination of applications introduces an element of random variation. Some technologies may become subject to patent protection, because the application was randomly assigned to a more lenient examiner, whereas other technologies, subject to a stricter examination, enter the public domain. While this element of randomness is troublesome from a policy perspective, it provides a great research opportunity to study the various causal effects of patents. Sampat and Williams (2015) compare granted and rejected applications and use variation in examiner leniency to study the effect of patents on human genome research. Farre-Mensa et al. (2016) use the same methodology to study the effects of patents on job creation, innovation and firm growth in a large sample of entrepreneurial firms, and Gaule (2015) analyze the effect of patents on the success of start-up companies backed by venture capital funds. Like the present study, these different studies analyze samples of patent applications, compare successful and unsuccessful applications, and use the leniency of the examiner as instrumental variable (IV) to investigate the causal effect of patent protection. All these studies have in common that they investigate the effect of the patent protection itself, holding constant the existence of the underlying invention.

2.4 The technological progress of standards

The present analysis uses the same empirical strategy to analyze the causal effect of SEPs on the further technological progress of technology standards. The analysis of technology standards allows me to introduce an important distinction which has not been addressed in the previous studies of the effect of patents on follow-up innovation. Previous studies, and in particular the analysis by Galasso and Schankerman (2015a), investigated the effect of patents on follow-up innovation by studying citations to the focal patent from subsequent patents. These citations could originate from inventions improving the technology including the focal patent, or from inventions using the technology including the patented invention for some novel purpose. The analysis of patent citations does not allow making the distinction between the two types of follow-up innovation.

In contrast to patents or academic articles, standards are dynamic technological objects subject to continuous technological progress and change. The adoption and modification of technology standards is the result of the contributions of competing firms, as technology standards are determined in competitive markets (Spulber, 2013). SSO members and standardization participants compete and cooperate to have their technological contributions adopted as part of technology standards (Leiponen, 2008). Conflicts between the sponsors of competing contributions are resolved through vote (Farrell and Simcoe, 2012; Simcoe, 2012; Bonatti and Rantakari, 2016). While firms may compete with other firms for inclusion of their technologies into a standard, they may also rely upon each other's contributions to the development and improvement of a jointly used standard. In equilibrium, a firm's contributions may either increase or decrease contributions by other firms (Baron et al., 2014).

In many SSOs, technology standards advance through standard revision, i.e. the release of a new version of the same standard, or of a new standard replacing the existing standard (Baron et al., 2016). At other organizations, and in particular at 3GPP, technology standards progress through the contribution and acceptance of new work items and change requests (Baron and Gupta, 2016).

3GPP members who wish to add a new feature (specification) to a 3GPP standard submit a work item. A proposal has to be endorsed by at least four 3GPP members to be placed on the agenda and proceed as a work item (Leiponen, 2008). Work items are discussed by representatives of the different 3GPP members in specialized working groups. After a work item has been submitted to a working group with the endorsement of four members, other 3GPP members can submit change requests to modify or add technical features of the proposed specification. These change requests are subject to vote in the working group. After processing all change requests, the resulting draft specification is submitted by the working group to the 3GPP Technical Specification Group (TSG) Plenary, and adopted by a 72% majority vote. Even though work items can result in the creation of a new technical specification, both change requests and work items impact specific existing technical specifications. These impacted specifications can be clearly identified. Change requests and work items are thus a direct measure of technological contributions to the improvement of an existing standard.

Whereas work items and change requests are measures of the improvement and further progress of technology standards, standard references are a direct measure of the use of a standard for a different, novel technical purpose (Baron and Spulber, 2016). A standard references another standard if using the referenced standard is also required to implement the referencing standard. A standard reference is thus to be distinguished from a citation (e.g. between articles or patents), because it indicates a novel use of the standard rather than a knowledge flow. Some SSOs distinguish between normative and informative standard references. A normative reference indicates that using the referenced standard is necessary to implement the referencing standard, whereas an informative reference indicates that the referenced standard is merely useful, but not necessary, for implementing the referencing standard.

The technological content of a technology standard also generates knowledge flows that can be useful for subsequent technological progress (Delcamp and Leiponen, 2014). Some of these knowledge flows are captured by citations from new patent applications. Patents make citations to other patents, but also to a variety of other documents (called the non-patent literature, or NPL). These citations describe the prior art against which the novelty of a patented invention is assessed. NPL citations to technology standards therefore indicate that the content of a technology standard constitutes prior art to subsequent patentable inventions, i.e. that patented inventions build upon the technological information codified in the standard information. This measure is very similar to citations among patents which have been used in previous studies of the effect of patents on follow-on innovation.

3 Empirical methodology

3.1 Data

This paper uses the combination of three large scale databases collected as part of an important effort to make comprehensive statistical databases on technology standards available for economic research. First, it uses a large database of technology standards, including information on the dates of release of the different versions, and normative and informative references among standards (Baron and Spulber, 2016). Second, it uses a comprehensive database of declared SEPs, which are carefully matched to specific technology standards and technical specifications (Baron and Pohlmann, 2016). The vast majority of SEP declarations indicate a specific technology standard for which the declared patent is essential, and many declarations indicate a specific version. Finally, this paper builds on a comprehensive database of technical contributions to 3GPP standardization, including data on work items and change requests (Baron and Gupta, 2016).

The data on technology standards draws from various sources. First, I used PERINORM, a bibliographical database with data on ca. 1.5 million standard documents, including information such as the title and identifier of the standard, dates of release, and for many of these documents also information on the version history, international correspondence between standards, and references.[5] The international correspondence between standards is useful to identify equivalent technology standards that are published under different titles in different countries by different SSOs.

All declared SEPs relate to technology standards published by either international or US-based SSOs. I therefore create a database with all references to US or international standards, but I use references from all standards included in the PERINORM database. PERINORM provides data on references from most formal SSOs, including ISO, IEC, ITU, CEN, most formal national SSOs in Europe, as well as IEEE. Second, I scraped several databases of technology standard documents offered for sale on websites such as the IHS Standards Store (www.ihs.com) or the Document Center (www.document-center.com).

[5]PERINORM is provided and regularly updated by Deutsches Institut fuer Normung (DIN), British Standards Institute (BSI) and Association Francaise pour la Normalisation (AFNOR). These three national SSOs collect bibliographic information on standards (including their own standards and standards from other SSOs). More information on Perinorm at www.perinorm.com

These websites provide the electronic version of standard documents for sale, but provide some bibliographic information for free, including information such as the title, release date, version history and references for some organizations. From IHS, I create the database of references from TIA/EIA, NEMA and ATIS standards. Finally, for a list of important SSOs (ETSI,[6] IETF, OASIS and W3C), I scraped the entire set of standard documents, and created a database with document titles, release dates, and all normative and informative references.

In addition to standard references, I use a comprehensive database of NPL citations to technology standards and standardization documents. The dataset was created by searching for the name of the major SSOs in the list of NPL references in the worldwide Espacenet database of 75 million patent documents.[7] This resulted in a sample of approx. 300,000 patent documents citing at least one document of one of the major SSOs in their NPL references, and a total of 1,650,274 NPL citations. This includes citations to standards, citations to contributions to standardization (such as work items or change requests), and citations to many other documents that are not directly related to standards (such as articles in one of the many technical journals edited by IEEE).

In a second step, I cleaned this large database of references and citations to precisely identify references and citations to specific documents. To this end, I wrote a cleaning protocol that identifies the various standard identifiers used by the different major SSOs (e.g. RFC 1645 by IETF, TS 35.430 by 3GPP, IEEE 802.11j by IEEE, ISO/IEC 14496.10 by ISO and IEC), eliminates citations and references to documents which are not published standards, and standardizes different spellings of the same document to create a clean and standardized citation or reference database. Table 1 provides an overview over the number of references, citations or contributions by data source; and compares the total number of references or citations with the number of references or citations that can be matched to a specific standard using the cleaning protocol.

Source	**Before cleaning**			**After cleaning**		
type	normative	inform.	unknown	normative	inform.	unknown
NPL citations			1,650,274			387,379
Work items			17,313			17,313
Change requests			237,892			237,892
References						
PERINORM&IHS	0	0	2,438,601	0	0	2,236,208
ETSI / 3GPP	706,066	21,512	0	619,703	13,772	0
IETF	31,025	46,510	0	29,635	31,182	0
W3C	4,657	4,088	4,319	1,330	492	475
OASIS	1,504	722	771	517	135	169

Table 1: Number of citations or references by datasource

I used the same cleaning protocol to clean and standardize the standard designations in a large database of patent declarations (provided by IPlytics). The database draws

[6] All 3GPP specifications are also published as ETSI standards. My database of ETSI standards therefore also covers the entire sample of 3GPP specifications.

[7] Special thanks to Tim Pohlmann and IPlytics for sharing this data. For more information on IPlytics, see www.iplytics.com

from 6,492 patent declaration letters to all major SSOs which make databases of declared SEPs publicly available. In these declaration letters, firms have declared 50,844 patent publication and 36,860 patent application numbers. These declared numbers are "as to declaration", as firms use different spellings or reporting styles to report the same patent document. I wrote a different cleaning protocol to clean declarations of different US patent numbers, including patent publication numbers, application publication numbers, application file numbers, provisional application numbers, re-issue publication numbers etc. I matched all declared numbers with the USPTO pair database, and identified 11,968 different US patents (or pending or abandoned patent applications) that were declared as essential. In many cases, multiple numbers were declared for the same patent (e.g. the application file number, application publication number and the publication number of the patent). Overall, 19,900 US patent numbers were declared to the SSOs, including 10,677 application numbers and 9,223 publication numbers (see Table 2).

Type	Number
Application file number	5,580
Application publication number	4,123
PCT application number	855
Provisional application number	119
Subtotal application numbers	10,677
Patent publication number	9,026
Re-issue publication number	197
Subtotal publication numbers	9,223
Total patent numbers	**19,900**

Table 2: Number of declared US patent numbers by type

Finally, I create a dataset of 3GPP standardization documents. From the 3GPP website, I scraped the entire dataset of technical specifications, listing the unique ID (UID) of all work items impacting the specific specification. In a second step, the UID can be matched with a comprehensive database of work items to identify the date at which work on the work item began, and the identity of the supporting entities. 3GPP also provides a comprehensive database of all change requests, listing among other information the date of the meeting at which the change request was submitted, and the impacted technical specifications. The database thus created includes 17,313 work items and 174,296 change requests.

I standardize company names across all datasets. To this end, I collect the names of the companies declaring the SEPs, the assignees of the patents citing the standards, the source of the change requests to 3GPP, and the supporting entities of 3GPP work items. All company names are standardized using a common name standardization file.

3.2 Creating the sample

Starting from the database of declared SEPs, I create the analysis sample. First, I identify declarations of US patent application numbers. The declarations are matched to clean standard identifiers as described. In addition, different standard identifiers can relate to the same standard (e.g. if different SSOs publish the same standard under different titles). I use PERINORM information on international correspondence, as well as specific datasets on the equivalence between GSM, ETSI and 3GPP specification numbers, to create a dataset of unique standard IDs. I remove declarations when the same patent had already been declared to the same standard with a different patent number or standard designation. In particular, I remove declarations to a new version of a standard, if the same patent had already been declared essential to a previous version. Second, I remove declarations made after the declared patent application was granted or abandoned; as well as applications that were still pending at the time of data collection (February 2016). I thus create a sample of patent applications that were pending at the time of declaration, but for which I can now observe the grant outcome. Third, I removed declarations when more than one pending applications were declared essential to the same standard within less than two years. This results in a sample of 574 declarations of pending US applications to clearly identified technology standards. The dataset consists in 237 unique applications (the same application being often declared essential to multiple standards), and 511 different standards (the same standard can be included twice in the sample if the second application was declared after a sufficient time has lapsed after declaration of the first application). The SEPs were declared by 80 different firms.

Table 3 provides an overview over the number of standards included in the sample, by SSO issuing the standard.[8]

SSO	Freq	Percent
ANSI	2	0.39
Broadband Forum	2	0.39
ETSI	218	42.66
IEC	6	1.17
IEEE	11	2.15
IETF	204	39.92
ISO	6	1.17
ITU-R	2	0.39
ITU-T	35	6.85
OASIS	1	0.20
OMA	24	4.70

Table 3: Standards by SSO

I use this sample of application-standard pairs to create a panel database, spanning the 7 years before and the up to 7 years after the year in which the patent application was declared essential (up to 15 years in total, including the declaration year; less if the declaration was made after 2008). In several instances, the declaration date is earlier than the patent application date. This happens when the original patent declaration designated

[8]Note that I have standardized standard designations between 3GPP and its various member SSOs, as well as technical specification numbers relating to specific 3GPP projects (such as GSM or UMTS). For all these standards, I keep the technical specification number used by ETSI. ETSI hosts the declarations of SEPs to 3GPP standard.

a foreign priority patent, and the declaration is later amended by the SSO to include the US patent application. In these cases, I use the earliest application publication date as declaration date, because it is the date at which the existence of the standard-essential US application is publicly disclosed.

I observe the number of SEPs (granted patents) that the firm owned for this standard at the disclosure date, as well as the number of firms that have made SEP declarations by the disclosure date. On average, the firm declaring the SEP application included in my sample already had declared 1.45 US patents for the same standard that were granted by the time the focal SEP application was declared; and including the owner of the focal SEP, there were on average 4.89 firms declaring to own SEPs for the specific standard at the time of declaration.

In Table 4, I distinguish between the intensive and extensive margin: I identify SEP applications that are *pivotal* in the sense that if granted, they would be their owner's first SEP for this standard; and *only firm* SEPs, i.e. SEPs declared to a standard when no other firm except the owner of this SEP had declared to own SEPs for this standard.

	Only-firm SEP	Non-*only-firm* SEP	**Total**
Pivotal SEP	192	152	**344**
Non-*pivotal* SEP	53	177	**230**
Total	**245**	**329**	**574**

Table 4: Observations at the intensive and extensive margin

There are 192 observations in the sample that are fully pivotal, i.e. a rejection of this SEP application will place the implementation of the entire standard in the public domain. In 152 other cases, the specific firm would lose its only SEP for this standard, but other firms have also declared to own SEPs for the same standard.

3.3 Outcome variables, descriptive statistics

I match the 511 unique standards in my sample with the comprehensive data on references, citations and standardization contributions. I use the same approach as before to assign citations, contributions and references to different document identifiers to unique standard IDs. Furthermore, I remove duplicate citations from patents (e.g. one patent citing different identifiers designating the same standard, and different patents of the same family citing the same standard), and keep only one citation for each patent family. I use the INPADOC family ID to identify patent families. The citation date is defined as the application date for the earliest priority patent of the family citing the standard. Similarly, I remove multiple references by standard (e.g. new versions of the same standard reiterating references already made in previous versions, or different SSOs publishing the same standard under different document designations, all making the same references). I thus count unique standard references, the reference date being defined as the publication date of the earliest standard version including the reference. I also count work items and change requests by 3GPP technical specification and year.

The counts of new citations, new references, work items and change requests are matched to the sample by unique standard and year, with a total of 7,686 observations.

Table 5 presents sample statistics for the average numbers of references, patent citations and technical contributions related to each standard per year.

Variable	Mean	Std. Dev.	Min.	Max.
3GPP change requests	8.023	41.522	0	721
3GPP work items	1.129	3.957	0	102
NPL citations	4.515	16.483	0	363
Standard references				
ETSI normative	1.36	4.091	0	111
ETSI informative	0.097	0.471	0	10
IETF normative	0.235	1.334	0	30
IETF informative	0.256	1.03	0	26
W3C normative	0.001	0.032	0	2
W3C informative	0	0.016	0	1
W3C unclassified	0.001	0.028	0	1
PERINORM & IHS	0.305	1.941	0	61
N		7686		

Table 5: Summary statistics

On average, each standard in the sample thus receives 33.9 new references from other standards and 67.9 citations from priority patent applications over the entire observation period. For each ETSI/3GPP standard, there are on average 282.7 change requests and 17.0 new work items related to the standard over the observation period.

3.4 Creating the Instrumental Variable

Following Sampat and Williams (2015), I use the examiner leniency as instrumental variable for the grant of the patent. I thus calculate the average grant propensity for each examiner over the entire sample of US patent applications, using the USPTO Pair Database. I exclude the focal patent from the calculation of the grant propensity of the examiner. It is important to account for the fact that the grant rate varies between technological fields, and not to confound this variation with examiner leniency. I therefore also calculate the average grant rate per art unit (once again excluding the focal patent from the calculation). The allocation of applications to examiners within art units is randomized.

One potential concern is initial selection in the data generating process resulting from the fact that patent applications that are unlikely to succeed are also less likely to be declared. Another potential bias is that potential SEPs are especially valuable patents, inducing the applicants to invest greater efforts in the application process, and making them less likely to abandon a pending application. The average grant propensity of examiners in my sample is 76.47 %, whereas the average grant rate of the applications in my sample is 76.76 %. There is thus no evidence for the presence of initial selection bias.

4 Results

4.1 Instrumental variable estimation

Following the existing literature (Sampat and Williams, 2015; Farre-Mensa et al., 2016), I assume that the grant or rejection of a patent produces its effects before the date of the final decision. The examination process consists in a series of many individual decisions, and continuously reveals information on the likelihood that the patent will ultimately be granted. Sampat and Williams (2015) and Farre-Mensa et al. (2016) therefore use the application date as cut-off date for their difference-in-differences estimation. In my data, the declaration usually occurs after the application date, and using the application date would therefore condition sampling on future events. In particular, if a change in the standard induces the declaration, this change would be picked up as a causal effect of the declaration. I therefore use the disclosure date, which is generally the declaration date. Only in the cases when the declaration date is before the application date (because a foreign priority patent was declared first, and the SSO added the US patent later to the database), the disclosure date is defined as the application publication date.

I estimate the following regression equation:

$$\begin{aligned} y_{j,t} = \alpha + \beta_1 post_{i,j,t} * issued_i + \beta_2 post_{i,j,t} * artunitgrantrate_i + \beta_3 post_{i,j,t} \\ + \beta_4 T_t + \eta_{i,j} + \epsilon_{i,j,t} \end{aligned} \quad (1)$$

Where i designates patent application, j designates a unique standard identifier, $post_{i,j,t}$ indicates that the analysis time t is after the disclosure date, $issued_i$ is a time invariant variable indicating that the patent application effectively resulted in the grant of a patent, T_t is a vector of year dummies, $\eta_{i,j}$ is an application-standard pair fixed effect. y designates the different outcome variables, which vary between equations. In order to account for the skewed distribution, I use the logs of all outcome variables. $post_{i,j,t} * issued_i$ is instrumented by $post_{i,j,t} * examinergrantrate_i$.

The baseline results of the IV estimations are presented in Table 7 (the results of the first stage of the 2SLS IV estimation are presented in Table 6).

	(1-2) issued_post	(3-5) issued_post
examinergrantrate_post	1.316***	0.572***
	(17.14)	(12.94)
post	1.221***	0.175***
	(22.02)	(5.18)
artunitgrantrate_post	-2.029***	-0.195***
	(-18.00)	(3.64)
N	3740	7686

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001
32 year dummies included but not reported

Table 6: Results of the IV regressions, OLS fixed effects (first stage)

	(1) log_changerequests	(2) log_workitems	(3) log_inf.ref	(4) log_norm.ref	(5) log_npl
issued_post	0.532	0.434**	-0.325**	-0.144	0.590*
	(1.82)	(2.62)	(-2.67)	(-0.62)	(2.36)
post	0.0901	0.320***	0.220	0.527***	0.835***
	(0.22)	(4.07)	(0.88)	(0.93)	(6.51)
artunitgrantrate_post	-0.353	-0.664**	0.324**	-0.555**	-1.612***
	(-0.94)	(-3.10)	(3.22)	(-2.91)	(-7.80)
N	3740	3740	7686	7686	7686

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001
32 year dummies included but not reported

Table 7: Results of the IV regressions, OLS fixed effects (second stage)

These results indicate contrasted causal effects of SEPs on different measures of follow-on innovation related to technology standards. On the one hand, I find a positive effect of SEP grant on citations to the standard from patents and on contributions to the improvement of the standard itself (a positive and significant effect on the number of new work items, and a positive effect on change requests significant at 10% confidence). On the other hand, I find no or a negative significant effect of SEP grant on implementation of the standard in different technology standards (no effect on normative references, and a significant negative effect on informative references).

In Table 14 in the Appendix, I differentiate between references from standards developed by different SSOs. There are three different groups of standard references with a sufficient sample size for this analysis in our data: references from ETSI, IETF, and from the standards included in Perinorm or IHS (these are mostly standards developed by more formal national and international SSOs, such as ISO or ITU). I find that the grant of the SEP has a significant negative effect only on references from IETF standards. The much larger samples of references from ETSI or from other standards do not display any significant effect of SEP grant.

I furthermore differentiate between different types of change requests to better understand the mechanisms explaining the effects of SEPs. There are five categories of change requests: correction to an earlier release (A), addition of a feature (B), functional modification of a feature (C), editorial modification (D), and essential correction (F). I classify categories B and C as functional change requests, and the remaining categories as non-functional. According to this definition, 21.4 % of the change requests are functional. This relatively small group of change requests represents however the sample of change requests that constitute potentially patentable contributions.[9] Differentiating between functional and non-functional change requests, I find that the grant of the SEP has a significantly positive effect on other firms' patentable contributions. At odds with the

[9] In order to verify this assertion, I search the NPL citations database for prior-art citations to 3GPP contributions (by *tdoc-number*). There are 121,072 such citations. Among change requests, functional change requests concentrate more than 95 % of the prior art citations. This indicates that this type of change requests is much more likely to constitute a potentially patentable invention. Details of this analysis, which relates to ongoing work on a parallel project, are available upon request.

internalization hypothesis, the grant of the SEP does not induce the SEP owner to make a higher number of non-patentable contributions to the standard (see Table 15).

4.2 Effects at the intensive and extensive margin

The baseline results presented in Table 7 reflect the average marginal effect of the grant of a single SEP. Many standards include several or even many SEPs, that were sometimes declared by a relatively large number of firms. Other standards however are subject to only few or even only to a single SEP declaration. Based upon the literature, the grant of an SEP can be expected to produce different results depending upon whether it is the first and only SEP that a firm declares to own for a specific standard, and whether this firm is the only firm to declare SEPs for this standard. I identify *pivotal* SEP applications, that - if granted - result in a specific firm's first US SEP for a specific standard. I furthermore identify *only firm* SEP applications. These are applications that were declared essential to a standard for which no other firm than the owner of this SEP application had declared to own SEPs.

The following tables provide the results of this analysis. Table 8 presents the IV regression results for the effect of SEP grant on change requests, differentiating between the different types of SEP applications:

	(6)	(7)	(8)	(9)
	log_changereq.	log_changereq.	log_changereq.	log_changereq.
	only-firm	non-*only-firm*	*pivotal*	non-*pivotal*
issued_post	0.957*	0.435	0.837	0.464
	(2.28)	(1.19)	(1.71)	(0.75)
post	0.817	-0.118	0.449	-0.623
	(0.91)	(-0.26)	(1.11)	(-0.46)
artunitgrantrate_post	-1.349	-0.0635	-1.012*	0.563
	(-1.48)	(-0.16)	(-2.08)	(0.45)
N	779	2961	1798	1942

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001
32 year dummies included but not reported

Table 8: IV regressions intensive and extensive margin, OLS fixed effects (second stage)

Table 9 presents the results of the same analysis for work items:

Table 10 presents the effects of SEP grant on informative references:

Table 11 presents the effects of SEP grant on normative references:

Finally, Table 12 presents the effects of SEP grant on NPL citations to the standard:

Overall, the differences between effects at the intensive and extensive margin are inconsistent and do not provide significant support for theories emphasizing the increased transaction costs and reduced internalization benefits resulting from ownership fragmentation.

The grant of an SEP has a significantly positive effect on change requests only in the case of a single SEP owner; but the reverse is true for work items. The effect of SEP grant

	(10) log_workitems *only-firm*	(11) log_workitems non-*only-firm*	(12) log_workitems *pivotal*	(13) log_workitems non-*pivotal*
issued_post	0.116	0.504*	0.965**	0.874*
	(0.48)	(2.44)	(3.13)	(2.55)
post	0.397	0.250	0.492	-1.629*
	(0.77)	(0.96)	(1.94)	(-2.18)
artunitgrantrate_post	-0.749	-0.730**	-1.534***	1.382*
	(-1.44)	(-3.17)	(-5.01)	(2.00)
N	779	2961	1798	1942

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001
32 year dummies included but not reported

Table 9: IV regressions intensive and extensive, OLS fixed effects (second stage)

	(14) log_inf.ref. *only-firm*	(15) log_inf.ref. non-*only-firm*	(16) log_inf.ref. *pivotal*	(17) log_inf.ref. non-*pivotal*
issued_post	-0.0657	-0.347**	-0.338	-0.274*
	(-0.36)	(-2.98)	(-1.42)	(-2.53)
post	-0.0977	0.243*	-0.0931	0.396*
	(-1.46)	(2.20)	(-1.55)	(2.06)
artunitgrantrate_post	0.288	0.0882	0.576*	-0.213
	(1.31)	(0.88)	(2.01)	(-1.22)
N	3286	4400	4692	2994

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001
32 year dummies included but not reported

Table 10: IV regressions intensive and extensive, OLS fixed effects (second stage)

	(18) log_norm.ref. *only-firm*	(19) log_norm.ref. non-*only-firm*	(20) log_norm.ref. *pivotal*	(21) log_norm.ref. non-*pivotal*
issued_post	-0.153	-0.0432	0.448	-0.380
	(-0.52)	(-0.18)	(1.05)	(-1.75)
post	0.150	0.793***	0.473***	0.861*
	(1.41)	(3.43)	(4.38)	(2.23)
artunitgrantrate_post	0.00539	-1.011***	-1.038*	-0.845*
	(0.02)	(-4.82)	(-2.02)	(-2.41)
N	3286	4400	4692	2994

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001
32 year dummies included but not reported

Table 11: IV regressions intensive and extensive, OLS fixed effects (second stage)

on work items is positive and significant for both *pivotal* and non-*pivotal* SEP applications, whereas there is no significant effect on change requests for either *pivotal* or non-*pivotal*

	(22) log_NPL-cit. *only-firm*	(23) log_NPL-cit. non-*only-firm*	(24) log_NPL-cit. *pivotal*	(25) log_NPL-cit. non-*pivotal*
issued_post	0.272	0.634*	1.167*	0.263
	(1.02)	(2.34)	(2.49)	(1.11)
post	0.383***	1.015***	0.735***	0.898*
	(3.98)	(3.94)	(6.21)	(2.14)
artunitgrantrate_post	-0.638*	-1.857***	-2.037***	-1.400***
	(-2.00)	(-7.94)	(-3.60)	(-3.68)
N	3286	4400	4692	2994

t statistics in parentheses

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

32 year dummies included but not reported

Table 12: IV regressions intensive and extensive margin, OLS fixed effects (second stage)

SEP applications. The negative effect of SEPs is significant only at the intensive margin (for SEPs declared by firms that already had declared to own SEPs for this standard, and in the case of standards including SEPs by multiple firms). The effect of SEP grant on NPL citations is significant only for *pivotal* SEPs, and in the case of standards subject to SEPs declared by multiple firms.

4.3 Effects on the SEP owners and others

Finally, I differentiate between the effects of SEP grant on the behavior of the SEP owner itself and the effects on the behavior of other firms. I can identify the firm responsible for the follow-on innovation for at least two types of outcome variables: change requests and NPL citations.[10] I therefore clean and standardize firm designations both in the SEP declaration data and in the data on 3GPP contributions and patent applications citing technology standards. For each observation in the sample, I count contributions and patent applications citing the standard authored by the same firm declaring to own the SEP application, and contributions and patent applications authored by all other firms (including other owners of SEPs for the same standard).

Table 13 presents the second stage result of the IV estimation of the causal effect of SEP grant on change requests and patent citations, differentiating between self-citations and other citations. Interestingly, both the effect on change requests and the effect on patent citations are positive and significant (at 10 % in the case of change requests) only for other firms, not for the SEP owner itself.

These results are difficult to reconcile with the hypothesis that the effect of SEP grant on follow-on progress in the technology standard is attributable to internalization effects. It rather seems that the increased rate in follow-on progress is driven by competitive forces. Indeed, the effect on change requests by other firms than the SEP owners is significant only for patentable contributions, i.e. functional change requests. This finding resonates

[10]Work items have multiple "supporting entities", because 3GPP policies require that a work item is supported by at least four 3GPP members.

	(26) log_changereq. SEP owner	(27) log_changereq. other firms	(28) log_NPL-cit. SEP owner	(29) log_NPL-cit. other firms
issued_post	-0.123	0.522	0.179	0.539*
	(-0.77)	(1.83)	(1.71)	(2.20)
post	0.379	0.0530	0.0911	0.824***
	(1.65)	(0.13)	(6.21)	(2.14)
artunitgrantrate_post	-0.544**	-0.258	-0.335***	-1.537***
	(-2.63)	(-0.70)	(-3.60)	(-3.68)
N	3740	3740	7686	7686

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001
32 year dummies included but not reported

Table 13: IV regressions OLS fixed effects on SEP owners / other firms (second stage)

with the seminal analysis of patenting in complex technologies in Cohen et al. (2000), who find that patent applications in these technologies are often motivated by the desire to enter into cross-licensing agreements with forms owning patented technologies that the firm needs for its own activities. In a similar vein, these findings could also indicate that technology standards including SEPs are subject to portfolio races between different firms owning portfolios of SEPs for the same standard (Siebert and von Graevenitz, 2010).

5 Preliminary Conclusion

This is a preliminary draft on an ongoing research project. This project combines various novel, large-scale databases on standardization and detailed patent application data from the USPTO to analyze causal effects of SEPs on various dimensions of innovation related to technology standards. In particular, I compare standards subject to declared applications which effectively result in a granted patent with technology standards subject to declared applications which are eventually abandoned or finally rejected after declaration. I use the grant propensity of the examiner randomly assigned to the patent application to account for the potential endogeneity of patent grant.

My analysis distinguishes between measures of technological progress in the standard including the patented technology, and measures of the development of novel technological implementations using the standard. I find a significant negative effect of the grant of the pending application on novel implementations of the standard. This effect is however attributable to implementations by reference from a single SSO, IETF, which practices a policy explicitly discouraging the use of patented technologies.

The grant of the pending SEP application produces a positive effect on NPL citations from new patent applications, and different types of contributions to the improvement of the existing standard. These results qualify previous research, e.g. Galasso and Schankerman (2015a), which has highlighted a negative ex-post effect of patents on subsequent technological progress in ICT. My results suggest that this negative effect is limited to the use of the patented technology in new applications, but contrasts with a positive effect on contributions to the further improvement of the technology including the patented invention.

My analysis also sheds a new light on the mechanisms behind the observed causal effects of patent protection. In particular, the findings described in this paper are difficult to reconcile with theories emphasizing transaction costs and internalization benefits as main drivers behind these causal effects. There is no evidence that the effect of SEPs on follow-on innovation is overall less favorable in the case of SEPs increasing the number of licensors for a standard subject to SEPs declared by multiple firms. Furthermore, the positive effects of SEPs on patent citations and contributions to standard development are not attributable to the SEP owner itself. Alternatively, the findings suggest that the effects of SEPs on follow-on innovation related to the standard reflect the efforts of other firms to produce standard-related patents, which may be used for cross-licensing agreements with the SEP owner.

More work is needed to assess the robustness of these results. Based on these preliminary results, I suggest that research on SEPs should pay more attention to the potential benefits from competitive R&D induced by the prospect of patent protection. The literature currently seems to overly focus on potential transaction costs related to SEPs. In particular, substantial policy efforts and academic discussions focus on the transaction costs resulting from incomplete contracts (vague FRAND commitments) and patent thickets (multiple marginalization, search costs etc). The causal evidence presented in this draft suggests that these costs may be outweighed by potential positive effects of SEPs on technological contributions to standard development and standard-related patenting.

References

J. Baron and K. Gupta. Unpacking 3gpp standards. Searle Center on Law, Regulation and Economic Growth Working Paper, 2016.

J. Baron and T. Pohlmann. Mapping standards to patents using databases of declared standard-essential patents and systems of technological classification. Searle Center on Law, Regulation and Economic Growth Working Paper, 2016.

J. Baron and D. Spulber. Technology standards and standards organizations: An introduction to the searle center database. mimeo, 2016.

J. Baron, Y. Meniere, and T. Pohlmann. Standards, consortia and innovation. *International Journal of Industrial Organization*, 36:22–35, September 2014.

J. Baron, T. Pohlmann, and K. Blind. Essential patents and standard dynamics. *Research Policy*, 45(9):1762–1773, 2016.

R. Bekkers and A. Updegrove. A study of ipr policies and practices of a representative group of standards setting organizations worldwide. Project on intellectual property management in standard-setting processes, US Natiaonal Academies of Science, Board of Science, Technology and Economic Policy (STEP), 2012.

J. Bessen and E. Maskin. Sequential innovation, patents, and imitation. *RAND Journal of Economics*, 40(4):611–635, 2009.

K. Blind, P. Neuhaeusler, and T. Pohlmann. Standard essential patents to boost financial returns. *R&D Management*, June 2015.

A. Bonatti and H. Rantakari. The politics of compromise. *American Economic Review*, 106(2):229–259, February 2016.

B. Chiao, J. Lerner, and J. Tirole. The rules of standard-setting organizations: an empirical analysis. *The RAND Journal of Economics*, 38(4):905–930, December 2007.

W. Cohen, R. Nelson, and J. Walsh. Protecting their intellectual assets: Appropriability conditions and why u.s. manufacturing firms patent (or not). NBER Working Paper No. 7552, National Bureau of Economic Research, February 2000.

H. Delcamp and A. Leiponen. Innovating standards through informal consortia: The case of wireless telecommunications. *International Journal of Industrial Organization*, 36: 36–47, September 2014.

J. Farre-Mensa, D. Hegde, and A. Ljunqvist. The bright side of patents. USPTO Economic Working Paper No. 2015-5, United States Patent and Trademark Office, 2016.

J. Farrell and T. Simcoe. Choosing the rules for consensus standardization. *RAND Journal of Economics*, 43(2):235–252, Summer 2012.

M. Frakes and M. Wasserman. Is the time allocated to review patent applications inducing examiners to grant invalid patents?: Evidence from micro-level application data. *Review of Economics and Statistics*, forthcoming, 2016.

A. Galasso and M. Schankerman. Patents and cumulative innovation: Causal evidence from the courts. *Quarterly Journal of Economics*, 130(1):317–369, 2015a.

A. Galasso and M. Schankerman. Patent rights and innovation by small and large firms. NBER Working Paper No. 21769, National Bureau of Economic Research, December 2015b.

A. Galetovic, S. Haber, and R. Levine. An empirical examination of patent hold-up. *Journal of Competition Law and Economics*, forthcoming, 2015.

P. Gaule. Patents and the success of venture-capital backed startups: Using examiner assignment to estimate causal effects. mimeo, 2015.

J. Green and S. Scotchmer. On the division of profits in sequential innovation. *RAND Journal of Economics*, 26(1):20–33, 1995.

E. W. Kitch. The nature and function of the patent system. *Journal of Law and Economics*, 20(2):265–290, October 1977.

A. Layne-Farrar, J. Padilla, and R. Schmalensee. Pricing patents for licensing in standard-setting organizations: Making sense of frand commitments. *Antitrust Law Journal*, 74 (3):671–706, 2007.

A. Leiponen. Competing through cooperation: Standard-setting in wireless telecommunications. *Management Science*, 54(11):1904–1919, November 2008.

M. Lemley and C. Shapiro. A simple approach to setting reasonable royalties for standard-essential patents. Stanford Public Law Working Paper No. 2243026, 2013.

M. A. Lemley and B. Sampat. Examiner characteristics and patent office outcomes. *Review of Economics and Statistics*, 94(3):817–827, 2012.

M. A. Lemley and C. Shapiro. Patent holdup and royalty stacking. *Texas Law Review*, 85, 2007. Stanford Law and Economics Olin Working Paper No. 324.

J. Lerner and J. Tirole. Standard-essential patents. *Journal of Political Economy*, 123(3): 547–586, 2015.

G. Llanes and S. Trento. Patent policy, patent pools, and the accumulation of claims in sequential innovation. *Economic Theory*, 50(3):703–725, 2012.

F. Murray and S. Stern. Do formal intellectual property rights hinder the free flow of scientific knowledge? an empirical test of the anti-commons hypothesis. *Journal of Economic Behavior and Organization*, 63:648–687, 2007.

M. Rysman and T. Simcoe. Patents and the performance of voluntary standard-setting organizations. *Management Science*, 54(11):1920–1934, November 2008.

B. Sampat and H. Williams. How do patents affect follow - on innovation? evidence from the human genome. NBER Working Paper No. 21666, National Bureau of Economic Research, 2015.

C. Shapiro. Navigating the patent thicket: Cross licenses, patent pools, and standard setting. In J. L. Adam Jaffe and S. Stern, editors, *Innovation Policy and the Economy, Volume 1*, NBER Chapters, pages 119–150. National Bureau of Economic Research, 2001.

J. G. Sidak. The meaning of frand, part i: Royalties. *Journal of Competition Law and Economics*, 9(4):931–1055, November 2013.

R. Siebert and G. von Graevenitz. Jostling for advantage or not: Choosing between patent portfolio races and ex ante licensing. *Journal of Economic Behavior and Organization*, 73:225–245, 2010.

T. Simcoe. Standard setting committees: Consensus governance for shared technology platforms. *American Economic Review*, 102(1):305–336, February 2012.

T. Simcoe, S. Graham, and M. Feldman. Competing on standards? entrepreneurship, intellectual property and platform technologies. *Journal of Economics and Management Strategy*, 18(3):775–816, Fall 2009.

D. Spulber. Innovation economics: The interplay among technology standards, competitive conduct, and economic performance. *Journal of Competition Law and Economics*, 9(4): 777–825, December 2013.

D. Spulber. How patents provide the foundation of the market for inventions. *Journal of Competition Law and Economics*, 11(2):271–316, 2015.

W. Wen, C. Forman, and S. Jarvenpaa. Standards, intellectual property rights, and strategic patenting: Evidence from ietf. mimeo, 2015.

H. Williams. Intellectual property rights and innovation: Evidence from the human genome. *Journal of Political Economy*, 121(1):1–27, 2013.

Appendix 1

Effects on references by referencing SSO

	(30) log_ETSI_ref.	(31) log_IETF_ref.	(32) log_PerinormIHS_ref.
issued_post	0.0477	-0.316*	-0.0283
	(0.23)	(-2.35)	(-0.25)
post	0.458***	0.147*	-0.0182
	(4.39)	(2.12)	(-0.32)
artunitgrantrate_post	-0.675***	0.211	-0.00271
	(-4.02)	(1.90)	(-0.03)
N	7686	7686	7686

t statistics in parentheses

* p<0.05, ** p<0.01, *** p<0.001

32 year dummies included but not reported

Table 14: IV regressions (second stage): effects on references by referencing SSO

Effects on contributions by type of contribution

	(33) log_cr (funct.) SEP owner	(34) log_cr (nf) SEP owner	(35) log_cr (funct.) other firms	(36) log_cr (nf) other firms
issued_post	-0.142	-0.107	0.375*	0.536
	(-1.59)	(-0.72)	(1.98)	(1.95)
post	0.424***	0.231	-0.0557	0.0337
	(3.32)	(1.09)	(-0.21)	(0.09)
artunitgrantrate_post	-0.460***	-0.357	-0.0887	-0.271
	(-3.98)	(-1.87)	(-0.36)	(-0.76)
N	3740	3740	3740	3740

t statistics in parentheses

* p<0.05, ** p<0.01, *** p<0.001

32 year dummies included but not reported

Table 15: IV regressions (second stage): effects on contributions, by type and source