

Free to innovate? Intellectual property (in)validation and standard development in wireless telecommunications¹

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ABSTRACT

We study the effect of patent invalidation on innovation of standard-related technologies through the examination process of the U.S. Patent Trial and Appeals Board (PTAB) that was launched in 2012 as part of the America Invents Act. We focus on the decision to “institute” a patent challenge. Institution is an administrative decision by the PTAB to rule on the validity of the patented claims. It is highly likely to lead to at least partial invalidation of the patent’s claims, and in most cases leads to the invalidation of all claims. We find that when a challenge to the validity of a standard essential patent (SEP) for 5G wireless networks is instituted in PTAB, it opens space in the technological domain for the rivals of the patent holder to make changes and create new features for the standard. These firms also file for additional patents. When the PTAB challenge is not instituted, meaning that the standard-essential patent was effectively validated, the rivals of the patent holder reduce their related standard contributions and patent filings. We conclude that the PTAB *inter partes* review reveals strategically valuable information and allows firms to reposition themselves in the market for standardized technologies. In ongoing research, we explore how the characteristics of firms and their positions in the ecosystem moderate these outcomes.

KEY WORDS Patent challenges, PTAB, standard development organization, wireless communication technologies, innovation

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INTRODUCTION

Intellectual property (IP) rights embodied in firms' patents serve as the bedrock of the innovation economy (e.g. Grossman and Helpman 1993). By granting exclusive commercialization rights to inventors for a limited period, IP rights incentivize the development of socially beneficial innovations such as life-saving medicines and other productive technologies (Arrow 1962, Cockburn and Henderson 1998, Somaya 2012). IP rights also influence competition. They confer market power on firms that possess technological capabilities and innovations (e.g. Griliches 1990), thereby enabling the generation of lasting competitive advantages in rapidly changing markets. Accordingly, firms attempt to develop and defend their IP rights as well as undermine the power of rivals' IP (Somaya 2003, Ziedonis 2004, Polidoro and Toh 2011). Apart from such proprietary and defensive IP strategies (see Somaya 2012 for a review), firms may also leverage their IP through collaborative licensing agreements (Teece 1986, Arora and Fosfuri 2003) and participation in standards development (Shapiro and Varian, 1999; Leiponen, 2008). Still, bargaining failures in markets for technology and standards development are common, hindering the creativity of other firms and blocking the dissemination of valuable technologies (e.g. Jones et al. 2021, Galasso and Schankerman 2015). Consequently, in some markets, the societal costs of IP rights may exceed their benefits (Jaffe and Lerner 2011).

In this study, we examine the consequences of conflicts over IP. In particular, our interest lies in examining the private and public benefits that accrue when firms challenge others' IP (such as patents) and seek to remove exclusionary rights in an innovation ecosystem. As IP rights have unclear boundaries and are characterized as "probabilistic" rights (Lemley and Shapiro 2005, Somaya 2003), a formal examination in court is required to ascertain their validity. Firms may therefore, attempt to weaken rivals' IP rights through legal contestation. Furthermore, the America Invents Act of 2012 created new examination processes to make it easier to challenge patents via an administrative review by the Patent Trial and Appeals Board (PTAB). The intent of PTAB was to weaken the market power of Patent Assertion Entities that were deemed to expropriate excessive value from high-tech product innovators

(Reitzig et al. 2007). Indeed, after 2012, it has become significantly easier to remove questionable patents, regardless of ownership, from the U.S. economy.

We suggest that while contestation of IP is a sign of innovation competition, the outcomes of such contests present dialectical expectations for challenging firms. On one hand, prior research notes that, “successful challenges of validity generate positive externalities” (Lanjouw and Schankerman, 2001; Anton and Yao, 2003). This implies that when the legal systems invalidate contested IP, it opens free spaces for not only the challenging firm but also other innovating firms. Innovating firms may then develop alternatives or freely use the original IP for their technology innovation. On the other hand, an often-overlooked aspect of such contestation pertains to when the IP in question is enforced in court or a failure to invalidate occurs. IP conflicts tend to arise for more valuable IP because such assets are worth enforcing or contesting (Lanjouw and Schankerman 2001). Thus, when the IP in question survives the scrutiny of institutional review involving courts and administrative processes, it suggests that the associated rights are legitimate. Such validating outcomes from IP contests may result in strengthening the bargaining power of the IP holder, with a potential adverse or chilling effect on subsequent innovation activity.

We explore these issues in the context of standard development and IP competition in wireless telecommunication. Wireless telecom is a high-tech industry that relies on patents to protect key inventions. Each telecommunication product and network component are likely to contain multiple patented inventions. Some of these patents may be related to 5G communication standards and become essential for anyone implementing the standard. These standard-essential patents (SEPs) are some of the most valuable IP rights because the patent holder may be able to force all other firms in the industry to pay royalty fees to implement the standardized features while preventing rivals from creating similar or related features of their own. Thus, SEPs are the most restrictive assets in that they can deter rivals from competing in a specific technology space. Therefore, getting rid of or invalidating SEPs of rivals is highly desirable for any firm operating in this market.

Our findings reveal that, indeed, IP rights in the 5G standard development community constrain the development of new technological features as well as patenting activity. When the administrative review at PTAB invalidates an SEP, it opens a free space for firms in the corresponding standards development community, spurring them to initiate new technical features as well as patent applications. Notably, failure to invalidate an SEP has an almost equal and opposite effect, portending a stronger competitive advantage for the SEP owner in the standards development innovation ecosystem. Thus, failure to invalidate is not a neutral outcome.

These findings provide important insights regarding IP contests in innovation ecosystems. First, by considering the impact of such contests on the broader innovation community, our study highlights the externalities of such contests that extend beyond the dyad involving the IP owner and challenging firm (e.g. Jones et al. 2021). Second, while most studies focus on the outcome associated with IP right invalidation, we draw attention to how failure to invalidate can have a deterrence effect (e.g. Clarkson and Toh 2010). In this manner, our study provides a more complete account of the positive and negative externalities of IP right contests. Third, our standards development context allows for examining the impact of IP right contests not only on firms' subsequent patenting activities but also on changes to technical standards. This is a crucial distinction because while patenting outcomes point to firm-specific or private gains, the introduction of new technical features can yield broader societal or public benefits by improving an open technological standard. Taken together, these findings suggest that while IP right challenges can open free spaces and facilitate the creation of public and private goods, such contests are not without risks. Institutional processes for invalidation may unexpectedly reveal the technological strength of the targeted firms and their IP rights, thereby deterring innovation by others.

THEORETICAL FRAMEWORK

Standards Development and IP Rights

While IP rights such as patents are a key asset for firms in high-tech competition, they may also facilitate follow-on innovation through cooperative agreements between the patent holders and subsequent innovators. Still, the outcomes of licensing agreements in terms of how profits from subsequent

innovations are distributed depends on the strength of the patent and bargaining powers of the parties (e.g. Scotchmer 1991, Arora and Gambardella 2010). Licensing negotiations have become especially contentious in the context of technology standards development (Shapiro 2000, p. 122).

Open interoperability standards represent a critical technological resource for the communication and computing industry, a type of public good that is available for all and free of charge. Still, standards are distinct from other open systems such as open-source software (Hippel and von Krogh 2003, Murray and O'Mahony 2007) in that standards may contain technological features that are covered by SEPs that must be licensed from the patent holder to implement the standard. Thus, although the standard specifications themselves are free, firms must license or cross-license certain SEPs and features to bring the technology product or service to market (Shapiro 2000, Katz and Shapiro 1985). Despite cooperative agreements, SEPs often become "blocking patents" that hold up subsequent innovation or product development by firms who possess complementary technology (Shapiro 2000, Galasso and Schankerman 2015).

Against the backdrop of such patent conflict, Jones et al. (2021) model the choices of communication technology firms participating in standards development as a prisoners' dilemma of cooperation. Firms can cooperate by contributing to standards and obtain three types of benefits: public benefits in the form of standards that are available to all, club benefits that are available to firms that work together in standards committees and gain valuable technological knowledge in that way, and private benefits that require developing features protected by SEPs. Cooperation requires R&D effort, but if the firm creates patentable contributions and hence private benefits, it can receive royalty revenue. The authors examine when and why firms cooperate and thus contribute to standards, including public and club benefits, even when acrimonious patent disputes arise, such as efforts to invalidate IP rights. Their empirical finding is that cooperative behavior is surprisingly robust to conflict events in an ecosystem where firms depend on each other's contributions for market access and performance. There are thus significant opportunities and strong incentives in an interdependent technological ecosystem for

cooperation and the creation of broader club and public benefits of innovations that go beyond the private benefits of patents.

Patent Invalidation Appeals and Implications for Standards Development

Meanwhile, firms involved in standard development may have varying capabilities to participate in the patent race (e.g. Somaya 2012) and thereby appropriate different private benefits or club benefits from the cooperative ecosystem (Jones et al. 2021). Developing patented technologies in a high-tech industry requires large and sustained investments in R&D and, as a result, most patents are owned by a few leading firms. This concentration of IPR results in what Heller and Eisenberg (2000) termed as the “tragedy of the anticommons,” resulting in the underutilization of privately owned innovations—the antithesis of Hardin’s (1968) “tragedy of the commons” highlighting the costs of overuse of a scarce public good. Given the barriers to licensing (e.g. Scotchmer 1991, Green and Scotchmer 1995, Shapiro 2000), firms are thus interested in invalidating and removing rivals’ patents from the standard development ecosystem. If successful, such moves open technological space for all firms to enter and start innovating features for the ecosystem (Anton and Yao 2003, Galasso & Schankerman 2015).

Prior research has examined the implications of patent invalidation via regular court proceedings. For example, Galasso & Schankerman (2015, 2018) found that the rivals of the invalidated patent holder increased their patenting, particularly if the patent holder was a large and dominant firm (one of the industry leaders). This happens because a large and well-resourced firm is more capable of enforcing its patents than a smaller firm with less legal or financial capacity to use in the courtroom. Furthermore, per Gaessler et al. (2024), the invalidated patent subsequently gains prior-art citations, suggesting that the rivals of the invalidated patent holder enter the newly opened technological space. Thus, while patents can incentivize innovation, they also constrain innovation and technology adoption in the industry.

We study the implications of patent invalidation proceedings at the U.S. Patent Trial and Appeal Board (PTAB) in mobile communications standard development ecosystem. Communication and computing systems are complex technological systems that can exhibit strong indirect and direct network effects (Arthur 1989, Lerner and Tirole 2015). Owing to such network effects, per Jones et al. (2021),

standardized communication systems provide broader incentives beyond patents to create technological features. Thus, such systems may create significantly more value when they open up to include components and complementary elements from a larger number of providers than when they remain closed and controlled by a single or a small number of innovators.

A complex communication system needs to be modularized, and the interfaces between the modules need to be standardized (Ethiraj and Levinthal 2004). The development of interface standards for a large communication or computing system can take years and involve thousands of inputs by hundreds of firms across countries (e.g. Leiponen 2008, Vasudeva, Alexander and Jones 2015). Consequently, technology contributors and system implementors must navigate a complex landscape of standardized features and patented technologies. Even when the community requires patent licensing under fair, reasonable and non-discriminatory (FRAND) terms, patent litigation is quite common. This is because the licenses are negotiated privately and bilaterally ex post whereas FRAND commitments, at best, reflect “loose price agreements” based on ex-ante technology competition (Lerner and Tirole 2015, see also Rysman and Simcoe 2011).

We consider two possible outcomes of petitions made at the PTAB: the patent challenge is either instituted and moves to a trial, or alternatively, the case is not instituted and the patent validity review is completed. In the first scenario, when a patent is instituted and examined in a PTAB trial, there is a high likelihood that some or all of its claims are invalidated based on prior art or patentability. After complete or partial invalidation, we expect a significant increase of follow-on innovation (FOI) in standard development. Interestingly, FOI can take many forms in the standard-development context. It can involve patented invention which aims to capture private benefits from the standardized system via SEPs (Rysman & Simcoe 2008). FOI can also take the form of unpatented standardized features that aim to capture club benefits from the standard. Club benefits include the returns on the development of specifications that benefit a small group of firms that cooperated to develop the specifications (Bar & Leiponen 2014). Finally, FOI in standard-development can also entail the development of standardized elements that generate primarily public benefits that enhance the value of the whole system and thereby

increase its potential market demand. Submissions such as general technical reports, tests, and documents provide information for the whole ecosystem rather than benefits that are immediately appropriated by a subgroup.

In the second scenario, the contested patent may survive the scrutiny of the PTAB during the initial review and not get instituted, meaning its claims will not be invalidated. The AIA established the PTAB with the goal of improving patent quality by streamlining the legal and administrative processes and reducing costs for petitioners. Thus, a failure to invalidate the contested patent can reveal the technological and market strengths of the patent holder and send a powerful “keep out” signal to others in the technical community (Clarkson and Toh, 2010). Therefore, we suggest that while patent invalidation results in the expansion of private benefits and public goods through increased follow-on innovation by other firms, by surviving the PTAB review, the patent owner’s deterrence on subsequent innovation is strengthened.

EMPIRICAL ANALYSIS

Context

3GPP. The Third Generation Partnership Project (3GPP), a standards development organization (SDO), sets mobile telecommunication standards globally. It has hundreds of members that contribute to standards development, including mobile carriers, network and handset manufacturers, and other information and communication technology firms; interested nonprofits and governmental agencies; universities; and other standards bodies. Standards development occurs in working groups (WGs), which consist of engineers and experts who work for 3GPP members. WGs normally meet quarterly to review and approve corrections and enhancements to existing technical specifications (TSs) within their purview. They also consider proposals for larger work items that can result in new TSs.

Each TS constitutes a specific agreed-upon solution for a technical domain. For example, TS 29.562 is the specification for “5G Home Subscriber Server services,” which defines how users are authenticated and authorized on the network. 3GPP coordinates TS corrections and enhancements using a release schedule. It releases the latest TS updates every one to three years, as shown in Figure 1. The

work on 3G specifications began in 1996 and were introduced over four major releases (Release 1999 to Release 7, in 2003). 4G LTE specifications were introduced over 7 releases (Release 8-14, between 2008 and 2017), with work beginning in 2006. Finally, 5G specifications, the development of which started in 2016, were introduced over 5 releases (Release 15-19) through 2024. Over time, some specifications were withdrawn, and nearly all were corrected or enhanced.

Member firms often patent the technologies and solutions they introduce into 3GPP standards. Such patents are considered “standard-essential” because their intellectual contributions form the foundation of the TSs. They also create private benefits for the patenting firms. Specifically, the owners of SEPs license their IP to mobile telecommunication hardware, software, and service providers, thereby gaining royalties or licensing revenue. At times, licensors and licensees disagree about the fair value of SEPs, which can lead to a breakdown of licensing negotiations. This often leads to litigation. SEP owners sue licensees for patent infringement, and licensees countersue patent owners on antitrust grounds. In such countersuits, licensees claim that patent owners are breaking their obligation to license their IP on fair, reasonable, and non-discriminatory (FRAND) terms, which patent owners agreed to in the first place as a condition for having their IP included in 3GPP standards.

PTAB. The Patent Trial and Appeal Board (PTAB) began operating in September 2012. It removes the burden on federal district courts to adjudicate some patent-related suits, including those dealing with 3GPP SEPs. The PTAB allows a petitioner to file a challenge, called an *inter partes* review, against a patent owner when the petitioner believes the patent is invalid. Thus, while PTAB does not adjudicate antitrust complaints of FRAND terms brought by licensees, it does offer a different and less-costly avenue of relief from royalty payments: attack the contested patent directly by challenging its validity.

Figure 2 illustrates the institutional process and timeline of a PTAB proceeding. After a petition is filed, the patent owner has an opportunity to respond and argue against institution. The PTAB then issues an institution decision, typically within about six months of filing, determining whether there is a reasonable likelihood that the petitioner would prevail with respect to at least one challenged claim. If the

trial is denied, the proceeding ends at this stage, effectively affirming the patent's validity. A case may also be settled before an institution decision is made, as shown in Figure 2. If the PTAB institutes a trial, the case proceeds to a phase that culminates in a final written decision (FWD), usually within twelve months of institution. In the final written decision, the panel of administrative judges may find all claims unpatentable, invalidate only a subset of claims, or uphold all challenged claims. The parties may also settle after institution but before a final written decision is issued, as depicted in Figure 2. Figure 3 summarizes the distribution of these institution decisions and final outcomes for PTAB cases involving 3GPP-related SEPs.

Firms who file PTAB petitions have often been sued by the patent owners in federal court for infringement about a year before their PTAB filing, based on the PTAB's historical data. It then takes about 2 quarters for the PTAB judges to reach a decision on whether to institute a trial. If it moves to trial, the final written decision is issued 4 to 6 quarters after the institution decision. The panel's decision to institute a trial normally leads to a negative outcome for the patent owner. That is, the most likely outcome is that a patent's claims will be invalidated (see Figure 3).

Sample

We retrieved all 3GPP TSs and their enhancements through September 2024 from 3gpp.org. Some TSs, particularly those created before 3G, were superseded by other TSs, but we deemed them as the same TS for our analysis because the preceding and superseding TSs possessed the same technical foundation and scope. We downloaded 3,423 TSs in total.

TS enhancements were captured by change requests with "B" or "C" designations that identify additions or deletions of features or functional modifications of features. Change requests with these designations contrast from those that merely correct errors, resolve ambiguities, or align earlier TS versions with the latest versions. Change requests are detailed in "temporary documents," which are presented at working group meetings. Temporary documents are not reused from one meeting to the next, so a change request can appear in multiple documents if it is presented at multiple meetings. We combined temporary documents for the same change request to ensure that each TS enhancement was

counted only once. Each change request lists the firms proposing it. We downloaded 68,330 TS enhancements belonging to 1,270 TSs and proposed by 395 firms.

We retrieved all disclosed 3GPP-related SEPs with U.S. publication numbers through September 2024 from the European Telecommunications Standards Institute (ETSI), which maintains an IP rights database for 3GPP-related SEPs. When firms add SEPs to the IP rights database, they list the TSs with which the SEPs are associated. This allowed us to link SEPs to specific TSs and their enhancements. We downloaded 78,246 SEPs associated with 946 TSs and owned by 128 firms.

We retrieved PTAB trial data through September 2024 from Unified Patents,² an organization that works to deter frivolous patent litigation. Each PTAB case only adjudicates a single patent's claims or a subset of its claims, but a patent's claims may be adjudicated in multiple cases over time. We matched the contested patents in the PTAB cases to the ETSI SEP disclosures. We found 174 contested SEPs associated with 103 TSs in 292 PTAB cases with 39 unique patent owners and 49 unique petitioners.

Data Panel and Variables

We constructed a data panel in which each observation was uniquely identified by TS, firm, and quarter. Our observation window was from 2006 Q1 to 2024 Q3. This period includes all 4G LTE standards development (Release 8-14) and all 5G development to the end of our sample (Release 15-19).

We calculated two outcome variables. *TS enhancements* is the count of a firm's change requests with "B" or "C" designations within a quarter. A change request's date is the date of the meeting at which the change request was proposed. *TS-related patent filings* is the count of a firm's patent filings associated with a TS within a quarter. A patent's filing quarter is based on the provisional patent filing date, which establishes the priority date—or the date from which the patent can be considered prior art. A patent's association with a TS is based on the patent's (eventual) disclosure as an SEP in the ETSI IPR database. In our sample, there was often 3 years between a patent's priority date and its eventual

² No author was compensated by Unified Patents for this research.

publication and disclosure as an SEP. As such, we end our observations for TS-related patent filings in 2021 Q3 instead of 2024 Q3. After 2021 Q3, we cannot reliably match provisional patent filings with specific TSs.

We calculated four PTAB-related explanatory variables. *PTAB decision baseline* is the count of PTAB cases associated with the focal TS that had an institution decision from six quarters before to six quarters after the focal quarter. The PTAB baseline includes cases with a decision concerning instituting a trial, including those that had trials instituted and those that were dismissed (not instituted), but it excludes cases that were settled before the institution decision or were still pending at the end of our sample (see Figure 3). *PTAB institution baseline* is the count of PTAB cases associated with the focal TS that were instituted—meaning the cases had trials set—from six quarters before to six quarters after the focal quarter. It excludes cases that were not instituted. Thus, PTAB institution baseline is a subset of the PTAB decision baseline.

PTAB post-decision (both instituted and not instituted) and *PTAB post-institution* (only those instituted) mirror PTAB decision baseline and PTAB institution baseline, respectively, but they only count cases with PTAB decisions one to six quarters before the focal quarter, not those on or after the focal quarter. In this way, the effect of a PTAB decision will be tracked over the six quarters following the decision. Table 1 presents a stylized example of how these four variables were constructed for any given TS. TS A and B give a simple example of one institution decision: a trial is instituted in TS A but not in B. TS C is more complex. Two trials were instituted in 2013 Q4 and one was instituted in 2014 Q2. Also, two cases were not instituted: one in 2014 Q1 and another in 2014 Q4.

Estimation Approach

Firms that participated in a TS which had at least one related PTAB case with an institution decision (either instituted or dismissed) were included in our study, which reduced our examination to 97 TSs and 449 firms. These 97 TSs were the most active and held the most patents. A decision by the PTAB panel of judges to institute a trial “treated” all firms involved in the TS to which the contested patent was related. We consider this decision a treatment because the institution event signals to firms that some or

all of the contested SEP's claims are very likely to be invalidated once the final written decision is issued, which is a win for the petitioners. On the other hand, a decision to dismiss the case placed all firms involved in the related TS in a “control” group. A dismissed case leaves the SEP in place and removes uncertainty regarding its validity, which is a win for the patent owner. Importantly, firms are uncertain *ex ante* whether the panel of judges will institute a trial or dismiss the case.

We use a difference-in-differences (DiD) approach to estimate the causal effect of a PTAB institution decision on a firm's (1) technical enhancements within a TS and (2) provisional patent filings related to the TS. For any given firm i and TS s , we observe the number of enhancements by firm i introduced in s during the 6 quarters following the treatment quarter and compare it to the number of enhancements firm i introduced in s during or up to six quarters before the treatment quarter. We observe the same for the number of provisional patent filings as well. Because we are observing counts, we model outcome Y for firm i in TS s at quarter t as a negative binomial distribution, $Y_{ist} \sim \text{NegBin}(\mu_{ist}, \mu_{ist} + \omega\mu_{ist}^2)$, where ω is the dispersion parameter.

If a TS only has one institution decision, as shown in TS A and B in Table 2, then the count explanatory variables simplify to a basic DiD model. In such case, *PTAB post-institution* is equivalent to the interaction of the post-treatment and treated group variables in a DiD specification. However, the occurrence of institution decisions in the sample requires us to modify the usual DiD specification. Specifically, institution decisions (a) are staggered, happening during different quarters, (b) are occurring multiple times for the same TS, and (c) have both trial institution and case dismissal outcomes within the same TS, leading firms in a TS to be both a treatment and control. To account for these complexities, we model the mean μ_{ist} as:

$$\begin{aligned} \ln\mu_{ist} &= \alpha_{is} + \lambda_t + \beta_1 \sum_{l=-6}^6 N_{s(t-l)} + \beta_2 \sum_{l=1}^6 N_{s(t-l)} + \beta_3 \sum_{l=-6}^6 N_{s(t-l)}^{(1)} + \beta_4 \sum_{l=1}^6 N_{s(t-l)}^{(1)} + \varepsilon_{ist} \\ &= \alpha_{is} + \lambda_t + \beta_1 \text{DECISION_BASELINE} + \beta_2 \text{POST_DECISION} \\ &\quad + \beta_3 \text{INSTITUTION_BASELINE} + \beta_4 \text{POST_INSTITUTION} + \varepsilon_{ist} \end{aligned}$$

In this specification, $N_{s(t-l)}$ is the count of PTAB decisions related to TS s at quarter $t - l$, where l is the number of quarters before or after the focal quarter t . When summed together from 6 quarters after to 6 quarters prior to t , it creates the *PTAB decision baseline* variable (*DECISION_BASELINE*) and effectively sets the event window similar to a stacked DiD approach (Cengiz et al. 2019). When $N_{s(t-l)}$ is summed together from 1 to 6 quarters prior to t , it creates the *PTAB post-decision* variable (*POST_DECISION*). For the post-decision variable, we sum the counts before quarter t (not after) because we want to know how the outcome at quarter t is affected by any PTAB decisions in the prior 6 quarters.

Similarly, $N_{s(t-l)}^{(1)}$ is the count of instituted PTAB trials related to TS s at quarter $t - l$. When summed together from 6 quarters after to 6 quarters prior to t , it creates the *PTAB institution* variable (*INSTITUTION_BASELINE*). And when $N_{s(t-l)}^{(1)}$ is summed together from 1 to 6 quarters prior to t , it creates the *PTAB post-institution* variable (*POST_INSTITUTION*).

Because we use a negative binomial model, e raised to a coefficient estimates a rate. In our specification, e^{β_1} estimates the average rate at which a firm's TS enhancements increase or decrease, prior to a decision in which a case is dismissed, for each additional decision. This sets the baseline for other estimates. e^{β_2} estimates the average *change* in the rate of a firm's TS enhancements after the dismissal decision is made. When multiplied together, $e^{\beta_1} \times e^{\beta_2}$ estimates the average rate at which a firm's TS enhancements increase or decrease, after a dismissal decision, for each additional decision.

e^{β_3} estimates a change in rate from e^{β_1} . Specifically, e^{β_3} estimates the average *change* in the rate of a firm's TS enhancements for instituted trials, before the institution decision, over the baseline set by e^{β_1} . Thus, $e^{\beta_1} \times e^{\beta_3}$ is the average rate at which a firm's TS enhancements increase or decrease for each additional instituted trial, prior to the institution decision. Finally, e^{β_4} is the focal DiD estimate. It captures the average *change* in rate of a firm's TS enhancements when a trial is instituted over and above the change in the rate when a trial is not instituted (i.e., a case is dismissed). In this way, it estimates the difference in differences for the rate of TS enhancements.

The parameter α_{is} is a fixed effect for firm i in TS s , and λ_t is a fixed effect for quarter t . We estimated our model using the package *fixest* (Berge, 2018) in the R statistical environment (R Core Team, 2024) that allows for fast estimation of fixed effects (Correia, 2017). We calculated robust standard errors clustered by specification and firm.

Results

Descriptives. Figure 4 shows the average number of TS enhancements and TS-related provisional patent filings per TS from 2006 Q1, the beginning of 4G LTE standards development, to the end of our observation window. It shows that patent filings increased substantially at the introduction of a new generation and then declined.

Table 2 shows the Top 10 firms that introduced TS enhancements. Huawei, Nokia, and Ericsson are the largest contributors, each contributing to more than 600 TSs. Five of the top 10 firms introduced enhancements in TSs that had related PTAB cases. Eight of the 10 owned patents that cited contested SEPs.

TS enhancements. Firms with no enhancements in a TS were dropped from the model, which left 187,939 observations of 274 firms in 92 TSs. The PTAB post-decision estimate was -0.058 ($p < .01$), which indicates that firms decreased their introduction of TS enhancements by 6%, on average, after a PTAB case was dismissed. In contrast, the PTAB post-institution estimate was 0.121 ($p < .01$), which indicates that firms' introductions of TS enhancements were 13% higher, on average, when a PTAB case was instituted than when it was dismissed. In an actively developing TS, firms may introduce 50 enhancements over a 6-quarter period. If 2 SEPs were upheld in such a TS, enhancement introductions would decrease by an estimated $50 \times (1 - 1.00^2 \times 0.94^2) = 6$ enhancements. In contrast, if 2 SEPs were invalidated, enhancement introductions would increase by an estimated $50 \times (0.94^2 \times 1.13^2 - 1) = 6$ enhancements, which is a difference of 12 enhancements based on the PTAB decisions.

TS-related patent filings. Firms with no provisional patent filings related to a TS were dropped from the model, which left 87,126 observations of 88 firms in 89 TSs. The PTAB post-decision estimate was -0.036 ($p < .01$), which indicates that firms decreased their patenting by 4%, on average, after a

PTAB case was dismissed. In contrast, the PTAB post-institution estimate was 0.066 ($p < .001$), which indicates that firm patenting was 7% higher, on average, when a PTAB case was instituted than when it was dismissed. Similar to TS enhancements, firms may file 50 provisional patents related to a TS over a 6-quarter period. If 2 SEPs were upheld in such a TS, new patent filings would decrease by an estimated $50 \times (1 - 0.96^2) = 4$ patents. In contrast, if 2 SEPs were invalidated, provisional patent filings would increase by an estimated $50 \times (0.96^2 \times 1.07^2 - 1) = 3$ patents, or a patent filing difference of 7 when the contested SEPs are invalidated instead of upheld.

Robustness Checks

Industry professionals have noted that firms may over-declare technical specifications (TSs) during standards development, including TS disclosures that are only weakly related to the patent. To address this concern and ensure that our results are not driven by spurious patent-TS linkages, we conduct a robustness check that removes suspicious disclosures. Specifically, we measure semantic similarity between patent texts and the text of the declared TSs using cosine similarity scores computed from TF-IDF representations of the documents. Patent-TS pairs with low cosine similarity scores are excluded from the sample. This procedure restricts attention to disclosures in which the declared TS is meaningfully related to the patented technology. Moreover, we estimate specifications that include TS fixed effects and firm fixed effects, in addition to quarter fixed effects and firm-TS fixed effects, to further absorb unobserved heterogeneity across technologies and firms.

Table 4 reports the results after removing suspicious disclosures. The estimated coefficients and their statistical significance closely mirror those in the baseline regressions. For both TS enhancements and TS-related patent filings, the PTAB post-institution coefficients remain positive and statistically significant, while the PTAB post-decision coefficients remain negative and statistically significant. The magnitudes of the estimated effects are also comparable to those in the main specification. These results indicate that our main findings are robust to excluding potentially spurious patent-TS disclosures and to more stringent fixed-effects controls.

Moderating Role of Technological Prowess

We next examine whether firms' responses to PTAB decisions vary with their technological prowess. To this end, we interact each DiD variable with the logarithm of the firm's cumulative stock of declared SEPs plus one, $\log(\text{Firm SEPs} + 1)$.

Table 5 presents the results. For TS enhancements, the interaction between PTAB post-institution and $\log(\text{Firm SEPs} + 1)$ is small and statistically insignificant, while the interaction between PTAB post-decision and $\log(\text{Firm SEPs} + 1)$ is negative and statistically significant. This pattern indicates that firms with greater technological prowess reduce their TS enhancement activity more strongly following SEP validation. In contrast, following SEP invalidation, the increase in TS enhancements does not differ systematically by firms' technological prowess.

For TS-related patent filings, the moderating effects are more pronounced. The interaction between PTAB post-institution and $\log(\text{Firm SEPs} + 1)$ is negative and statistically significant, implying that the positive effect of SEP invalidation on patent filings is concentrated among firms with lower technological prowess. Similarly, the interaction between PTAB post-decision and $\log(\text{Firm SEPs} + 1)$ is positive and statistically significant, indicating that firms with greater technological prowess are less likely to reduce patenting activity following SEP validation.

Conceptually, TS enhancements can be interpreted as contributions to public goods whereas TS-related patent filings represent efforts to appropriate private benefits within the same technological domain. Combining the results in Tables 4 and 5 yields four key insights. First, when an SEP is invalidated, firms increase their contributions to the public good by introducing more TS enhancements. Second, when an SEP is validated, firms—particularly those with greater technological prowess—reduce their public-good contributions. Third, SEP invalidation increases firms' efforts to appropriate private benefits through patent filings, but this response is driven primarily by firms with lower technological prowess. Finally, SEP validation reduces private-benefit seeking through patent filings, again primarily among firms with lower technological prowess.

DISCUSSION AND CONCLUSION

We have examined the impact of the PTAB *inter partes* review on subsequent innovation within the standard-development community of 3GPP. We examined the review processes of patents that were declared as standard essential for 4G or 5G wireless telecommunication standards developed within 3GPP. We found that when the PTAB panel of judges decides to “institute” the case, meaning that it goes to trial and that the claims of the patent are highly likely to be invalidated, then the other firms that are “at risk” of contributing to the technical specification (TS) are more likely to do so. The other firms are also more likely to file follow-on patents related to the TS. Meanwhile, when the challenged patent is not instituted, meaning its claims are viewed as valid in the PTAB review process, then the other firms associated with the TS are likely to reduce their related contributions and patenting. These effects were statistically and economically significant. The PTAB review decisions thus reveal strategically valuable information and influence the market positions of the affected firms.

Our results are preliminary and in ongoing work we examine various contingencies pertaining to the type and quantity of follow-on innovation. We will focus on several factors that may influence the outcomes.

First, if the holder of the invalidated patent is a large Practicing Entity (PE, as opposed to a Non-Practicing Entity, NPE), we expect the amount of FOI to be greater than if the patent holder is a small PE firm (Galasso & Schankerman, 2014). The hold-up power of a large firm is more significant due to its legal and financial capacity to pursue infringement cases, therefore large firms have a greater impact on FOI than small firms.

Second, if the holder of the invalidated patent is an NPE, we expect the amount of FOI to be larger than if the patent holder is a PE firm of the same size. Patents held and asserted by NPEs tend to have a more severe “chilling” effect on FOI because of their incentives to aggressively pursue infringement cases for monetary compensation instead of cross-licensing that expands freedom to operate (cf. Chen et al., 2023).

Third, if the invalidated patent is a core technology to the patent holder and has a high market value prior to invalidation, the FOI is likely to facilitate entry into the patent holder’s core market (cf.

Gaessler et al., 2024). When the patent was previously utilized to block a valuable market niche, its removal is expected to open opportunities for entry into that market.

Fourth, the invalidation of an SEP held by a large PE will spur FOI by small firms in the standard-development sphere (as opposed to patent filing). Small firms hold fewer resources to participate in the patent race and may instead attempt to open up the market for everyone by submitting unpatented standard specifications, i.e. specifications that generate club or public benefits. By publishing specifications in the SDO, small firms can potentially prevent other firms from attempting to patent these features (cite; Bar, 2006 Defensive Publication).

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Figure 1. 3GPP technical specification (TS) creation and withdrawal by generation and release.

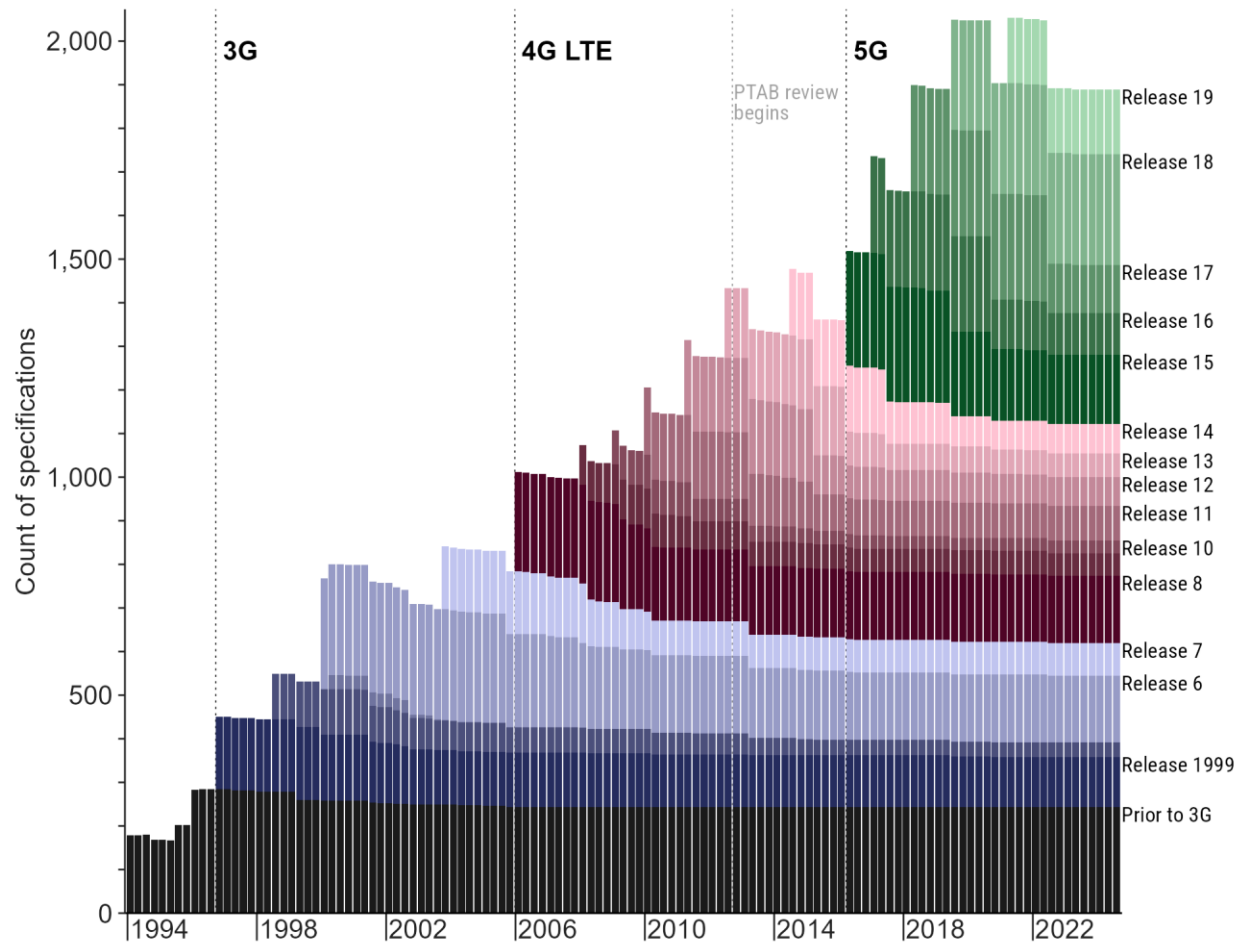


Figure 2. PTAB inter partes review process.

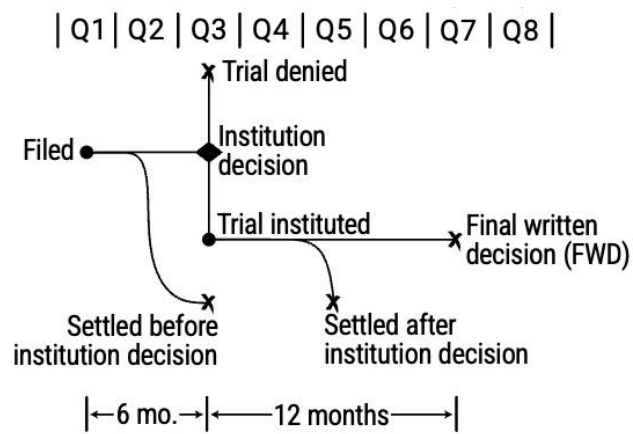


Figure 3. Outcomes of Patent Trial and Appeal Board (PTAB) cases involving 3GPP-related standard essential patents (SEPs).

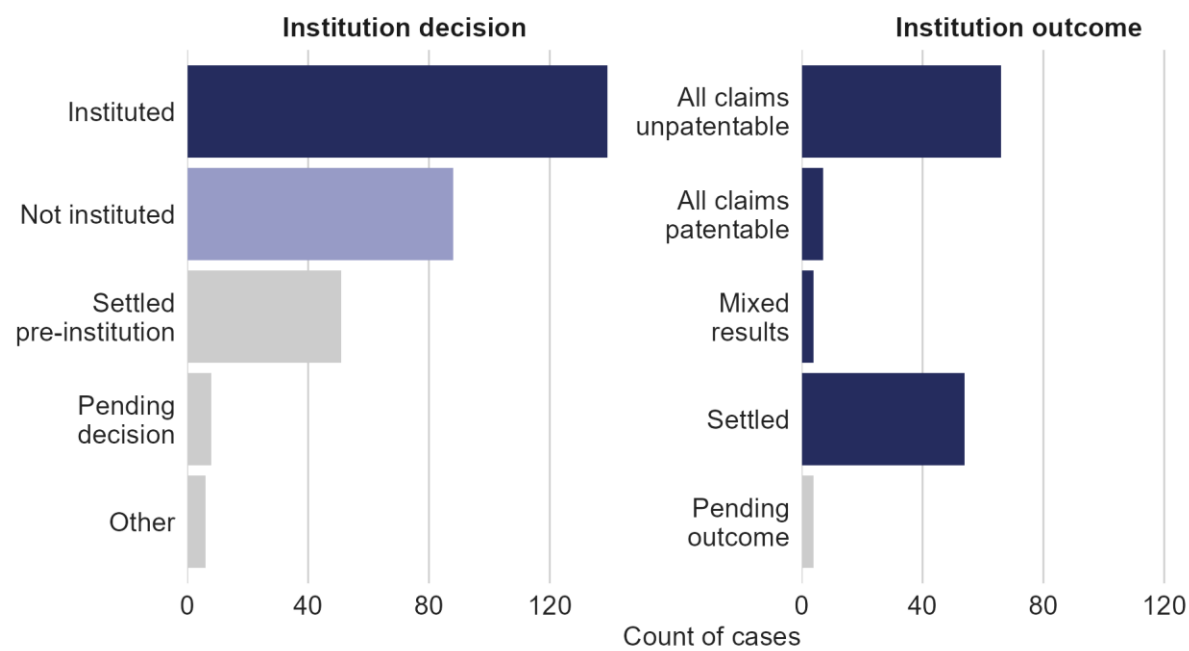


Figure 4. Per-specification average number of TS enhancements and TS-related provisional patent filings for specifications connected to PTAB cases.

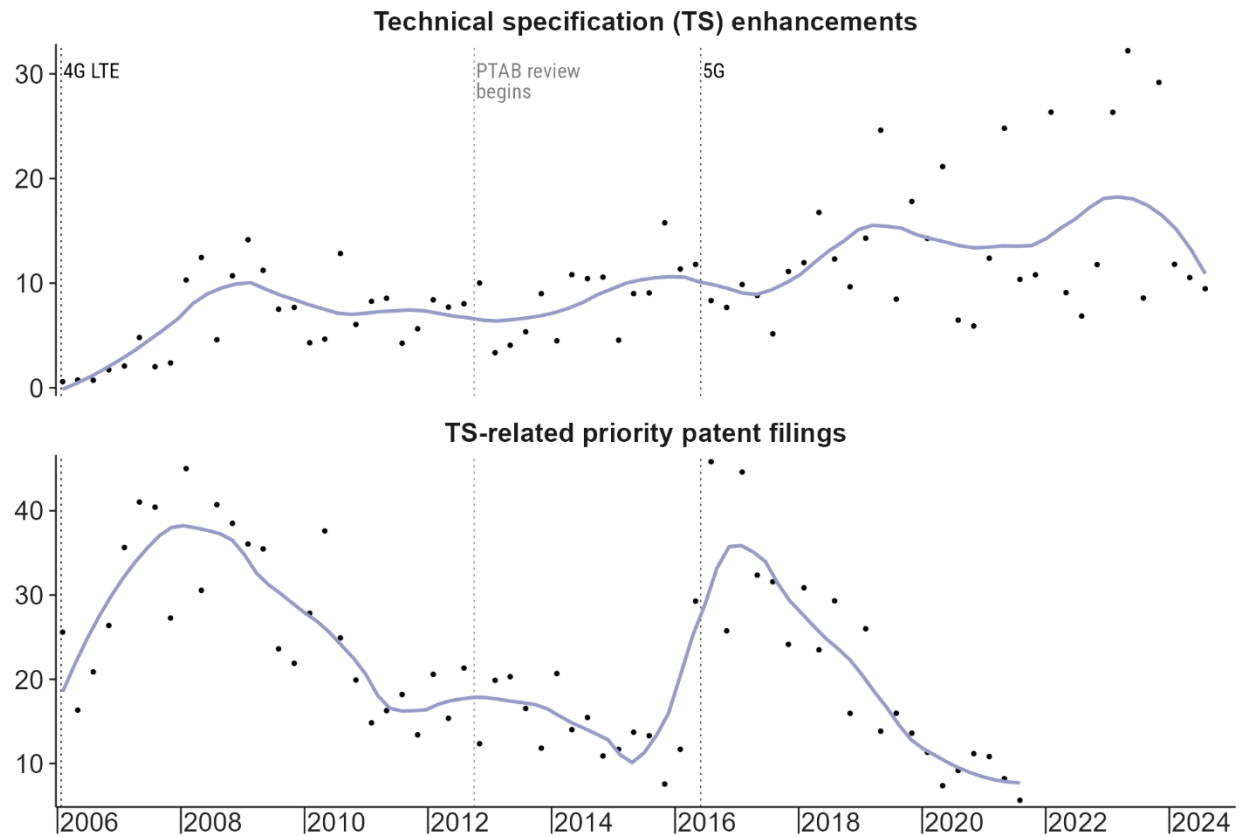


Table 1. Stylized Example of PTAB Count Variables

TS	Firm	Quarter	Institution decision	Trial instituted	PTAB decision baseline	PTAB post- decision	PTAB institution baseline	PTAB post- institution
A	APPLE	2012 Q2	0	0	1	0	1	0
A	APPLE	2012 Q3	0	0	1	0	1	0
A	APPLE	2012 Q4	0	0	1	0	1	0
A	APPLE	2013 Q1	0	0	1	0	1	0
A	APPLE	2013 Q2	0	0	1	0	1	0
A	APPLE	2013 Q3	0	0	1	0	1	0
A	APPLE	2013 Q4	1	1	1	0	1	0
A	APPLE	2014 Q1	0	0	1	1	1	1
A	APPLE	2014 Q2	0	0	1	1	1	1
A	APPLE	2014 Q3	0	0	1	1	1	1
A	APPLE	2014 Q4	0	0	1	1	1	1
A	APPLE	2015 Q1	0	0	1	1	1	1
A	APPLE	2015 Q2	0	0	1	1	1	1
...
B	APPLE	2012 Q2	0	0	1	0	0	0
B	APPLE	2012 Q3	0	0	1	0	0	0
B	APPLE	2012 Q4	0	0	1	0	0	0
B	APPLE	2013 Q1	0	0	1	0	0	0
B	APPLE	2013 Q2	0	0	1	0	0	0
B	APPLE	2013 Q3	0	0	1	0	0	0
B	APPLE	2013 Q4	1	0	1	0	0	0
B	APPLE	2014 Q1	0	0	1	1	0	0
B	APPLE	2014 Q2	0	0	1	1	0	0
B	APPLE	2014 Q3	0	0	1	1	0	0
B	APPLE	2014 Q4	0	0	1	1	0	0
B	APPLE	2015 Q1	0	0	1	1	0	0
B	APPLE	2015 Q2	0	0	1	1	0	0
...
C	APPLE	2012 Q2	0	0	2	0	2	0
C	APPLE	2012 Q3	0	0	3	0	2	0
C	APPLE	2012 Q4	0	0	4	0	3	0
C	APPLE	2013 Q1	0	0	4	0	3	0
C	APPLE	2013 Q2	0	0	5	0	3	0
C	APPLE	2013 Q3	0	0	5	0	3	0
C	APPLE	2013 Q4	2	2	5	0	3	0
C	APPLE	2014 Q1	1	0	5	2	3	2
C	APPLE	2014 Q2	1	1	5	3	3	2
C	APPLE	2014 Q3	0	0	5	4	3	3
C	APPLE	2014 Q4	1	0	5	4	3	3
C	APPLE	2015 Q1	0	0	5	5	3	3
C	APPLE	2015 Q2	0	0	5	5	3	3
...

Table 2. Top 10 Firms Enhancing 3GPP Technical Specifications

Firm	TS enhancements	SEPs disclosed	TSs enhanced	TSs enhanced with PTAB Cases	Contested SEPs cited
Huawei	20,829	21,285	653	16	83
Nokia	19,190	12,378	623	19	42
Ericsson	15,635	3,091	694	13	69
ZTE	4,928	13,515	371	24	12
Qualcomm	4,566	19,471	386	0	104
Samsung	3,918	22,383	292	18	87
Alcatel-Lucent	2,815	154	252	0	7
CATT	2,733	247	231	0	0
Intel	2,373	3,932	263	0	27
China Mobile	1,852	0	253	0	0

Table 3. Negative Binomial Fixed-Effects Regression

	TS enhancements		TS-related patent filings	
	β	e^{β}	β	e^{β}
PTAB post-institution	0.121 ** (0.046)	1.13	0.066 *** (0.017)	1.07
PTAB institution baseline	0.033 (0.059)	1.04	0.010 (0.020)	1.01
PTAB post-decision	-0.058 ** (0.019)	0.94	-0.036 ** (0.011)	0.96
PTAB decision baseline	-0.004 (0.023)	1.00	0.008 (0.009)	1.01
Quarter fixed effects	Included		Included	
Firm-TS fixed effects	Included		Included	
Pseudo Adj. R-square	0.163		0.174	
Observations	187,939		87,126	
Quarters	75		63	
TSs	92		89	
Firms	274		88	
Firm-TS combinations	3,050		1,782	

Cluster-robust standard errors, clustered by technical specification (TS) and firm, in parentheses

** $p < .01$, *** $p < .001$

Table 4. Negative Binomial Fixed-Effects Regression after Removing Suspicious TS Disclosures

	TS enhancements		TS-related patent filings	
	β	e^{β}	β	e^{β}
PTAB post-institution	0.132 ** (0.047)	1.14	0.049 *** (0.013)	1.05
PTAB institution baseline	0.018 (0.065)	1.02	-0.013 (0.030)	0.99
PTAB post-decision	-0.059 ** (0.023)	0.94	-0.024 * (0.011)	0.98
PTAB decision baseline	0.002 (0.026)	1.00	0.015 (0.012)	1.02
Quarter fixed effects	Included		Included	
TS fixed effects	Included		Included	
Firm fixed effects	Included		Included	
Firm-TS fixed effects	Included		Included	
Pseudo R-square	0.201		0.232	
Observations	116,936		52,726	
Quarters	55		43	
TSs	91		82	
Firms	227		103	
Firm-TS combinations	2,464		1,533	

Cluster-robust standard errors, clustered by technical specification (TS) and firm, in parentheses

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 5. Negative Binomial Fixed-Effects Regression: Moderating Role of Technological Prowess

	TS enhancements		TS-related patent filings	
	β	e^{β}	β	e^{β}
PTAB post-institution	0.131 ⁺ (0.068)	1.14	0.196 *** (0.053)	1.22
PTAB institution baseline	-0.097 (0.075)	0.91	-0.059 ⁺ (0.035)	0.94
PTAB post-decision	-0.021 (0.031)	0.98	-0.066 ** (0.023)	0.94
PTAB decision baseline	0.020 (0.029)	1.02	0.055 *** (0.015)	1.06
PTAB post-institution × log(Firm SEPs + 1)	0.001 (0.007)	1.00	-0.033 ** (0.011)	0.97
PTAB institution baseline × log(Firm SEPs + 1)	0.025 *** (0.007)	1.03	0.010 (0.008)	1.01
PTAB post-decision × log(Firm SEPs + 1)	-0.009 * (0.004)	0.99	0.010 ** (0.004)	1.01
PTAB decision baseline × log(Firm SEPs + 1)	-0.003 (0.003)	1.00	-0.009 ⁺ (0.005)	0.99
Quarter fixed effects	Included		Included	
TS fixed effects	Included		Included	
Firm fixed effects	Included		Included	
Firm-TS fixed effects	Included		Included	
Pseudo R-square	0.201		0.233	
Observations	116,936		52,726	
Quarters	55		43	
TSs	91		82	
Firms	227		103	
Firm-TS combinations	2,464		1,533	

Cluster-robust standard errors, clustered by technical specification (TS) and firm, in parentheses

⁺ $p < 0.1$, * $p < .05$, ** $p < .01$, *** $p < .001$