Standard-Setting and the Incentives to Innovate: Evidence from the IEEE Patent Policy Update

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Abstract

This paper investigates how stricter licensing rules affect firms' incentives to innovate in standard-related technologies. I study the 2015 patent policy revision by the Institute of Electrical and Electronics Engineers (IEEE), which limited SEP holders' ability to seek injunctions and encouraged royalties based on the smallest salable unit. Using a continuous difference-in-differences approach, I show that the new policy increases standard-related patenting, with the strongest effects among firms furthest from the standards' technology space. However, the effects differ across firm types. SEP holders reduced their innovation activity, consistent with weaker royalty incentives, while non-SEP firms expanded patenting, benefiting from lower licensing costs and new opportunities to reposition themselves. Although the policy created challenges for SEP owners, my results suggest that the broader increase in innovation among other firms outweighed these declines. These results highlight how patent policy design within standard setting organizations can reallocate innovation incentives across firms.

JEL Classification: O31, L15, O34, L44

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1 Introduction

Technology standards play a crucial role in the Information and Communication Technology (ICT) sector, where independently designed innovations need to interoperate. These complex systems demand collaboration among firms to ensure that technologies, products, and services are compatible. Standard setting organizations (SSOs) facilitate this process by coordinating the development of standards with contributions from various stakeholders. One of the SSOs' most critical functions is regulating the licensing of standard-essential patents (SEPs), intellectual property rights essential for implementing these standards (Bekkers et al., 2014).

Licensing rules for SEPs have long been a controversial topic, drawing attention from both academics and legal experts[1]. Since the early 2000s, concerns have arisen about the potential for opportunistic behavior by SEP holders (Lemley and Shapiro, 2006; Farrell et al., 2007; Geradin and Rato, 2007; Ganglmair et al., 2012), leading SSOs to adopt stricter intellectual property rights (IPR) policies.[2] These policy changes seek to balance the incentives for developing essential technologies with the goal of promoting widespread adoption of standards. However, the impact of these patent policies on innovation remains unclear. While tighter licensing requirements may discourage firms from contributing to standards, lenient policies may increase costs for implementers and discourage downstream innovation.

This paper addresses this ambiguity by investigating the effects of licensing requirements on innovation. I focus on a major policy change in 2015 by the Institute of Electrical and Electronics Engineers Standards Association (IEEE SA), which introduced significant revisions to its licensing policy. Using a continuous difference-in-differences approach, I analyze how this policy change affected innovation in standard-related technologies at the firm level. The findings indicate that the IEEE's IPR policy revision led to an increase in standard-related patenting among affected firms, but reduced patenting among SEP-declaring firms.

The 2015 IEEE policy aimed to provide greater clarity around the definition of SEPs

[1] See for example Sidak (2014); Contreras and Gilbert (2015); Bekkers et al. (2022)

[2] For instance, the World Wide Web Consortium, VITA, and IEEE have all implemented more restrictive patent policies. See W3C (2001), VITA (2006), and IEEE (2015).

royalties.[3] In so doing, the revision included two important changes: all entities holding patents that are essential for the standard are strongly recommended to base their royalties on the Smallest Salable Patent Practicing Unit (SSPPU) , and they are constrained in their right to take injunctions against potential licensees of SEPs. Although the policy did not directly cap SEP royalties, it arguably affected SEP holders' ability to collect them by weakening their bargaining position. Injunction restrictions reduced the threat point in negotiations (Contreras and Gilbert, 2015), potentially leading to fewer concluded agreements, while the SSPPU recommendation lowered the benchmark against which royalties could be claimed (Layne-Farrar et al., 2014; Llobet and Padilla, 2016).

The updated patent policy affected not only SEP holders, by impacting their ability to collect royalties, but also had broader implications for firms not directly involved in standards development. By reducing SEP holders' bargaining power and the royalties they could expect to collect, the policy potentially opened new opportunities for firms to innovate with standardized technologies, even if they had not contributed to the original standard-setting process. This demonstrates the broader influence of standardization on innovation, affecting both contributors to and users of standards.

The theoretical literature has extensively studied how licensing commitments influence firms' incentives to invest in standard-related innovation (Layne-Farrar et al., 2014; Lerner and Tirole, 2015; Spulber, 2019). In standard setting organizations, unfavorable licensing requirements may discourage technology developers from investing in, or participating in, standards development. Conversely, strong SEP rights can stifle the adoption of the standard in downstream markets, reducing the returns to innovation. Changes in licensing rules can thus affect standard-related profits, as royalty fees directly affect the costs of adoption and thus the demand for a standard. Stricter licensing rules, however, may promote innovation among vertically integrated firms that are both contributors and implementers. For these firms, SEPs might be valued less for direct royalty revenues and more as strategic assets that strengthen their bargaining position in cross-licensing negotiations and expand the market for their own downstream products that implement the standard (Simcoe and Zhang, 2021).

[3]See *IEEE Request for Business Review Letter*, The United States Department of Justice, September 30, 2014, available at https://www.justice.gov/sites/default/files/atr/legacy/2015/02/17/311483.pdf and *Draft IEEE Standards Board Bylaws: Draft 39 versus Current Policy*.

To analyze the effects of stricter licensing rules, one would need to identify the full range of firms involved in standardization and distinguish their roles between upstream innovators (firms developing technologies incorporated into standards), downstream implementers (firms applying standards to end-user technologies), and vertically integrated firms (engaged in both). However, identifying these types of firms presents challenges due to the complexity of technological overlap across industries [4].

To address these challenges, I employ a novel empirical approach. Using data from the Searle Center Database, PATSTAT, and Compustat, I construct a dataset of companies potentially involved in both upstream and downstream technologies related to IEEE standards in the ICT sector. My sample includes firms that declared at least one SEP for an IEEE standard before the policy change, along with firms active in the same industries and countries as SEP holders, that did not declare SEPs. This allows me to capture different types of firms and their varying responses to the policy revision: SEP holders, likely upstream innovators or vertically integrated firms, and non-declaring firms, which are potential downstream implementers or vertically integrated firms without declared SEPs. Although I observe firms declaring SEPs, distinguishing between pure upstream innovators and vertically integrated firms remains challenging. Furthermore, it is unclear whether non-declaring firms are entirely uninvolved in standards development or participate through other channels.

An additional empirical challenge arises from the fact that licensing requirements affect all firms, though in different directions. To identify the causal effect of adopting stricter licensing rules on firms' standard-related innovation, I need to define an appropriate control group of similar firms unaffected by the policy revision. However, due to the widespread diffusion of technology standards across industries, finding an unaffected sample of firms is difficult.

My approach addresses this by using firms' technological proximity to the standard to define continuous treatment groups. Specifically, I compute the cosine similarity between each firm's patent portfolio and all standards issued by IEEE. This allows me to assess how the 2015 policy change affected firms with varying degrees of involvement in

[4] See Bekkers et al. (2012) for an attempt to identify the business models of firms and the associated limitations.

standardization.

The identification strategy relies on the assumption that firms closer to the standards' technology space provide a good counterfactual for those that are technologically further away. It is motivated by both theoretical predictions and empirical evidence. Empirically, I show that firms declaring SEPs are typically closer to the standards' technology space, confirming that SEP holders are the most involved in developing standard-related innovations. Moreover, firms with different technological ties to the standard behaved similarly before the policy change but diverged afterward. Specifically, firms closely aligned with the standard did not change their innovation effort post-2015. Theoretically, I show that firms less aligned with the standard's technology space are predicted to be more sensitive to variations in SEP holders' ability to collect royalties. This relationship holds across different firm types, whether pure upstream innovators, vertically integrated firms, or downstream implementers.

I, therefore, employ a difference-in-differences approach with continuous treatment, allowing me to assess the intensity of the policy change's effects on different groups exposed to varying levels of treatment. I define this continuous treatment based on technological similarity, clustering firms into quartiles. To account for potential spillovers across standards and avoid biases from technological overlap, I control for the technological distance between firms and all IEEE standards. I also adjust for the relative importance of each technology class within a standard when measuring standard-related patenting.

The empirical analysis shows that the IEEE's 2015 policy revision led to a statistically and economically significant increase in standard-related patenting, with the strongest effects among firms furthest from the standards' technology space. The response, however, is non-linear across quartiles: while patenting rises sharply for fourth-quartile firms, the effects for the second and third quartiles are comparable in magnitude. To better understand this pattern, I analyze technological proximity across quartiles and find that second-quartile firms are closer to fourth-quartile firms than those in the third quartile. This suggests that second-quartile firms may benefit from spillovers generated by fourth-quartile firms' intensified patenting activity. Consistent with this interpretation, when I examine patents filed in technology classes unrelated to IEEE standards, I find positive and statistically significant effects of the policy change for the second and fourth quartiles, but no effect for the third.

I further test for the effect of the policy revision on SEP and non-SEP holders. The policy's impact on standard-related patenting differs across firm types. SEP holders in the first quartile, those technologically closest to the standard, show no significant change in standard-related patenting, while SEP holders in the second quartile experience a marked decline. By contrast, non-SEP firms in the second quartile increase their standard-related patenting after the policy revision. To understand these heterogeneous effects, I analyze firms' responses across alternative innovation channels. SEP holders in the second quartile, more reliant on upstream inventions, reduce R&D expenditures, non-standard patenting, and total patenting. This pattern indicates that lower royalty revenues make returns on innovation insufficient for firms positioned further from the standard, and as primarily upstream specialists, they cannot compensate by reallocating resources downstream. SEP holders in the first quartile, instead, are more likely vertically integrated. Although they reduce R&D after the policy change, they offset this by reallocating efforts into other innovation channels, leading to increases in non-standard and total patenting. Lastly, non-SEP holders, particularly in the second quartile, increase both non-standard-related and total patenting despite a marginal decrease in R&D spending. This suggests they benefit from cost relief in deploying upstream inventions and view the new licensing framework as an opportunity to reposition themselves for future SEPs.

Taken together, my findings suggest that stricter licensing rules can stimulate innovation in standard-related technologies at the firm level. Although SEP holders experience a decline in patenting, the overall increase in innovation among other firms outweighs this effect.

Contribution to the literature. This paper contributes to the literature on licensing and innovation in the context of standardization. Prior economic research has extensively examined the relationship between standardization and patenting, with particular attention to the economic impact of standard-essential patents (Rysman and Simcoe, 2008; Lerner and Tirole, 2015) and the strategic considerations underlying firms' decisions to declare intellectual property ownership at standard organizations (DeLacey et al., 2006; Bekkers et al., 2011; Hussinger and Schwiebacher, 2013; Layne-Farrar et al., 2014). I contribute to this literature by adopting a broader definition of standard-related patenting and by emphasizing the roles of both upstream innovation and downstream standard-related technologies.

Further research has extended this literature by exploring the role of firms' technological positioning in their involvement in standards development. This literature has analyzed the technological distance between firms, focusing on membership in standard consortia (Baron and Pohlmann, 2013), committees (Bar and Leiponen, 2014), and submission of technical contributions (Rosa, 2019) as indicators of participation in standard setting. However, these studies have not directly examined how the alignment between a firm's technological capabilities and the standard's technological domain shapes its incentives to invest in standard-related patenting.

Despite the growing literature on technology standards and declared essential patents, empirical evidence of the effect of SSOs' patent policy on innovation is limited (Gandal et al., 2004; Chiao et al., 2007; Bekkers et al., 2017). Gandal et al. (2004) empirically study the interaction between intellectual property and participation in standardization committee meetings in the modem industry. Chiao et al. (2007) theoretically and empirically explore standard setting organizations' policy choices. Bekkers et al. (2017) develop a model to study the link between SSO patent policies and firms' disclosure commitments. In contrast to my work, these papers focus solely on the effect of patent policies on firm participation in standard organizations and the declaration of SEPs. My research extends this literature by estimating the causal relationship between stricter licensing rules and the behaviors of developers and implementers of standard-essential technologies.

In addition to this broader focus, my study directly examines the IEEE policy revision, a topic explored in only a few prior papers, which provide mixed evidence on its impact on standard-related innovation (IPlytics, 2017, 2018; Gupta and Effraimidis, 2018; Simcoe and Zhang, 2021). Simcoe and Zhang (2021), the most comprehensive analysis to date, found little evidence that the IEEE policy change reduced participation in SSOs or innovation by SEP holders. However, their analysis relies on unweighted patent counts and specific committees, focusing primarily on participation through standards' contributions. In contrast, my research introduces a novel identification strategy that allows for a more complete assessment of the policy's net impact on standard-related innovation, accounting for both upstream and downstream activities. I also employ a class-weighted patent count to reflect the relative importance of each technology class for the standard, offering a more nuanced view of standard-related innovation. By providing new insights into the effects of licensing commitments on innovation incentives, my research contributes to the long-standing debate among policymakers, specialists, and SSOs on how technology standards and standard-essential patents should be regulated.

The paper proceeds as follows. Section 2 provides an overview of IEEE and its patent policy revision. Section 3 presents a stylized model that motivates the identification strategy. Section 4 describes the database construction, and Section 5 details the estimation procedure. The results of the empirical analysis and robustness checks are discussed in Section 6. Section 7 concludes.

2 Institutional Setting

The Institute of Electrical and Electronics Engineers Standards Association (IEEE SA) is a globally recognized private standards development organization. Founded in the United States in 1890, it has since expanded its international reach and influence. IEEE SA specializes in creating standards in the fields of electricity, electronics, and telecommunications.[5] Participation requires the payment of a fee, and IEEE SA members enjoy benefits such as eligibility to hold working group positions, vote on standards, assume leadership roles, and participate in elections for IEEE SA governance. However, membership does not obligate contributions to standards development, and most members do not actively participate.[6]

To address potential opportunistic behavior by SEP holders, IEEE SA requires the declaration of essential patents.[7] When an entity believes it holds patents essential to a standard, it must submit a Letter of Assurance (LoA). In this document, the patent holder may choose among three options: (i) to commit to license essential patents on fair, reasonable, and non-discriminatory (FRAND) or royalty-free terms; (ii) to decline such a commitment; or (iii) to provide a blanket declaration without specifying individual

[5] Appendix A.1 provides a detailed explanation of the process followed by IEEE for standards development.

[6] For more information, see IEEE SA Standards Association.

[7] For a detailed discussion of standard-setting organization patent policies, see Bekkers et al. (2017) and Baron and Spulber (2018).

patents.[8]

In February 2015, IEEE SA adopted a major revision of its patent policy, following a process that had begun two years earlier.[9] While the policy revision was not publicly disclosed until 2015, it is likely that members and stakeholders were aware of the organization's intention to amend the policy before its official release.

The policy revision sought to provide greater clarity and reduce uncertainty around SEPs.[10] The revision process was motivated by concerns that ambiguity in the definition of FRAND had led SEP owners and implementers to adopt widely divergent interpretations of what constituted a reasonable royalty.[11] However, a legal debate has since emerged over whether the revisions represent substantive changes, applying only to licensing commitments made after the policy's implementation, or merely clarifications addressing prior ambiguities surrounding the definition of FRAND royalties (Simcoe and Zhang, 2021).[12]

The 2015 revision clarified four aspects of FRAND licensing commitments: (i) the definition of a *Reasonable Rate*; (ii) guidance for calculating royalties and defining *Compliant Implementation*; (iii) limits on the availability of *Prohibitive Orders* (injunctions); and (iv) permissible conditions for *Reciprocal Licensing*.[13] Among these, the two most relevant for firms' incentives to innovate are (ii) and (iii). First, although not binding, firms declaring essential patents were encouraged to base royalty calculations on the Smallest Salable Patent Practicing Unit. This recommendation shifts the baseline for calculating royalties away from the value of the end product, which critics argue effectively lowers the maximum royalties that SEP holders can demand (Layne-Farrar et al., 2014; Llobet and Padilla, 2016). Second, the policy restricted SEP holders' ability to seek injunctions against prospective licensees except under narrow conditions, thereby limiting their bargaining power and reducing the likelihood of licenses being concluded under the threat of exclusion. Notably, this limitation may also incentivize patent infringement: implementers could infer that the worst consequence they face is paying a reasonable royalty (Contreras

[8]See the official IEEE LoA form at IEEE SA Patent Policy Resources.

[9]See supra note 3.

[10]See supra note 3.

[11]These concerns were highlighted by antitrust agencies, including the DoJ, FTC, and European Commission, which criticized vague language in SSO IPR policies and urged organizations to adopt clearer rules. See Simcoe and Zhang (2021) for an exhaustive list of government references.

[12]Appendix A.2 provides a detailed description of the process undertaken by IEEE for the policy revision. See also Zingales and Kanevskaia (2016) for a comprehensive explanation of the IEEE SA policy update.

[13]See supra note 3.

and Gilbert, 2015). Such an expectation weakens the innovation incentives of firms that rely on SEP royalties to recoup investments in standard-related technologies.[14]

The remaining provisions, clarifying that a reasonable rate excludes any value derived solely from inclusion in the standard and specifying reciprocal licensing obligations, are less directly tied to firms' innovation incentives but nonetheless reflect a broader effort to reduce licensing uncertainty. Taken together, these changes are best interpreted not as direct controls on royalty levels, but as measures that weakened SEP owners' ability to enforce and collect royalties, with implications for both upstream and downstream innovation incentives.

The policy update was strongly debated, both for its content and for the process leading to its adoption. Following the revision, several major contributors to IEEE standards, including Qualcomm, Alcatel-Lucent, Ericsson, General Electric, and InterDigital, refused to submit Letters of Assurance under the new policy. These firms, prominent players in the ICT sector, argued that the changes disrupted the balance of power between upstream innovators and downstream implementers of ICT technologies (Teece, 2015). Conversely, some participants in IEEE standards development, including Apple, Broadcom, Dell, Hewlett Packard, Intel, and Samsung, supported the changes. The existence of standards contributors who do not monetize their SEPs indicates that licensing revenue is not always necessary to induce upstream innovation. Some SEP holders, in fact, expressed support for the new policy.

A second major criticism of the policy revision concerned the process itself. The drafting was largely driven by major standard implementers who pursued changes aligned with their interests (Hoffinger et al., 2015; Zingales and Kanevskaia, 2016), while developers of standard-related technologies, who could have provided a counterbalance to manufacturers, were involved only in the final stages of the revision process (Zingales and Kanevskaia, 2016). This imbalance prompted discontent among several stakeholders. Following the revisions, Qualcomm stated that over 15 major technology companies, whose engineers contribute to IEEE standards, objected to the changes but were excluded from the rule-making process. They criticized the lack of open debate on the revisions' merits,

[14] See Appendix A.2 for details of the four elements of the new IEEE patent policy.

consequences, and rationale.[15] InterDigital voiced similar concerns in an open letter to the IEEE and in a public article, highlighting dissatisfaction with the process's lack of transparency and inclusivity.[16]

3 Analytical Framework

In this section, I present a stylized theoretical model that explores how changes in the ability of SEP holders to collect royalties affect firms' incentives to invest in standard-related technologies, conditional on their technological proximity to the standard. The analysis provides theoretical results that guide my empirical strategy.

Building on the framework developed by Baron et al. (2014), I adapt the model to incorporate firms' technological proximity to the standard and to account for both upstream and downstream innovations. For clarity, I present the baseline model with two firms in the industry, i and j. Appendix B extends this model to allow for the general case. Each firm can participate in standard development as an upstream innovator, implement the standard in its inventions as a downstream implementer, or engage in both activities as a vertically integrated firm. For firm i, x_i denotes the number of patented inventions that are essential to the implementation of the standard, while y_i represents the number of patented inventions that deploy the standard. I refer to (x_i, y_i) as the firm's innovative effort. Aggregate upstream and downstream standard-related innovations are $x = x_i + x_j$ and $y = y_i + y_j$, respectively.

In my model, I consider a standard that is developed and deployed within the industry. The standard generates aggregate profits $v(x, y)$, which increase with the number of inventions included in the standard (x) and the number of inventions deploying it (y). For tractability, I assume a linear functional form of the aggregate profits defined as $v(x, y) = 1 + x + \beta(1 + y)$.[17]

The constant term normalizes the legacy stock of standard-related knowledge to one.

[15] *Qualcomm Responds to Updated IEEE Standards-Related Patent Policy*, Qualcomm, February 2015.

[16] *Re: Licensing Assurances and IEEE's 2015 Patent Policy*, InterDigital, March 2015. See also *Why We Disagree with the IEEE's Patent Policy*, March 2015, available at https://www.eetimes.com/why-we-disagree-with-the-ieees-patent-policy/.

[17] The function $v(x, y)$ is specified in reduced form as an aggregate profit function that separates the contribution of upstream inventions (x) from that of downstream implementations (y). This formulation isolates how changes in r reallocate incentives between the two margins. Modeling y as an explicit function of x would mechanically conflate these channels and make the comparative statics harder to be interpreted.

For interpretation, I assume $\gamma_i + \gamma_j = 1$, so that current innovative efforts x and y are measured relative to this baseline. The parameter β scales the contribution of downstream innovation, making the weight of downstream legacy explicit.

I denote $r \in [0, 1]$ as the share of profits accruing to upstream inventions, treating it as an exogenous parameter set by standard setting organizations' licensing rules. This allows the model to isolate how changes in SEP holders' ability to collect royalties affect firms' innovative effort while maintaining tractability. Although the 2015 IEEE policy did not directly cap royalties, its injunction restrictions and licensing recommendations reduced SEP holders' ability to enforce royalty claims, possibly lowering royalty revenues.[18] Therefore, r represents the realized royalty share post-policy. Licensing revenue from upstream innovation is weighted by r and distributed among firms in proportion to their essential patents, $\frac{x_i}{x}$, while $(1 - r)$ weights downstream contributions and is allocated among implementers in proportion to their downstream innovations, $\frac{y_i}{y}$.

The revenue function for firm i is:

$$b_i = (1 + x_i + x_j + \beta(1 + y_i + y_j)) \cdot \left[r \cdot \frac{x_i + \gamma_i}{1 + x_i + x_j} + (1 - r) \cdot \frac{y_i + \gamma_i}{1 + y_i + y_j} \right] \quad (1)$$

I model the technological proximity as $\gamma_i \in [0, 1]$, reflecting the stock of past innovative knowledge and effort in standard-related technologies. For tractability, I treat γ_i as exogenous, capturing the effects of long-term strategic alignment on present revenues without making γ_i a dynamic decision variable.[19] My purpose is to account for asymmetric γ_i effects, enabling the analysis of innovation incentives across varying degrees of royalty revenue r, without introducing additional complexity into the profit function. Notably, I allow γ_i to serve as an intuitive measure of how past innovative effort affects current

[18] Empirical evidence indicates that effective SEP royalties declined after the 2015 policy. For instance, UK and US courts (*Unwired Planet v. Huawei, 2017*; *TCL v. Ericsson, 2017*) enforced SSU-based royalties, lowering rates by 30–50%. The FTC (2016) documented a 15–30% decline in SEP royalties post-2015. Industry reactions also confirm this shift. See *Qualcomm Responds to Updated IEEE Standards-Related Patent Policy*, Qualcomm, February 2015, available at https://www.electronicdesign.com/..., and *Re: Licensing Assurances and IEEE's 2015 Patent Policy*, InterDigital, March 2015, available at http://wpuploads.interdigital.com/.... These studies and industry views justify modeling the policy as a reduction in r.

[19] In principle, firms' short-run innovative choices (x_i) could affect their relative technological position (e.g., through terms such as $\frac{\gamma_i + x_i}{1+x}$). I abstract from this channel because standards evolve slowly, and rankings in SEP ownership are highly persistent over relevant policy horizons (Baron and Gupta, 2018).

incentives without requiring a direct impact on the complexity of the profit function.

Firms choose (x_i, y_i) simultaneously to maximize:

$$\pi_i = (1-\epsilon)b_i + \epsilon \sum_{k=1}^{2} b_k - \frac{x_i^2}{2} - \frac{y_i^2}{2(1+\theta(x_i+\gamma_i))} \tag{2}$$

To develop upstream innovations, a firm incurs a cost $\frac{x_i^2}{2}$. The cost of downstream innovation, $\frac{y_i^2}{2(1+\theta(x_i+\gamma_i))}$, decreases with prior and current upstream efforts $(x_i+\gamma_i)$. Firms with high $x_i+\gamma_i$ can leverage existing infrastructure and knowledge from upstream innovation to deploy downstream inventions. Following Baron et al. (2014), I weight total industry revenue by ϵ to account for imperfect cooperation among firms, thereby relaxing the assumption of joint profit maximization common in the R&D cooperation and standardization literature. The parameter $\theta > 0$ captures cost complementarity between upstream effort and downstream implementation.[20]

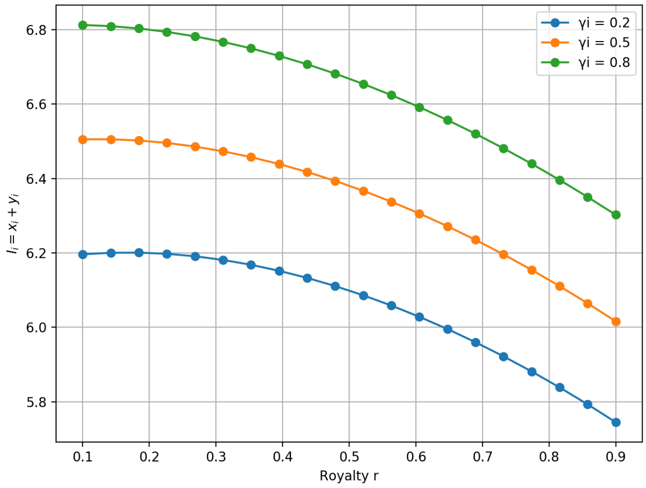
The first-order conditions for innovation decisions are reported in Appendix B. Given the complexity of the system, I rely on numerical simulations to solve for the equilibrium innovation levels and to study their sensitivity to changes in r across different values of γ_i. The cross-partial derivatives of optimal innovative effort with respect to r and γ_i provide the key insights, as they show whether firms technologically closer to the standard adjust their effort more or less strongly when r changes. Results of the implicit cross-partial derivatives are reported in Appendix B and illustrated in Figures 1, 2a, and 2b.

For vertically integrated firms (Figure 1), the cross-partial derivative is negative for all γ_i and r, indicating that a higher r reduces incentives to innovate. Intuitively, because vertically integrated firms both contribute to and deploy the standard, an increase in r shifts payoffs toward upstream royalty income and away from downstream returns. This shift weakens the marginal benefit of additional innovative effort, leading to lower equilibrium innovation even when the firm is technologically close to the standard.

As expected, the effect of a decrease in r depends on the firm's technological proximity,

[20] An increase in upstream innovation x_i or legacy proximity γ_i lowers the marginal cost of implementation and raises the equilibrium response in y_i. Thus, the model captures complementarity between x and y through costs rather than by imposing a functional form $y = y(x)$, preserving both analytical clarity and tractability.

Figure 1
Equilibrium Total Innovative Effort vs. Royalty



The figure plots the distribution of optimal innovations from the numerical simulations, comparing low-γ_i values with high-γ_i values of vertically integrated firms. Parameters are set to $\beta = 2.0$, $\epsilon = 0.5$, and $\theta = 0.5$.

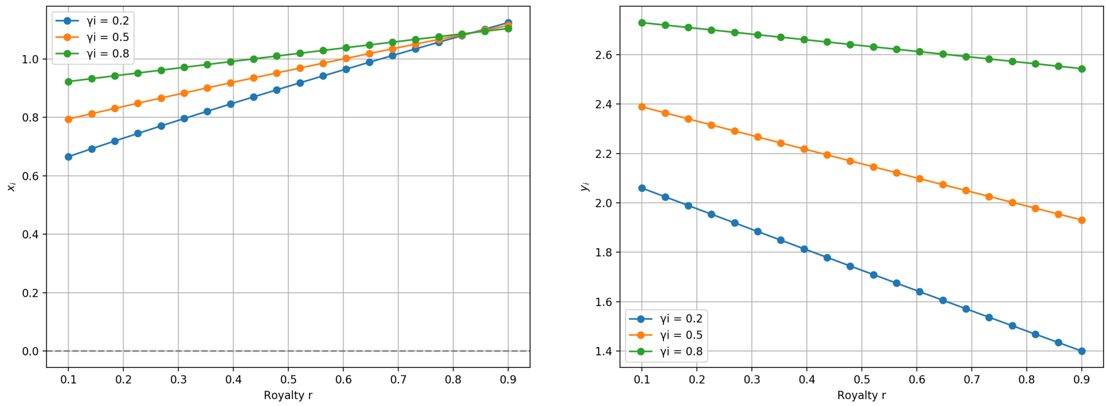
γ_i. Firms with lower proximity respond more strongly to a reduction in r, while firms with higher proximity exhibit weaker or offsetting responses. The intuition is straightforward: firms further from the standard's technological core have greater scope for adjustment, whereas those already close to the standard's technology space face diminishing incentives to invest further. This leads to the following prediction:

Hypothesis H1. *A decrease in r leads to an increase in total innovation for both low-γ and high-γ firms, with a larger increase for low-γ firms.*

To disentangle the effects on x_i and y_i, I separately analyze changes in upstream and downstream innovation (Equation 10). For high-γ firms, upstream effort declines when royalties fall, since their returns are largely tied to licensing revenues. Their downstream adjustment is modest, as strong technological proximity already keeps implementation costs low. By contrast, low-γ firms show little change in upstream effort but respond strongly in downstream innovation, where lower royalties substantially reduce costs and make implementation more attractive.

These patterns reflect three interacting channels. First, a revenue composition effect. High-γ firms rely more heavily on upstream licensing returns, so a fall in royalties directly reduces their incentive to invest in R&D. Second, a cost-relief effect. Downstream costs

Figure 2
Equilibrium Innovative Effort vs. Royalty for Upstream and Downstream Innovators



(a) Upstream contributors (b) Downstream implementers

These figures plot the distribution of optimal innovations from the numerical simulations, comparing low-γ_i values with high-γ_i values. The first graph accounts for the optimal innovations in x_i^* when firms only invest in upstream innovations ($y = 0$). The second graph accounts for the optimal innovations in y_i^* when firms only invest in downstream innovations ($x = 0$). Parameters are set to $\beta = 2.0$, $\epsilon = 0.5$, and $\theta = 0.5$.

fall more for low-γ firms, amplifying their expansion in implementation. Third, a spillover effect. Industry-wide spillovers further reinforce downstream innovation by low-γ firms, while offering only partial compensation to high-γ firms.

The corner cases of pure upstream and pure downstream innovation (Figures 2a and 2b) confirm the same pattern. Upstream-only firms innovate more when r rises, with the effect being stronger for low-γ firms whose marginal licensing returns are most sensitive to changes in r. Downstream-only firms innovate more when r falls, again with stronger responses for low-γ firms, who experience larger marginal cost reductions and benefit more from spillovers. This stronger downstream response among low-γ firms reflects both their greater cost reductions and their broader scope for expanding implementation, which together amplify their incentive to innovate downstream.

Hypothesis H2. *When r decreases, both low-γ and high-γ firms reduce upstream innovation and increase downstream innovation, with the reduction in upstream effort and the increase in downstream innovation being stronger for low-γ firms.*

These predictions form the basis for my empirical strategy. High-γ firms, being less responsive to changes in r, serve as an appropriate counterfactual in a difference-in-differences framework. Comparing innovative behavior across firms with varying technological proximity to the standard, before and after the 2015 IEEE policy revision, allows me to isolate the causal effect of reduced SEP holders' ability to enforce and collect royalties on innovation.

4 Data

My main data source is the Searle Center Database (SCDB), a comprehensive database of technology standards and information on standard setting organizations (SSOs).[21] The SCDB contains 629,438 standard documents issued by 598 SSOs between 1985 and 2018. For this study, I focus on standards related to the ICT sector, specifically those issued by the IEEE, and restrict the sample to the post-2000 period.[22] This selection yields 420 standard documents, each with publication dates, version histories, and identifiers.

In the SCDB, each standard document has a unique document identifier, and declarations referring to the same standard project share a common identifier. However, the term technology standard can vary in meaning. It may refer to a single technical specification[23] or to complex systems described by multiple interrelated documents. Moreover, standards evolve over time, and revision processes differ across organizations.[24]

I standardize the analysis by defining a technology standard as a set of documents linked by a shared version history and identifier. I aggregate information for 136 such standards, referred to hereafter simply as standards. This definition accounts for complementary and substitute documents that collectively define complex systems. By tracking each standard from its first release to final withdrawal, I can observe firms' standard-related patenting behavior over time and study how policy revisions affect their incentives to continue contributing to standard development.

[21]See Baron and Spulber (2018) and Baron and Pohlmann (2018) for a detailed description of the database.

[22]Most SCDB standardization data are from the post-2000 period, reflecting the rapid expansion of standardization activities in the early 21st century. Excluding pre-2000 observations results in minimal data loss.

[23]"A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes, and services are fit for their purpose." International Organization for Standardization (ISO), Standard Definition.

[24]Baron and Pohlmann (2018) show that many organizations issue successive versions of standards, each replacing the former one. Others issue new documents that amend existing standards, in which case previous versions remain active.

The SCDB also contains data on declarations of standard-essential patents, including the declaring entities, declaration dates, patent numbers, and International Patent Classification (IPC) codes for each SEP. From this data, I collect two types of information: the technology portfolio of each standard and the firms developing standard-essential technologies.

To define a standard's patent portfolio,[25] I use the 4-digit IPC classification of SEPs declared before the 2015 policy change, starting from the standard's first publication. This identifies the technology space of each standard. If blanket disclosures are made, however, it becomes difficult to accurately identify a standard's patent portfolio, which may lead to data gaps.[26] Nevertheless, when a standard contains a large share of blanket declarations, relying solely on the observed IPC classes is unlikely to provide a realistic representation of its technological scope and may bias the econometric analysis. To address this, I exclude standards for which more than 25% of IPC classes are missing, leaving 10 standards in the final sample.

To construct the sample of firms for the econometric analysis, I begin with the declaring entities associated with IEEE standards in the SCDB. Among 119 SEP holders, 107 are firms; the remainder are universities, research institutions, or government entities. Because my analysis focuses on firm-level innovation, I restrict the sample to these 107 firms. These firms represent upstream and vertically integrated innovators that both contribute to standardization and develop technologies embedded in the standards.

For the purpose of my analysis, I add firm-level data from Compustat, focusing on R&D expenditure, sales, and employee numbers between 2010 and 2018.[27] These variables are used in the analysis to capture different dimensions of firms' innovative and economic activity. (Hall et al., 2000; Hall and Ziedonis, 2001; Faber and Hesen, 2004). I further restrict the sample to firms with at least five consecutive years of data before and after the policy revision, resulting in 61 SEP-holding firms. From Compustat, I also retrieve firms' industry and country classifications, which I use to identify the broader population of firms potentially affected by the policy change.

[25] See the Empirical Measures subsection for details on the construction of the patent portfolio.

[26] Missing values of the 4-digit IPC classes may result from blanket disclosures or from incomplete observation by the researcher.

[27] Because I collect firms' characteristics from Compustat I focus specifically on publicly listed companies, representing the big players in the ICT sector.

To complete my sample and collect the set of potential downstream innovators, either vertically integrated firms without declared SEPs and implementers, I start by selecting firms active in the same industries and countries as SEP holders, using 4-digit NAICS industry codes. Applying similar data availability criteria yields 1,862 additional firms for inclusion.

To collect firms' innovation activity, I retrieve patent data from the European Patent Office's PATSTAT database, which includes over 100 million patent documents filed worldwide. I collect information on application dates, filing entities, and IPC codes. Because of the lag between application and issuance, all counts are based on unique application numbers, and each patent is attributed to all its associated technology classes.[28] This approach allows me to track firms' R&D investments over time. To avoid double-counting the same invention across jurisdictions, I follow standard practice and identify unique inventions by their original application number, retaining only the earliest filing. This corresponds to using a proxy for patent families as the unit of analysis, rather than raw patent counts.

From the full sample, I identify firms with at least one patent application between 2000 and 2017 in technology classes related to the 10 IEEE standards for which I have data.[29]

To merge patent data with firm data, I use the OECD's Harmonized Applicant Names (HAN) database, which standardizes applicant names across datasets.[30] Because matching errors are common, I retain only firms that can be confidently matched across Compustat, HAN, and PATSTAT. This results in patent data for 36 SEP holders and 507 non-declaring firms, covering approximately 1.2 million patent applications.

After merging firm-level data with standard information, I construct an unbalanced panel of 10 IEEE standards, 543 firms, and 5,053 firm–standard–year observations for 2010–2017. This dataset, spanning 28 4-digit NAICS sectors, provides a rich basis for analyzing how policy changes affecting SEP royalties influence firm-level innovation.

Of the 10 standards in the final sample, eight fall under information technology and

[28] In my sample, patents are linked to an average of 1.68 technology classes.

[29] This initial filter links firms to the relevant technology space and ensures coverage of marginal participants. However, the final analysis sample is more restrictive: merging with Compustat and applying data availability criteria eliminates most marginal or occasional patenters, leaving a set of large, consistently active innovators with substantial patent portfolios.

[30] The OECD HAN database groups variants of patent applicants' names, assigning a common identification number to each unique entity.

two under telecommunications.[31] The standards vary substantially in scope and importance, as reflected in their associated technology classes and the volume of essential patent disclosures.

Turning to firms, SEP holders are typically large corporations, with average annual R&D expenditures of $4,178 million and 107,600 employees. Non-SEP holders are much smaller, averaging $125 million in R&D and 7,600 employees. This size gap extends to patenting: SEP holders file roughly 3,000 patents per year, compared with 130 for non-SEP holders. About half of SEP holders' patents are standard-related (47.2%), only slightly higher than for non-SEP holders (42.2%).[32]

These patterns highlight two points. First, standards differ widely in technological scope and firm engagement, underscoring the heterogeneity of the underlying data. Second, while SEP holders dominate in scale due to their size and resources, non-SEP holders also devote a substantial share of innovation to standard-related technologies. Moreover, SEP holders are themselves heterogeneous, reflecting differences in firm size, technological focus, and innovation incentives.[33] The predominance of large firms among SEP holders may introduce selection bias if analyzed in isolation. It is therefore important to account for the broader population of firms, including non-SEP holders, to assess the full impact of the policy revision on innovation. The complete set of descriptive statistics is reported in Appendix C, Tables 3 and 4.

4.1 Empirical Measures

Because some variables in the analysis are unobserved, I construct empirical proxies to capture the relevant concepts. Below, I outline the key measures used in my analysis.

Standard-related Innovation: According to the theoretical model, changes in SEP holders' ability to enforce and collect royalties on standard-essential patents directly affect firms' innovation in standard-related technologies. The IEEE's policy revision, which

[31] ICT-related standards are identified using the International Classification for Standards (ICS) developed by ISO. Standards with an ICS code of 33 correspond to Telecommunications, while those with code 35 correspond to Information Technology. See ISO's documentation at International Classification for Standards.

[32] The data do not capture the relative importance of patents to IEEE standards. Some patents may also contribute to standards issued by other organizations, which could introduce confounding factors.

[33] This is supported by the high standard deviations among upstream innovators (see Table 7, second column, in Appendix C).

influences licensing returns on SEPs, alters firms' expected profits from innovation and thereby affects their investment decisions.[34]

Ideally, firm-level R&D directed toward technologies covered by IEEE standards would represent the most accurate measure of standard-related innovation. However, data on firms' investments specifically aimed at developing or implementing IEEE standards are not available.

To address this limitation, I follow the methodology proposed by Baron et al. (2014), using the number of patents filed by a firm in technology classes related to a standard as a proxy for standard-related innovation.[35] This approach aligns closely with the theoretical model, which links firms' efforts in standard-related technologies to their technological proximity (γ) and to changes in SEP royalty revenues (r).

First, I identify the relevant 4-digit IPC classes associated with each standard based on the technology classes of SEPs declared essential to that standard. I then count the number of patents a firm files in these standard-related IPC classes as a measure of standard-related innovation.[36]

However, not all technology classes contribute equally to each standard. Some IPC classes may be associated with a larger share of patented inventions essential to a standard. Moreover, certain IPC classes overlap across standards issued by different organizations (e.g., Wi-Fi standards by IEEE vs. cellular standards such as GSM and UMTS by 3GPP). As a result, patents classified under these categories may be jointly related to multiple standards, potentially introducing bias.

To mitigate this issue, I follow the weighting methodology developed by Baron and Pohlmann (2013) and Baron and Pohlmann (2018). This method adjusts patent counts by assigning weights to each IPC class according to its relative importance to IEEE standards. Specifically, the weight (W_{jt}) assigned to each class is determined by the proportion of SEPs declared in that class relative to the total SEPs for standard s in year t. This ensures that technology classes with a larger share of essential patents receive greater weight,

[34] The returns from a firm's innovation investment also depend on factors such as bargaining power in cross-licensing negotiations, portfolio size, the importance of a given invention to the standard, and the standard's adoption rate in downstream markets.

[35] Bekkers et al. (2016) also find that patent applications in standard-related classes are strongly influenced by standardization activities.

[36] Several analyses, such as Baron et al. (2014), confirm the reliability of this measure as an approximation of standard-specific R&D investment.

thereby refining the measure of standard-related innovation. Some SEPs are associated with IPC class zero, indicating a lack of specific classification. Including these would distort the relative importance of other classes, so I exclude IPC class zero from the weighting scheme.[37]

The dependent variable in my analysis is defined as follows:

$$P_{ist} = \sum_{j \in J_s} W_{jt} * PatentFile_{ijt} \tag{3}$$

where J_s is the set of technology classes defining standard s, $PatentFile_{ijt}$ is the total number of patents filed by firm i in technology class j at time t, and W_{jt} is the weight associated with class j, measured as the share of SEPs declared in class j for standard s over the total SEPs for s in year t.

Firms participating in IEEE standardization are formally required to disclose patents essential to the implementation of a standard. In practice, however, compliance with disclosure rules may be imperfect, leaving room for strategic behavior or inadvertent underreporting. For example, firms may fail to disclose certain essential patents due to omission, limited awareness of their portfolio's scope in relevant technical committees, or deliberate non-compliance. In addition, some patents filed in standard-related technology classes may be commercially essential, that is, critical for implementing a standard but not formally declared as essential (Bekkers et al., 2012). Both declared and commercially essential patents are important for assessing the innovative development of a standard.

Moreover, IEEE permits blanket disclosures, which can bias SEP counts downward by underrepresenting a firm's true innovation effort related to a standard.[38] While the number of essential patents alone is a poor indicator of a firm's overall innovation effort, the total number of patents filed in technology classes associated with the standard provides a broader and more comprehensive measure of inventive activity.

Relying on the patenting behavior of firms as a window for standard-related innovation has several limitations. First, while patents reflect innovation outcomes, not all inventions are patented. Firms may choose to keep some innovations secret or refrain from patenting

[37] As a robustness check, I estimate the effect of the policy revision on standard-related patents including IPC class zero in the weights. Results are reported in Table 15 in the Results Section.

[38] Although IEEE allows blanket disclosures, these are relatively uncommon (Bekkers et al., 2017).

if commercial returns are uncertain (Archibugi, 1992; Archibugi and Planta, 1996). Furthermore, not all inventions are patentable, and patent-based measures may underestimate firms' total innovation efforts.

Conversely, firms may engage in strategic over-patenting in standard-related areas to strengthen their bargaining position in cross-licensing or to increase their chances of holding SEPs. In such cases, patent counts may overstate actual innovative effort. Over-declaration of SEPs can also inflate patent counts, introducing upward bias in innovation measurement by including some IPC classes in the standard's technology space that are not relevant. Industry experts and studies estimate that only 10-30% of declared patents are truly essential (Bekkers and Updegrove, 2013), further complicating the accuracy of patent-based innovation measures.[39]

Another challenge is that policy revisions may influence patenting behavior without changing the underlying innovation effort. Stricter intellectual property policies, for example, may alter firms' incentives to patent even if their R&D activity remains constant. Firms may also reallocate R&D toward standards governed by more favorable policies at other SSOs. However, evidence from Simcoe and Zhang (2021) suggests that such shifts in participation are limited, reducing concerns about this channel.

Despite these limitations, weighted patent counts in standard-related IPC classes offer a valuable proxy for firms' innovative efforts related to standards. This measure enables empirical testing of the theoretical model's predictions regarding how firms adjust their innovation activity in response to policy changes, particularly those affecting SEP holders' ability to enforce and collect royalties, across different levels of technological proximity between firms and standards. While the theoretical framework distinguishes between upstream and downstream innovation, my empirical analysis employs a unified measure of standard-related inventions.

Technology Similarity: To measure the similarity between a firm's technological portfolio and the standards, I rely on patent data, drawing on prior methods in the literature (Rosenkopf and Almeida, 2003; Gilsing et al., 2008; Baron and Pohlmann, 2013; Bar and Leiponen, 2014; Rosa, 2019). Using PATSTAT data, I construct a patent portfolio for

[39] This limitation does not invalidate my approach, as I do not directly count declared SEPs but rather weight all patents in related IPC classes. Section 6 discusses this issue in detail.

each firm based on the IPC technology classes in which the firm has filed patents. Similarly, I follow Baron and Pohlmann (2013), who assess the position of standards in the technology space by identifying the IPC classes associated with patents declared essential to a standard, to define the patent portfolios of standards.

Following Baron and Pohlmann (2013) and Rosa (2019), I use the cosine similarity to measure technological similarity between firms and standards. This vector-based method, originally applied by Rosa (2019) to compare SEP holders' technological portfolios, is adapted here to capture the degree of overlap between firms' and standards' patent portfolios. Specifically, the cosine similarity between firm i and all standards $s \in IEEE$ is defined as:

$$TECH_{i,IEEE} = \frac{\vec{S}_s \cdot \vec{I}_i}{\|\vec{S}_s\| \|\vec{I}_i\|} = \frac{\sum\limits_{s \in IEEE} \sum\limits_{j=1}^{J} \sum\limits_{t<2015} \mathbb{1}\left\{IPC_{sjt} = j\right\} \mathbb{1}\left\{IPC_{ijt} = j\right\}}{\sqrt{\sum\limits_{s \in IEEE} \sum\limits_{j=1}^{J} \sum\limits_{t<2015} \mathbb{1}\left\{IPC_{sjt} = j\right\}} \sqrt{\sum\limits_{j=1}^{J} \sum\limits_{t<2015} \mathbb{1}\left\{IPC_{ijt} = j\right\}}} \tag{4}$$

where $\vec{I}_i$ and $\vec{S}_s$ are, respectively, the firm's and IEEE's patent portfolios, and J is the set of IPC classes in which firms patent and SEPs have been declared for IEEE standards. In this measure, the firm's vector $\vec{I}_i = (\mathbb{1}\left\{IPC_{i1} = 1\right\}, \ldots, \mathbb{1}\left\{IPC_{iJ} = J\right\})$ is defined based on the presence of patents in specific IPC classes, where $\mathbb{1}\left\{IPC_{ij} = j\right\} = 1$ if firm i has filed patents in IPC class j.

Similarly, the IEEE vector $\vec{S}_s = (\mathbb{1}\left\{IPC_{s_1 1} = 1\right\}, \ldots, \mathbb{1}\left\{IPC_{s_S J} = J\right\})$ is defined based on the IPC classes associated with patents declared essential to standards issued by IEEE.

The cosine similarity takes values between 0 and 1, where 0 indicates no overlap between a firm's and IEEE's patent portfolios (orthogonal vectors), and 1 indicates perfect alignment (identical technology focus). Unlike Euclidean distance, cosine similarity captures the direction rather than the magnitude of the vectors, making it particularly appropriate for this context, where the number of patents filed in each class could otherwise distort the measure of technological proximity.

This distinction is especially important in the presence of blanket declarations. By focusing on IPC classes rather than raw patent counts, the cosine similarity measure mitigates potential distortions arising from such declarations. Firms may declare SEPs without disclosing specific patent details, thereby inflating the apparent size of a standard's patent portfolio. However, because declared SEPs typically cluster within particular IPC classes, measuring similarity at the class level reduces the risk that blanket declarations bias the observed technological proximity between firms and standards.[40]

Although the cosine similarity approach mitigates bias from blanket declarations, over-declaration of SEPs can still introduce non-standard-related IPC classes into the standard's portfolio, potentially inflating the measure of technological proximity. Nonetheless, given the high degree of IPC class overlap across standards in the ICT sector, the number of technology classes unrelated to a given standard but still included in its portfolio is likely to be small.

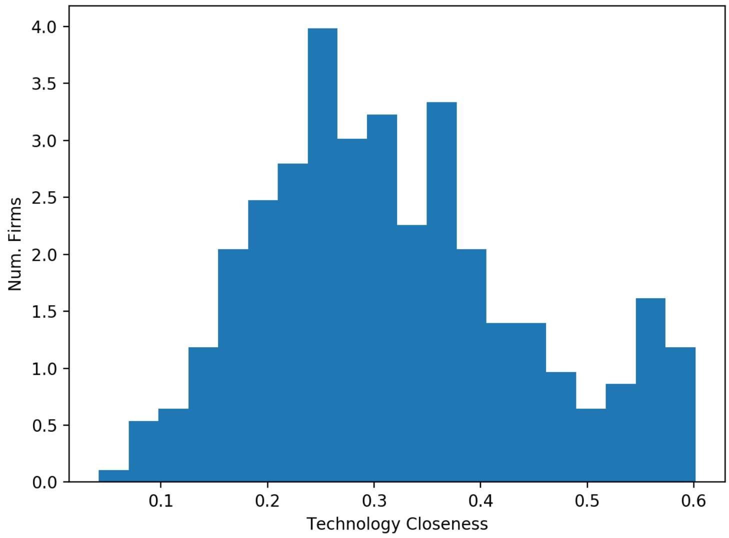
This empirical measure of technology similarity directly ties into the theoretical model's concept of technological proximity (γ), reflecting how closely a firm's innovation aligns with the technology space defined by standard-essential patents. This alignment is key to understanding how firms' innovative efforts respond to changes in standard-setting policies. As firms with a lower similarity (lower γ) are more exposed to the technological constraints imposed by the revised licensing requirements, this measure allows for the identification of heterogeneous effects across firms.

To validate this measure, I investigate how $TECH_{i,IEEE}$ correlates with observable firm types. SEP holders, that are by definition contributors of essential technologies, are disproportionately concentrated in the upper quartile of $TECH_{i,IEEE}$ (Table 7). Moreover, for a subset of 160 firms that can be classified as vertically integrated, pure upstream, or pure downstream [41], I find systematic differences: upstream and vertically integrated firms tend to display higher γ, while pure downstream firms are concentrated in the lower

[40] I further mitigate concerns over blanket declarations by restricting the analysis to standards with fewer than 25% blanket declarations.

[41] Classifications are based on a novel patent pool participation strategy. However, this approach has several limitations. First, I cannot observe the complete set of licensors and licensees for all patent pools worldwide. However, I can collect information on a subset of patent pools for which I have available data. Therefore, some firms classified only as licensors or licensees in my sample might be vertically integrated into other patent pools outside my sample. Besides, regarding the 111 downstream firms for which I observe information, it could be that those firms are vertically integrated but have decided to refrain from joining any patent pool to gain more bargaining power in cross-licensing negotiations, or that they do not hold any patent defined as standard-essential but they hold commercially-essential patents.

Figure 3
Technology Closeness before Policy Revision



The figure plots the distribution of firms' technological proximity to the IEEE technology space before 2015. IEEE technology space is defined based on the IPC classes associated with the 10 standards in my sample. Each observation is at the firm level.

range. Figure 9 (Appendix C) illustrates these patterns. These correlations support the validity of interpreting $TECH_{i,IEEE}$ as a measure of technological proximity to standards, consistent with its role in the theoretical model and identification strategy.

5 Empirical Strategy and Identification

The 2015 IEEE patent policy had heterogeneous effects on upstream and downstream innovation in standards-related technologies, depending on firms' types. Due to observational limitations, I do not assess firm-specific effects but focus on broader trends among firms of similar types. Specifically, I study the impact of IEEE revised policy on innovation in standards-related technologies by distinguishing between firms differentially affected by the policy change, based on the proximity of their technological portfolios to the IEEE technology space.

Figure 3 shows the distribution of firms' technological proximity to the IEEE technology space before 2015. There is significant variation across firms, largely explained by the different technological fields in which firms specialize. This variation allows me to classify firms into four groups based on their distance to the standards' technology space, where distance is defined as $1 - TECH_{i,IEEE}$. Firms in the first quartile are closest to the standards, while those in the fourth quartile are the furthest. Specifically, I cluster firms into four quartiles: those with a technological distance lower than 0.67 (minimum 0.40), between 0.67 and 0.76, between 0.76 and 0.83, and above 0.83.[42]

The theoretical model predicts that firms furthest from the standards' technology space should experience the largest effects from the policy revision. The policy aimed to encourage firms that were previously less involved in standard-related activities to participate, primarily by reducing SEP holders' ability to enforce and collect royalties. Post-2015 developments in IEEE standards, especially in software and internet technologies, aligned with the expansion of digital platforms and internet-based services, making the revised policy particularly attractive to implementers in emerging fields such as computer software and web services.[43] As shown in Table 6 in Appendix C, 43% of firms in the fourth quartile (furthest from the standards) are involved in internet and software-related activities, compared to only 7% in the first quartile.

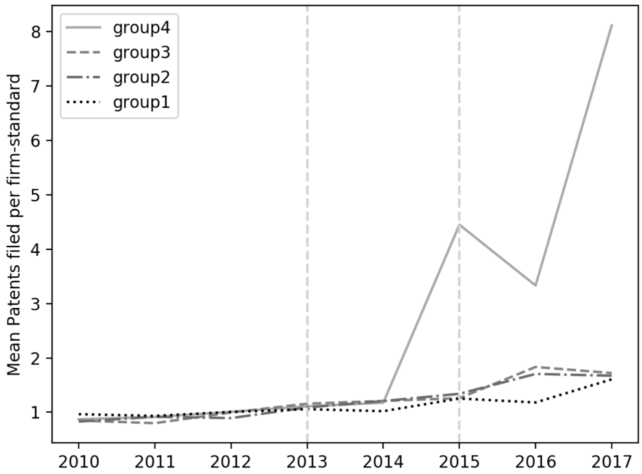
Several factors may explain why firms further from standards were less involved in standard-related activities. First, their technological focus may not have aligned with pre-2015 IEEE standards. Second, firms in higher quartiles, particularly those not declaring SEPs, may have lacked incentives to engage in the standardization process. Third, the stronger enforcement power of SEP holders before 2015 may have discouraged these firms from adopting standards in downstream technologies. Many of these firms, typically not direct contributors to standard setting organizations, may have viewed SEP licensing costs as a barrier to adopting these standards.

By contrast, firms in the same industries as SEP holders often face similar opportunities to declare standard-related technologies. Declaring a patent as essential is a strategic choice shaped by firm-specific factors and SSO policies. Some high-R&D performers may have limited their involvement in standardization to avoid knowledge spillovers (Blind, 2006), while others may have avoided SEP declarations due to restrictive pre-2015 patent policies. Structural barriers also matter: standardization entails fixed costs that can be

[42] Table 5 in Appendix C provides examples of real-world firms in the first and fourth quartiles, along with their respective distances to IEEE.

[43] Notable post-2015 IEEE standards include IEEE 1906 (Nanoscale Communication), IEEE 1914 (Packet-based Fronthaul Transport Networks), and IEEE 2301 (Cloud Portability and Interoperability Profiles).

Figure 4
Class-Weighted Patents Filed per Firm-Standard Pair, Before and After the IEEE Policy Revision



This figure shows the average number of patents filed per firm–standard pair over time across the four quartiles, normalized by each firm's pre-policy average. The dashed grey lines indicate the years 2013 and 2015, which mark the policy announcement and endorsement, respectively. The black line represents firms in the first quartile (control group), those technologically closest to IEEE standards. The dark grey point-dashed line represents firms in the second quartile, the grey dashed line the third quartile, and the light grey line the fourth quartile.

prohibitive for small and medium-sized enterprises (SMEs). Nevertheless, SMEs are often key users of standards, particularly in downstream applications.

The policy revision was effective in increasing standard-related innovation among firms further from the standards' technology space. Firms in the fourth quartile increased their patenting activity by roughly 100% relative to the pre-policy period, compared to a decline of about 3% among firms in the first quartile. To exploit this variation, I employ a continuous difference-in-differences approach (Acemoglu and Finkelstein, 2008; Farronato et al., 2020; Callaway et al., 2024), identifying the continuous treatment effect under a generalized parallel trends assumption (Callaway et al., 2024).

Figure 4 shows trends in class-weighted patent filings across quartiles, normalized by each firm's pre-period average.[44] I normalize by pre-period patenting behavior and adjust for firms' fixed effects to account for unobserved heterogeneity. Given differences in pre-treatment means across quartiles, as shown in Table 7 in Appendix C, it may be

[44] I divide the number of standard-related patents filed by the average number filed in the relevant technology classes by each firm in the pre-period.

unreasonable to expect that time-varying factors have equal level effects on the outcome. An alternative identifying assumption is to impose that, in the absence of the treatment, treated and control groups would have followed the same proportional trend in outcomes (See Wooldridge (2023)). Consistent with this assumption, Figures 11 and 12 show that R&D spending and the share of IEEE patents in total patenting, two complementary measures of innovation, evolve uniformly across groups both before and after the policy, suggesting no quartile-specific growth patterns.[45]

Because firms in the second and third quartiles exhibit similar trends and interpreting differences across continuous treatment values can be complex due to treatment effect heterogeneity (Callaway et al., 2024), I follow Farronato et al. (2020) and compare pre- and post-policy outcomes across quartiles, using firms in the first quartile as the control group.[46]

Firms that are technologically close to a given standard differ markedly from those further away. Table 7 along with Figures 13-16 in Appendix C provide comparisons of some observable demographic characteristics of firms across quartiles and time. Given such strong differences, I might be concerned that the parallel trends assumption does not hold for those groups. However, as noted by Farronato et al. (2020) and Wooldridge (2023), my difference-in-differences strategy does not require identical levels of the pre-treatment outcomes, but rather parallel trends, appropriately defined as reported in Figure 4 above.

To quantify the policy's impact on patenting behavior, I estimate the following model:

$$\begin{aligned}\mathbb{E}\left[P_{ist}|X_{it}, X_{st}\right] =& exp(\delta_1(dPOST_{t>2014} * dGroup_{i,IEEE}) + \lambda_1 SALE_{i,t-1} + \lambda_2 X'_{s,t-1} \\ &+ \tau_{age} + \varphi_i + \varphi_s)\end{aligned} \tag{5}$$

[45] In Appendix C, I also report event-study estimates that formally test for pre-trends. The results (Figure 18, Table 17) show no evidence of differential pre-trends, supporting the validity of the identification assumption. As an additional robustness check, I also perform a placebo analysis on ETSI-related patenting, a comparable field of standardization. The results reported in Table 14, show similar post-2015 coefficients across quartiles, consistent with the assumption that firms would have followed a similar growth rate in patenting in the absence of the policy update. However, it should be noted that patenting related to ETSI standards may not be entirely independent from patenting related to IEEE standards, as firms discouraged from patenting for IEEE standards after the policy change might reallocate their innovative efforts toward ETSI standards, which build on similar technological knowledge and may therefore become relatively more attractive. This substitution effect could partly explain the positive and statistically significant coefficients for ETSI patents.

[46] As a robustness check, I also estimate a multiple continuous difference-in-differences model (Acemoglu and Finkelstein, 2008). Results, reported in Appendix C, are consistent with the baseline specification. This approach preserves statistical power and efficiency relative to the standard model.

where P_{ist} is the weighted number of patents filed by firm i in the technology classes related to standard s in year t. The post-policy dummy $dPOST_{t>2014}$ captures the effect of the policy revision, while $dGroup_{i,IEEE}$ identifies firms by their quartile. Specifically, a firm is included in the treatment group if it is in a quartile that is technologically further from the standard's space compared to firms in the first quartile. The coefficient of interest, δ_1, should be interpreted as changes in the outcome variable relative to the control group, and relative to the years before the policy revision was endorsed, as a percentage of the baseline mean.[47] Control variables include firm size ($SALE_{i,t-1}$), observed standard characteristics (X'_{st}), standard-age fixed effects (τ_{age}), and firm and standard fixed effects (φ_i and φ_s). To account for immediate feedback of the dependent variable to the covariates, I lag all time-varying controls by one year.

I account for economies of scale in patent generation and the effect of firm's size on patent portfolios (Blind and Thumm, 2004; Blind and Mangelsdorf, 2008) by including $SALE_{i,t-1}$. Moreover, firms in certain industries are more likely to patent in specific technology classes due to the relative importance of these classes to their industry. Additionally, a firm's location may affect its patenting activity, driven by variations in patent systems or accessibility in different countries. Industry and country effects are controlled for through φ_i and φ_s in the econometric specification.

To account for the effect of standards-specific characteristics on patenting activities, I include several variables. The importance of a standard to the ICT industry may drive a firm's innovation decisions. To capture this, I include the total number of documents referencing a common standard in the $X'_{s,t\text{-}1}$ vector. Additionally, I include the total number of firms declaring essential patents as a measure of a standard's attractiveness. Prior theoretical work on standards and essential patents (Baron et al., 2014; Bekkers et al., 2017; Spulber, 2019) shows that the number of SEP holders affects the potential licensing revenues a firm can earn from its patents. Lastly, I control for autonomous growth in standard-related patenting by including an interaction between the treatment group indicator ($dGroup_{i,IEEE}$) and the age of the standard ($StdAge_t$), measured as the number of years since the publication of the first standard document. This specification allows treatment and control firms to exhibit different patenting trends as standards naturally

[47] To avoid bias from log transformations, I use a Poisson regression, following Chen and Roth (2024).

mature.[48]

Other regressors in Equation 5 address potential shocks and unobserved heterogeneity. I include firm- and standard-specific dummies to control for unobservable differences across standards and firms. For instance, pure innovators may focus their innovative efforts on selected standards, while vertically integrated firms might contribute to a wider range of standards. Additionally, firms might allocate innovation resources strategically to standards in which they are key players in developing related technologies, conditional on firm-specific characteristics that are unobserved by the researcher. Lastly, because multiple technology classes can correspond to various standards, I control for unobserved factors affecting the firm's decision to invest in a particular standard versus others with similar technology domains. Unobserved and time-invariant effects across firms and standards are identified by firms' participation in multiple standards.

To account for firms potentially adjusting their behavior in anticipation of the policy change, I extend the model to estimate separate coefficients for the anticipation period (2014) and the post-policy periods (2015-2017). This specification allows me to isolate any pre-policy adjustments from the actual effects of the policy revision.[49]

An econometric challenge of all specifications is the overlap in technology classes across standards. Sharing a large share of technology classes implies that firm-standard pairs are not independent of each other. It is possible that firms forum-shopping between standards sharing common technology classes and that the policy revision may cause firms to substitute away from one standard to another, leading to an upward bias of the estimates. To solve this problem, I account for the overall distance between the firm and the standard setting organization, IEEE, clustering firms in the different groups based on this overall measure. Besides, I might be concern about an endogeneity problem that

[48]Figure 10 in Appendix C reports the distribution of patents filed before and after a standard's publication. As expected, patent filings decrease over time as a standard ages. This declining pattern justifies the inclusion of $StdAge_t$ to account for differential patenting dynamics across standards at different stages of the technological cycle.

[49]I estimate a more flexible version of the baseline specification of the form:

$$\begin{aligned}\mathbb{E}\left[P_{ist}|X_{it},X_{st}\right] =& exp(\delta_{t_a}(dT_{t_a=2014} * dGroup_{i,IEEE}) + \sum_{t_p=2015}^{2017} \delta_{t_p}(dT_{t_p} * dGroup_{i,IEEE}) \\ &+ \lambda_1 SALE_{i,t-1} + \lambda_2 X'_{s,t-1} + \tau_{age} + \varphi_i + \varphi_s)\end{aligned} \tag{6}$$

Table 1
Effect of IEEE Policy Change on firm-standard patenting

		Standard-related Patents		Standard-related Patents		Standard-related Patents	
		(1)	(2)	(3)	(4)	(5)	(6)
Anticipation-Period							
	2nd Quartile		0.397***		0.398***		0.388***
			(0.042)		(0.042)		(0.042)
	3rd Quartile		0.313***		0.314***		0.308***
			(0.061)		(0.061)		(0.062)
	4th Quartile		0.378***		0.377***		0.373***
			(0.058)		(0.058)		(0.058)
Post-Period							
	2nd Quartile	0.169***	0.270***	0.168***	0.270***	0.104*	0.206***
		(0.056)	(0.063)	(0.055)	(0.062)	(0.057)	(0.063)
	3rd Quartile	0.169***	0.271***	0.168***	0.272***	0.130*	0.232***
		(0.064)	(0.079)	(0.064)	(0.079)	(0.069)	(0.084)
	4th Quartile	0.288***	0.417***	0.288***	0.417***	0.225***	0.352***
		(0.083)	(0.085)	(0.082)	(0.084)	(0.086)	(0.089)
Covariates		Yes	Yes	Yes	Yes	Yes	Yes
Standard Age FE		Yes	Yes	No	No	Yes	Yes
Year FE		No	No	Yes	Yes	No	No
Quartile_Time_trend		No	No	No	No	Yes	Yes
Standard FE		Yes	Yes	Yes	Yes	Yes	Yes
Firm FE		Yes	Yes	Yes	Yes	Yes	Yes

Note: The coefficients reported for each quartile are estimated separately comparing the outcomes of the quartile of interest with the baseline group, represented by firms in the first quartile. The dependent variable is the weighted number of patents per firm-standard. The method of estimation is maximum likelihood for the Poisson model. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels. For more granular difference-in-differences coefficients, see Appendix C Tables 8, 9, and 10.

arises since firms decide in which technology classes to invest. Because this decision was taken years before the sample of interest it is not of any concern.[50] Lastly, standard errors are clustered by firm-standard pair to address serial correlation.

6 Results

This section presents the empirical findings of my analysis, starting with tests on how firms' standard-related patenting behavior responds to the IEEE's policy update (Hypothesis 1). The results are validated through robustness checks. Based on the theoretical framework outlined in Section 3, I expect that firms in the fourth quartile, those furthest from the standards' technology space, experience the largest impact, with the effect diminishing across the third and second quartiles.

Table 1 reports the econometric results, showing a statistically and economically significant increase in standard-related patenting following the IEEE policy revision. Each

[50] As a robustness check, I clustered firms based on their pre-2012 patent portfolios. The results, reported in Table 15, are consistent with the main specification.

row corresponds to a different treatment group.

In Column 5, the results are based on the model specified in Equation 5, accounting for various fixed effects. The baseline period (2010-2014) precedes the 2015 policy revision, with the post-period beginning after this change. Consistent with theoretical expectations, standard-related patenting increased most significantly for firms that are technologically further. Firms in the fourth quartile increased patenting by 25.2%, followed by increases of 13.9% in the third quartile, and 11.0% in the second quartile. The coefficient estimates for δ_1 are consistent across all specifications.

As Figure 4 shows, firms began to increase their standard-related patent filings two years before the policy change, with a sharp rise between 2014 and 2015. Column 6 accounts for anticipation effects, confirming that the policy revision's impact became more pronounced post-2015.[51]

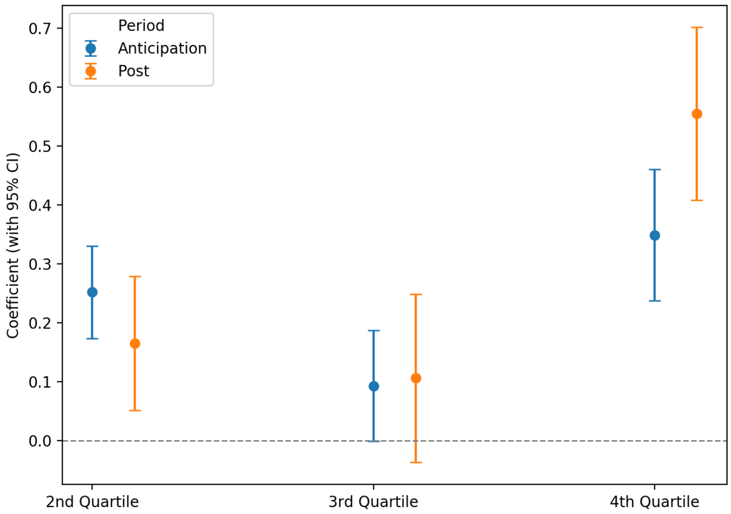
Furthermore, the results show a non-monotonic pattern across quartiles. To better understand this, I analyze technological proximity across quartiles (Figure 17 in Appendix C) and find that, in technology space, second quartile firms are positioned nearer to fourth quartile firms than third-quartile firms are. Since fourth-quartile firms exhibit the strongest increase in patenting post-policy, this proximity suggests that second-quartile firms benefit from spillovers generated by quartile-4 innovation, thereby decreasing the difference in direct patenting responses between the second and third quartiles.

To test this spillover interpretation, I focus on patenting in technology classes unrelated to IEEE standards. If spillovers from quartile-4 firms matter, they should raise second-quartile firms' innovation not only in IEEE-related domains but also in other technologies. Consistent with this prediction, Figure 5[52] shows that firms in quartiles 2 and 4 experience significant increases in non-standard patenting, whereas quartile-3 firms do not. This pattern supports the interpretation that spillovers from technologically proximate firms in quartile 4 underlie the non-monotonic responses across quartiles. Nevertheless, the overlap in technology classes between different ICT standards might confound these results, potentially amplifying the observed effect of the IEEE policy change.

[51] Because the Event study analysis shows a statistically significant effect in 2013, and because it is reasonable to assume that firms learned about the policy revision in the years before 2015, I also tested for other specifications of the anticipation period. The results are presented in Table 11 in Appendix C and they are not qualitatively different from the results reported in Table 1.

[52] The results of the econometric analysis are presented in Table 12 in Appendix C.

Figure 5
Effect of IEEE Policy Change on Non-standard-related Patents



The figure shows the results from regressions reported in Table 12 across three treatment groups: firms in the second, third, and fourth quartiles. Each observation corresponds to the estimated coefficient for each quartile for the anticipation (blue dot) and post period (orange dot). The vertical bars define the confidence intervals.

To expand my analysis, I assess the policy's impact on firms declaring standard-essential patents, as these firms are directly affected by stricter licensing commitments. Because SEP holders represent a small subset of firms with unique characteristics that influence their ability to develop technologies essential to standards, I focus on two groups: first and second quartiles, both of which include SEP-declaring firms. The objective is to create a balanced sample of treatment firms (those declaring SEPs) and control firms (those that have never declared patents as essential to the IEEE but have comparable characteristics to SEP holders). This allows for a robust comparison in a difference-in-differences analysis in line with my identification strategy, where the control group consists of firms that are closest to the standards' technology space and have never declared any patent as essential.

Table 2 presents the results, which reveal a nuanced relationship between the policy revision and standard-related patenting. I find no statistically significant effect on SEP holders who are technologically closest to the standards (1st Quartile SEP holders), while those in the second quartile experience a significant negative effect post-policy revision. This suggests that firms further from the core technology of the standard are more negatively impacted by the policy revision. Conversely, non-SEP holders in the second quartile

Table 2
Effect of IEEE Policy Change on SEP Holders

		Standard-related Patents	
		(1)	(2)
Anticipation-Period			
	1st Quartile - SEP Holders		0.005
			(0.060)
	2nd Quartile - Non-SEP holders		0.390^{***}
			(0.067)
	2nd Quartile - SEP Holders		0.759^{***}
			(0.135)
Post-Period			
	1st Quartile - SEP Holders	0.112	0.113
		(0.077)	(0.086)
	2nd Quartile - Non-SEP holders	0.236^{***}	0.334^{***}
		(0.075)	(0.087)
	2nd Quartile - SEP Holders	-0.369^{**}	-0.147
		(0.164)	(0.182)

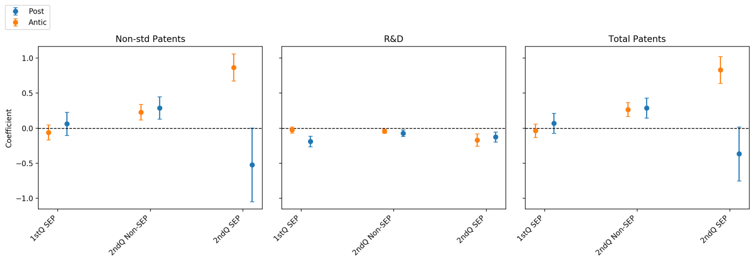
Note: The dependent variable is the weighted number of patents per firm-standard. The method of estimation is maximum likelihood for the Poisson model. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

show positive and significant effects in both the anticipation and post-policy periods.

These results are consistent with Hypothesis 2. The significant decline in patenting by second-quartile SEP holders reflects their reliance on upstream innovation, which falls when r decreases, while the positive effect for non-SEP holders in the same quartile suggests an expansion of downstream innovation, as predicted.

To shed light on the mechanisms underlying the heterogeneous effects of the IEEE policy revision, I study firms' responses across alternative innovation channels. Figure 6 shows that non-SEP holders in the second quartile increased both their non-standard patenting and overall patenting in the anticipation and post-policy periods, even as their R&D expenditures declined. This suggests a reallocation of innovative efforts toward patenting activities most likely to generate appropriable returns under the new licensing framework. In contrast, SEP holders in the second quartile, those positioned further from the technological core of the standard, experienced significant reductions in both non-standard patenting and total patenting post-policy, coupled with a decline in R&D. This indicates that stricter licensing commitments disproportionately constrained their ability to sustain innovation, in line with the theoretical prediction that lower-proximity firms (γ_i low) are more affected by changes in royalty conditions. Meanwhile, SEP holders

Figure 6
Mechanism Analysis: Effect of IEEE Policy Change



The figure shows the results from regressions reported in 13 across three treatment groups: SEP and non-SEP holders in the first and second quartiles. Each observation corresponds to the estimated coefficient for each quartile for the anticipation (blue dot) and post period (orange dot). The vertical bars define the confidence intervals.

in the first quartile, who are closest to the core technology space, show no meaningful decline in patenting but exhibit a post-policy reduction in R&D, suggesting that their established position in the standard allows them to maintain patenting output despite reduced innovation investment. However, it is likely that the control group may also have experienced an increase in patenting in the post-period. Therefore, assuming that the control and treatment groups, including SEP holders, are affected by the policy revision in divergent directions, my estimates should be interpreted as defining the upper bound of the negative impact of the IEEE policy revision on firms' incentives to innovate in standard-related technologies.

These patterns tie closely with the theoretical results in Section 3. The observed empirical heterogeneity maps directly into the structure of the model, where technological proximity (γ_i) shapes both the sensitivity to royalty changes and the capacity to reallocate across innovation channels. Firms further from the standard's technology space lack the upstream strength of high-γ SEP holders but also fail to expand downstream innovation, consistent with the model's prediction that policy-induced cost relief does not fully offset their weaker technological proximity. In turn, Figure 9 shows that pure upstream and pure downstream firms are primarily located in the low-γ range, while vertically integrated firms cluster at higher values. This mapping reinforces the interpretation that the observed decline in innovation among second-quartile SEP holders reflects their positioning in the technology space: low-γ upstream specialists, reliant on royalty income, face weaker returns on innovation after the policy and lack alternative downstream revenue streams to compensate. By contrast, first-quartile SEP holders are more likely to be vertically integrated and thus relatively insulated. Although they reduce upstream R&D, they maintain or even expand patenting in other domains, indicating reallocation across innovation channels that mutes the net effect on standard-related patenting.[53]

Despite these findings, the econometric analysis has several limitations. The more restrictive patent policy may have altered firms' patenting behavior in standard-related technology classes without necessarily reflecting increased innovation. Firms could have been incentivized to focus on patenting more mature inventions rather than investing in entirely new technologies. Moreover, there is mixed evidence on how SEP royalties affect innovation. Some studies suggest that allowing SEP holders to capture greater value from standardization stimulates innovation (Sidak, 2013, 2016; Epstein and Noroozi, 2017), while others argue that stronger patent rights can reduce innovation, particularly in sequential or complementary innovation settings (Bessen and Maskin, 2009; Galasso and Schankerman, 2015).

Weaker interpretations of FRAND commitments may also encourage the strategic over-patenting of marginal ideas (Kang and Bekkers, 2015; Righi and Simcoe, 2020), potentially lowering social welfare and diminishing the overall benefits of innovation (Shapiro, 2000; Geradin and Rato, 2007). Thus, while the observed increase in patenting among treated firms likely reflects a response to the policy change, it may also represent strategic behavior rather than genuine technological progress. These limitations are more likely to increase the variance of the error term, leading to less efficient, rather than biased, estimates of the coefficient of interest.

A further limitation concerns the definition of standard-related patents. My dependent variable is based on patents filed in IPC classes linked to IEEE standards through declared SEPs. While this approach captures a broader set of upstream and downstream innovations than SEP counts alone, it also inherits the problem of over-declaration. Over-declaration may inflate the number of IPC classes associated with a standard, causing some

[53] One potential concern is that the anticipation period may reflect a waiting effect, with firms delaying patent filings until the licensing framework was clarified. The results do not support this interpretation. Instead of a dip followed by a compensating surge, I find that firms adjusted immediately in directions consistent with their theoretical incentives: non-SEP holders in the second quartile increased patenting in anticipation, while SEP holders in the same quartile reduced both R&D and patenting before the policy's formal adoption. This suggests that firms did not wait to observe how the policy would proceed, but rather reallocated their innovative efforts in expectation of the new conditions. This interpretation is also supported by the results in Table 17.

patents to be counted as standard-related even when they are only loosely connected to the relevant technology.

In addition, despite my efforts to approximate unique inventions by collapsing applications with the same applicant, original application number, and filing year, some inventions filed in multiple jurisdictions may still be counted more than once. This can occur both because of firms' strategic filing choices and due to differences in examination outcomes across patent offices.

As a result, my estimates may partially capture the effects of over-declaration and residual double-counting, driven by both strategic and procedural factors, and should therefore be interpreted as an upper bound of the true effect on innovation. That said, because many IPC classes overlap across declared SEPs and across standards, the likelihood that entire classes are incorrectly included is limited. Accordingly, while some upward bias may persist, the measure still provides a meaningful approximation of firms' innovative activity related to IEEE standards.

6.1 Robustness

Several other policy changes related to the licensing of standard-essential patents occurred around the same time as the IEEE's revision of its patent policy. These include the the DOJ's policy statement on SEP licensing[54], *InterDigital vs. Nokia* in the ICT Court, [55], and the *Huawei vs. ZTE* in the Court of Justice of the European Union.[56] Given the timing of these developments, the effects of the IEEE's revised IPR policy could be confounded by these other changes.

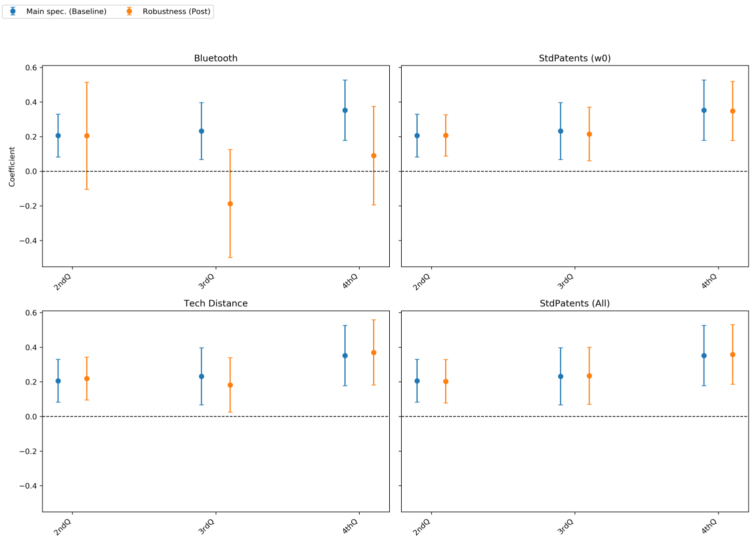
Each of these rulings and policy shifts addressed the ability of SEP holders to seek

[54] In 2013, the USPTO and DOJ jointly issued a policy statement on remedies for the infringement of SEPs subject to voluntary FRAND commitments. The statement noted that while, in some cases, exclusionary remedies for infringement of SEPs may conflict with the public interest, such remedies may be appropriate when the potential licensee refuses to negotiate FRAND terms. See *Policy Statement on Remedies for Standards-Essential Patents Subject to Voluntary F/RAND Commitments 1–10 (Jan. 8, 2013)*, available at https://www.justice.gov/sites/default/files/atr/legacy/2014/09/18/290994.pdf.

[55] In 2015, the ICT court, in the case of *InterDigital vs. Nokia*, found no evidence of patent hold-up by InterDigital but identified reverse hold-up by Nokia. The court issued an exclusion order favoring the SEP holder and did not require the SEP holder to prove the standard implementer's unwillingness to negotiate FRAND licensing.

[56] In *Huawei vs. ZTE*, the European Court of Justice ruled that a SEP holder who committed to license patents on FRAND terms could violate competition rules (Article 102 TFEU) by seeking an injunction against a licensee under certain conditions. The ruling also outlined steps for negotiating SEP licensing agreements.

Figure 7
Effect of IEEE Policy Change - Robustness



The figure shows the results from regressions reported in 15 and 16 across quartiles. Each observation corresponds to the estimated coefficient for each quartile for the post period of the baseline specification (Column 6 Table 1), the blue dot, and the robustness estimates, the orange dot. The vertical bars define the confidence intervals.

injunctions, as well as the burden of proof in patent hold-up and reverse hold-up claims. As these changes targeted FRAND licensing for SEPs, they could potentially affect the interpretation of my results. For instance, the increase in standard-related patenting could partially be attributed to the *Huawei vs. ZTE* ruling, which was less favorable to SEP holders.

To assess whether other policy forces have influenced my findings, I conducted a difference-in-differences analysis using patents related to Bluetooth standards. Unlike other IEEE standards, Bluetooth working groups are subject to additional royalty-free licensing requirements. If other policies were driving the increase in standard-related patents, I would expect to observe similar effects for Bluetooth firms after the policy revision. However, if the IEEE's 2015 policy revision, establishing a FRAND royalty higher than a royalty-free commitment, was the main driver, there should be no significant effect on Bluetooth patents in the post-period. The results are presented in Figure 7, Panel A, and show that the coefficient for Bluetooth patents is not statistically significant, suggesting that other policy changes are unlikely to have influenced my findings.[57]

Further robustness checks were conducted using alternative specifications of the base-

[57]See Table 15, Column (1) for the regression estimates.

line model.[58] Panel B of Figure 7 reports results for standard-related patents weighted by IPC classes to account for zeros in standards' patent portfolios. Panel C redefines the technology distance using firms' pre-2012 portfolios and re-clusters firms into quartiles. Panel D presents estimates from a multiple regression framework following Acemoglu and Finkelstein (2008). Across all cases, the results remain consistent with the baseline, showing no statistically significant differences.[59]

7 Conclusion

This paper studies how stricter licensing requirements in standard setting affect firms' innovation, focusing on the IEEE's 2015 patent policy revision. The results show that the policy significantly reshaped standard-related patenting, but with heterogeneous effects across firms. Overall, patenting in standard-related technologies increased, with the strongest growth among firms furthest from the standards' technological core. These firms, less constrained by lost royalty revenues, appear to have seized new opportunities to innovate once SEP holders' bargaining power declined.

By contrast, SEP holders were more negatively affected. Firms closest to the standards' technological space maintained their patenting activity, likely due to vertical integration or access to alternative innovation channels, while SEP holders further from the core reduced both R&D and patenting. Non-SEP firms increased their innovation, benefiting from lower barriers to deploying standardized technologies. These patterns underscore how licensing rules differentially shape upstream and downstream incentives, thereby redefining who contributes to standard-related innovation.

Taken together, the findings suggest that stricter licensing policies can broaden participation in innovation around standards by lowering costs for non-SEP firms, even as they reduce returns for some SEP holders.

While this paper focuses on the IEEE's 2015 revision, other SSOs have also revised their patent policies.[60] Understanding firms' strategic behavior across these parallel shifts,

[58] See Tables 15 and 16 in Appendix C

[59] Event-study estimates (Figure 18, Table 17) are consistent with the identification assumption, with Wald test p-values of 0.28, 0.55, and 0.43. Complementary placebo analyses on ETSI-related patenting (Table 14) yield similar results, with pairwise t-tests failing to reject equality of coefficients across quartiles (–2.81 for Q2–Q3, –1.67 for Q2–Q4, 0.50 for Q3–Q4).

[60] See supra note 2.

and across standards issued by different SSOs, remains an important direction for future research.

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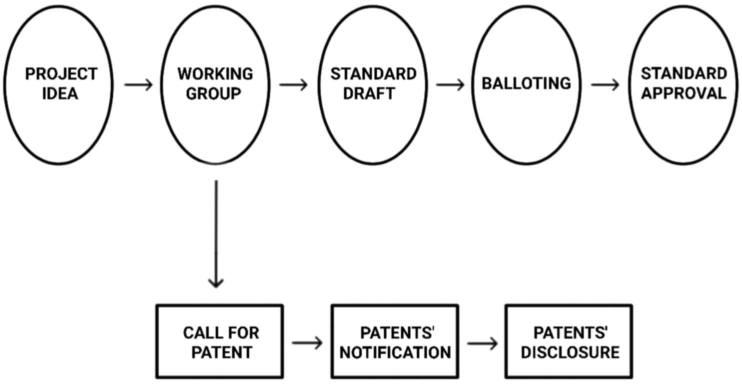
Figure 8
The IEEE Standardization Process



Source: *Standards Development at IEEE SA*, https://standards.ieee.org/beyond-standards/how-standards-are-made/

8 Appendix

A Additional Institutional Information

A.1 IEEE Standards development

The process of developing standards at IEEE SA can be described in five key steps, as illustrated in Figure 8.[61]

Before the formal process begins, a technological need is identified, often driven by market demand. This need typically leads to the proposal of a new feature and, ultimately, the creation of a new standard. Once the need is recognized, it is formalized into a project proposal, and a standards committee submits a request to the standard-setting organization for approval. IEEE SA then evaluates the proposal based on its necessity and the availability of qualified volunteers to support its development.[62] If approved, the committee establishes a working group composed of individuals and entities interested in developing the standard.[63]

In the second step, firms, agencies, and individuals are invited to join the working group, whose primary responsibility is to transform the project idea into a standard.

[61] This paragraph draws on *Standards Development at IEEE SA*, available at https://standards.ieee.org/beyond-standards/how-standards-are-made/.
[62] The IEEE Standards Board assesses whether the request is essential and whether sufficient volunteers are willing to contribute to its development.
[63] While IEEE SA facilitates the standardization process, the standards committee is responsible for organizing the working group and related activities.

The third step involves proposing technical solutions to the identified problem. Once these solutions are consolidated into a draft standard, the process moves to the fourth step—the balloting stage. At this point, the standards committee forms a balloting group of stakeholders authorized to vote on the proposed standard. While any interested entity may provide comments, only votes from the balloting group are counted. A standard is approved if at least 75% of ballots are returned and 75% of those votes are affirmative.[64]

The final step is the approval phase, in which the working group submits the draft to the organization's Review Committee and subsequently to the IEEE Standards Board for final approval. Once accepted, the standard is published and made publicly available.

Regarding the declaration of standard-essential patents, there is no fixed timeline relative to the standardization process. Firms may declare SEPs at any point after the working group has been established. During working group meetings, the chair issues a "call for patents," reminding participants that any technology proposed for inclusion in the standard must be disclosed if it is covered by patents. Firms holding essential patents are required to submit a Letter of Assurance, committing to license these patents on fair, reasonable, and non-discriminatory (FRAND) terms. The letter must be submitted "as soon as reasonably feasible" and no later than the standard's final approval. Although IEEE publishes a list of accepted Letters of Assurance, it does not assess or validate the essentiality, infringement, or validity of the claimed patents.[65]

A.2 Procedure of IEEE policy revision

The process of revising the IEEE patent policy formally began on March 13, 2014, when the Patent Committee (PatCom) appointed an Ad Hoc Committee to review and recommend updates to the existing policy. The motivation for the revision stemmed from growing disagreements between SEP owners and standards implementers, particularly over the interpretation of "reasonable rates" for SEP licenses. As noted in contemporaneous reports, "the last several years have shown wide divergence between the owners of standards-essential patents (SEPs) and the implementers of standards, particularly over

[64] The balloting process typically takes 30 to 60 days.

[65] This paragraph draws on *STANDARDS BOARD BYLAWS – CLAUSE 6 – 8*, available at https://standards.ieee.org/about/policies/bylaws/sect6-7/, and *Understanding Patent Issues During IEEE Standards Development*, available at https://standards.ieee.org/wp-content/uploads/import/documents/other/patents.pdf.

the meaning of 'reasonable rates' for potential SEP licenses."[66]

This concern was echoed by key regulatory authorities, including the U.S. Department of Justice (DoJ), the Federal Trade Commission (FTC), and the European Commission, all of which emphasized the need for greater policy clarity.[67]

After a 15-month review process, including the collection of over 600 public comments, the Ad Hoc Committee approved a revised fourth public draft in June 2014, which was subsequently forwarded to the Standards Board for consideration. In August 2014, the Standards Board voted to approve PatCom's proposed policy revision and recommended that the IEEE Board of Directors also adopt the changes.

In February 2015, the U.S. DoJ issued a Business Review Letter endorsing the revision, concluding that it had "the potential to benefit competition and consumers by facilitating licensing negotiations, mitigating hold-up and royalty stacking, and promoting competition among technologies for inclusion in standards."(Hesse, 2015) Shortly thereafter, on February 8, 2015, the IEEE Board of Directors formally approved the policy revisions, which took effect in March 2015.

The revision introduced four key amendments clarifying the interpretation of FRAND terms in SEP licensing:[68]

- Clarity of *Reasonable Rate*: the revised patent policy provides for the SEPs for which IEEE as an accepted Letter of Assurance "appropriate compensation to the patent holder for the practice of an Essential Patent Claim excluding the value, if any, resulting from the inclusion of that Essential Patent Claim's technology in the IEEE Standard."

- Definition of *Compliant Implementation*: in an attempt to provide clarifications on the word Non-Discriminatory the policy revision introduces a definition of Compliant Implementation as "any product (e.g., component, sub-assembly, or end-product) or service that conforms to any mandatory or optional portion of a normative clause of

[66] *IEEE Request for Business Review Letter*, The United States Department of Justice, September 30, 2014, p. 4, available at .

[67] See Hesse (2012), available at , Ramirez (2014), available at , and Almunia (2012).

[68] The four aspects quoted below are taken from *Draft IEEE Standards Board By-laws: Draft 39 versus Current Policy,*, IEEE, and *IEEE Request for Business Review Letter*, The United States Department of Justice, September 30, 2014, available at https://www.justice.gov/sites/default/files/atr/legacy/2015/02/17/311483.pdf.

an IEEE Standard and providing that the requested licensing assurance shall extend to any Compliant Implementation that practices the Essential Patent Claims for use in conforming with the IEEE Standard." In addition, the policy provides three factors that should be considered in determining a reasonable rate: "(1) the value the patented functionality contributes to the smallest salable Compliant Implementation; (2) the value contributed by all Essential Patent Claims for the same IEEE Standard practiced in that Compliant Implementation; (3) existing licenses covering use of the Essential Patent Claim, conditional on that such licenses were not obtained under the explicit or implicit threat of a Prohibitive Order (e.g., injunction or exclusion order), and are otherwise sufficiently comparable to the proposed license."

- Availability of *Prohibitive Orders*: the updated policy provides that "the submitter (or its successor) of a Letter of Assurance is not permitted to seek a Prohibitive Order unless the implementer fails to participate in, or to comply with the outcome of, an adjudication, including an affirming first-level appellate review, if sought by any party within applicable deadlines, in that jurisdiction by one or more courts that have the authority to determine Reasonable Rates and other reasonable terms and conditions; adjudicate patent validity, enforceability, essentiality, and infringement; award monetary damages; and resolve any defenses and counterclaims."

- Permissible demands for *Reciprocal License*: concerning cross-licensing negotiations, the revised policy clarifies that "where a Submitter's Accepted Letter of Assurance has indicated reciprocity, a potential licensee cannot both receive the benefit of the Submitter's Letter of Assurance and refuse to license to that Submitter the licensee's own Essential Patent Claims on the same standard."

B Analytical Framework - Extensions

This appendix provides the formal derivations underlying the analytical framework in Section 3.

For vertically integrated firms that invest in both upstream inventions (x_i) and downstream implementations (y_i), the first-order conditions are:

$$\begin{cases} \frac{\partial \pi_i}{\partial x_i} = (1-\epsilon)\left[r\frac{x_i+\gamma_i}{1+x} + (1-r)\frac{y_i+\gamma_i}{1+y} + v(x,y)r\frac{1+x_j-\gamma_i}{(1+x)^2}\right] + \epsilon - x_i + \frac{\theta y_i^2}{2[1+\theta(x_i+\gamma_i)]^2} \\ \frac{\partial \pi_i}{\partial y_i} = (1-\epsilon)\left[\beta(r\frac{x_i+\gamma_i}{1+x} + (1-r)\frac{y_i+\gamma_i}{1+y}) + v(x,y)(1-r)\frac{1+y_j-\gamma_i}{(1+y)^2}\right] + \epsilon\beta - \frac{y_i}{1+\theta(x_i+\gamma_i)} \end{cases}. \tag{7}$$

For the cases where firms only invest upstream or only downstream, the first-order conditions reduce to:

$$\frac{\partial \pi_i}{\partial x_i} = (1-\epsilon)\left[r\frac{x_i+\gamma_i}{1+x} + (1-r)\gamma_i + r\frac{(1+x+\beta)(1+x_j-\gamma_i)}{(1+x)^2}\right] + \epsilon - x_i \tag{8}$$

$$\frac{\partial \pi_i}{\partial y_i} = (1-\epsilon)\left[\beta(r\gamma_i + (1-r)\frac{y_i+\gamma_i}{1+y}) + v(y)(1-r)\frac{1+y_j-\gamma_i}{(1+y)^2}\right] + \epsilon\beta - \frac{y_i}{1+\theta\gamma_i} \tag{9}$$

Equations 7, 8, and 9 define the firm's best-response functions, linking investments in x_i and y_i to royalty revenues (r) and the firm's technological proximity to the standard (γ_i).

The comparative statics of interest are the cross-partial derivatives of the profit-maximization conditions with respect to the royalty revenue r.

For vertically integrated firms:

$$\begin{cases} \frac{\partial}{\partial r}\left(\frac{\partial \pi_i}{\partial x_i}\right) = (1-\epsilon)\left[\underbrace{\frac{x_i+\gamma_i}{1+x_i+x_j}}_{\text{(1) upstream licensing gain}} - \underbrace{\frac{y_i+\gamma_i}{1+y_i+y_j}}_{\text{(2) downstream rent shift}} + \underbrace{\frac{(1+x_j-\gamma_i)v}{(1+x_i+x_j)^2}}_{\text{(3) competition/spillover effect}}\right] \\ \frac{\partial}{\partial r}\left(\frac{\partial \pi_i}{\partial y_i}\right) = (1-\epsilon)\left[\beta\left(\underbrace{\frac{x_i+\gamma_i}{1+x_i+x_j}}_{\text{(4) upstream substitution}} - \underbrace{\frac{y_i+\gamma_i}{1+y_i+y_j}}_{\text{(5) downstream rent loss}}\right) - \underbrace{\frac{(1+y_j-\gamma_i)v}{(1+y_i+y_j)^2}}_{\text{(6) downstream competition}}\right] \end{cases} \tag{10}$$

For pure upstream or downstream firms:

$$\frac{\partial}{\partial r}\left(\frac{\partial \pi_i}{\partial x_i}\right) = (1-\epsilon)\left[\underbrace{\frac{x_i-\gamma_i(x_i+x_j)}{1+x_i+x_j}}_{\text{(1') revenue shift by } \gamma_i} + \underbrace{\frac{(1+x_j-\gamma_i)(1+x_i+x_j+\beta)}{(1+x_i+x_j)^2}}_{\text{(2') competition + system size}}\right]. \tag{11}$$

$$\frac{\partial}{\partial r}\left(\frac{\partial \pi_i}{\partial y_i}\right) = (1-\epsilon)\left[\underbrace{\beta\left(\gamma_i - \frac{y_i+\gamma_i}{1+y_i+y_j}\right)}_{\text{(3') downstream cost–revenue trade-off}} - \underbrace{v(y)\frac{1+y_j-\gamma_i}{(1+y_i+y_j)^2}}_{\text{(4') downstream competition}}\right]. \tag{12}$$

Equations 10 ,11, and 12 decompose the effect of a change in the royalty revenue r on firms' optimal investment incentives into distinct channels. Each term corresponds to a separate mechanism through which royalties shape the returns to upstream (x_i) and downstream (y_i) innovation, with the role of technology proximity γ_i entering as a key determinant of the magnitude of the effect. This section provides a structured interpretation of these terms for vertically integrated firms and for the corner cases of pure upstream and downstream firms.

For vertically integrated firms, the cross-partial derivative of the upstream condition with respect to r in Equation (10) highlights three forces. The first term,

$$\frac{x_i + \gamma_i}{1 + x_i + x_j},$$

captures the *upstream licensing gain*: higher royalties increase the marginal payoff from holding SEPs, raising incentives to invest in x_i. This effect is stronger for firms with higher technological proximity (γ_i), as they are better positioned to capture licensing revenues.

The second term,

$$-\frac{y_i + \gamma_i}{1 + y_i + y_j},$$

reflects a *downstream rent shift*. As royalties increase, part of the surplus is transferred from downstream implementers to SEP holders, lowering the return from y_i. For vertically integrated firms, this rent shift reduces the relative attractiveness of downstream innovation, thereby dampening incentives to expand y_i. The impact is again shaped by γ_i: downstream-leaning firms with high proximity are more exposed to this loss of downstream payoffs.

Finally, the third term,

$$\frac{(1 + x_j - \gamma_i)v}{(1 + x_i + x_j)^2},$$

represents a *competition and spillover effect*. Higher royalties amplify the strategic interaction between firms, as one firm's SEP position raises competitive pressure on others. When a firm has low γ_i, this effect is magnified, because it is less shielded by proximity to the standard and more vulnerable to rivals' upstream strength.

Turning to the downstream condition, the cross-partial in Equation (10) again decomposes into three channels. The first,

$$\beta \frac{x_i + \gamma_i}{1 + x_i + x_j},$$

is an *upstream substitution effect*: higher royalties make upstream investments relatively more profitable, which shifts the vertically integrated firms' portfolio away from downstream innovation. The second,

$$-\beta \frac{y_i + \gamma_i}{1 + y_i + y_j},$$

corresponds to *downstream rent loss*, reinforcing the discouragement of downstream activity as royalty revenues for upstream innovation rise. The third term,

$$-\frac{(1 + y_j - \gamma_i)v}{(1 + y_i + y_j)^2},$$

captures *downstream competition*, whereby increases in royalties exacerbate the extent to which downstream firms compete for shrinking residual rents.

Taken together, these expressions illustrate the three general mechanisms emphasized in the main text: (i) a *licensing revenue channel* that favors upstream investments; (ii) a *rent shifting channel* that reallocates surplus away from downstream innovators; and (iii) a *competitive spillover channel* that penalizes firms with low proximity γ_i, especially in markets with high rival activity.

For pure upstream firms, the cross-partial in Equation (11) shows that the effect of royalties is mediated by two terms. The first,

$$\frac{x_i - \gamma_i(x_i + x_j)}{1 + x_i + x_j},$$

reflects a *revenue shift by technological proximity*: higher γ_i attenuates the effect of royalty changes by ensuring that their upstream investments are already closely aligned with the standard. The second,

$$\frac{(1 + x_j - \gamma_i)(1 + x_i + x_j + \beta)}{(1 + x_i + x_j)^2},$$

captures a *competition and system-size effect.* Here, low-γ firms are particularly vulnerable: as royalties rise, their relative disadvantage increases because rivals' contributions are better rewarded.

For pure downstream firms, the derivative is shaped by two opposing forces. The first,

$$\beta\left(\gamma_i - \frac{y_i + \gamma_i}{1 + y_i + y_j}\right),$$

describes a *cost-revenue trade-off*: while higher γ_i cushions firms by allowing more effective downstream appropriation, increases in r shift profits away from deployment and toward upstream holders, weakening downstream incentives. The second,

$$-v(y)\frac{1 + y_j - \gamma_i}{(1 + y_i + y_j)^2},$$

captures *downstream competition.* low-γ firms face a stronger negative effect from royalty revenue increases, as they are less capable of differentiating themselves from rivals and suffer more intensely from competition in the residual downstream rents.

Overall, these comparative statics confirm that the sensitivity of investments to royalty revenue changes is greatest for low-γ firms. In line with the three channels identified in the main text, low-proximity firms experience weaker upstream gains, stronger downstream rent loss, and heightened exposure to competitive spillovers. High-γ firms, by contrast, are partly shielded from these effects, making their investment responses to royalty shifts comparatively muted.

Generalization to the n-Firm Case

Let $x = \sum_{k=1}^{n} x_k$, $y = \sum_{k=1}^{n} y_k$, and define $x_{-i} = x - x_i$, $y_{-i} = y - y_i$. Aggregate industry revenue is

$$v(x, y) = 1 + x + \beta(1 + y),$$

and firm i's revenue share is

$$b_i \;=\; v(x, y)\left[r\,\frac{x_i + \gamma_i}{1 + x} \;+\; (1 - r)\,\frac{y_i + \gamma_i}{1 + y}\right].$$

Profits are

$$\pi_i \;=\; (1 - \epsilon)\, b_i \;+\; \epsilon\, v(x, y) \;-\; \frac{x_i^2}{2} \;-\; \frac{y_i^2}{2\,(1 + \theta(x_i + \gamma_i))}.$$

Note $\partial v/\partial x_i = 1$ and $\partial v/\partial y_i = \beta$. For notational brevity set

$$A_i \;\equiv\; r\,\frac{x_i+\gamma_i}{1+x} \;+\; (1-r)\,\frac{y_i+\gamma_i}{1+y}.$$

The FOCs for firm i are as follows

$$\begin{cases} \dfrac{\partial \pi_i}{\partial x_i} = (1-\epsilon)\left[A_i \;+\; v(x,y)\,r\,\dfrac{1+x_{-i}-\gamma_i}{(1+x)^2}\right] \;+\; \epsilon \;-\; x_i \;+\; \dfrac{\theta\, y_i^2}{2\,[1+\theta(x_i+\gamma_i)]^2} = 0, \\ \dfrac{\partial \pi_i}{\partial y_i} = (1-\epsilon)\left[\beta\, A_i \;+\; v(x,y)\,(1-r)\,\dfrac{1+y_{-i}-\gamma_i}{(1+y)^2}\right] \;+\; \epsilon\beta \;-\; \dfrac{y_i}{1+\theta(x_i+\gamma_i)} = 0. \end{cases} \tag{13}$$

Using $\dfrac{\partial A_i}{\partial r} = \dfrac{x_i+\gamma_i}{1+x} - \dfrac{y_i+\gamma_i}{1+y}$ and noting that $v(x,y)$ does not depend on r,

$$\begin{cases} \dfrac{\partial}{\partial r}\left(\dfrac{\partial \pi_i}{\partial x_i}\right) = (1-\epsilon)\left[\;\underbrace{\dfrac{x_i+\gamma_i}{1+x}}_{\text{upstream share}} \;-\; \underbrace{\dfrac{y_i+\gamma_i}{1+y}}_{\text{downstream share}} \;+\; \underbrace{v(x,y)\,\dfrac{1+x_{-i}-\gamma_i}{(1+x)^2}}_{\text{upstream competition/denominator}}\;\right], \\ \dfrac{\partial}{\partial r}\left(\dfrac{\partial \pi_i}{\partial y_i}\right) = (1-\epsilon)\left[\beta\left(\underbrace{\dfrac{x_i+\gamma_i}{1+x}}_{\text{upstream substitution}} \;-\; \underbrace{\dfrac{y_i+\gamma_i}{1+y}}_{\text{downstream rent loss}}\right) \;-\; \underbrace{v(x,y)\,\dfrac{1+y_{-i}-\gamma_i}{(1+y)^2}}_{\text{downstream competition/denominator}}\;\right]. \end{cases} \tag{14}$$

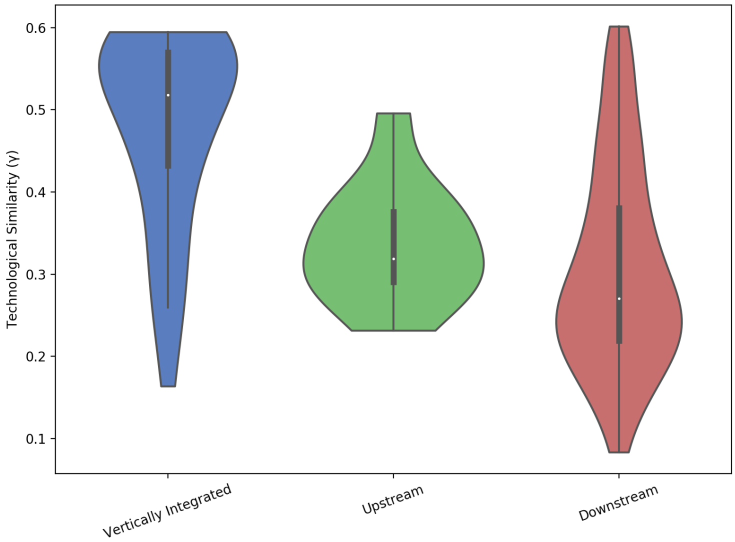
Under the same modeling primitives used in the two-firm analysis and standard assumptions (continuity, differentiability, and uniqueness of equilibrium), the comparative static patterns obtained in the two-firm case generalize to the n-firm economy. Specifically, the sign patterns of the cross-partials $\frac{\partial}{\partial r}!\left(\frac{\partial \pi_i}{\partial x_i}\right)$ and $\frac{\partial}{\partial r}!\left(\frac{\partial \pi_i}{\partial y_i}\right)$ in the n-firm expressions (Eq. (14)) have the same interpretation as in the two-firm model. They decompose into three components: an upstream licensing term, a downstream rent-shifting term, and a competition/spillover term that depends on rivals' aggregate investments and technological proximity.

Therefore, the qualitative comparative-static conclusions remain unchanged. First, firms with low γ_i are more sensitive to changes in r, with their total investment responding more strongly. Second, upstream-only SEP holders (high γ_i) reduce upstream investment when royalties fall, while downstream-oriented or low-γ firms expand downstream investment when royalties fall. The general n-firm first-order conditions and cross-partials (Eqs. (13) and (14)) retain the same three structural components that drive the two-firm results: an upstream share term $\frac{x_i+\gamma_i}{1+x}$, a downstream share term $\frac{y_i+\gamma_i}{1+y}$, and a competition/spillover term proportional to $v(x, y)$ with a denominator correction involving rivals' aggregate contributions x_{-i} or y_{-i}. The two-firm expressions are a special case where $x_{-i} = x_j$ and $y_{-i} = y_j$. Because the signs and economic interpretation of these three blocks do not depend on the number of rivals, the qualitative forces—licensing revenue, rent shifting, and competition/spillovers—remain the same.

Finally, the local comparative statics confirm that the sign of $\frac{\partial}{\partial r}!\left(\frac{\partial \pi_i}{\partial x_i}\right)$ and $\frac{\partial}{\partial r}!\left(\frac{\partial \pi_i}{\partial y_i}\right)$ depends on the relative magnitude of the upstream and downstream share terms and on the competition term. These relationships are preserved in the general n-firm case: an increase in n typically affects the magnitude of the competition term (more rivals $\Rightarrow$ stronger denominator effects) but not its qualitative role. Thus, the main comparative results—that low-γ firms are more responsive and that upstream-focused high-γ firms reduce upstream R&D when r decreases—persist provided equilibria remain interior and comparative signs are not reversed by extreme parameter values. While the qualitative directions are preserved, the magnitude of responses may vary with n, as higher n amplifies competitive denominator effects and reduces per-firm royalties. Heterogeneous distributions of γ_i across firms also affect the magnitude, but not the direction, of the responses.

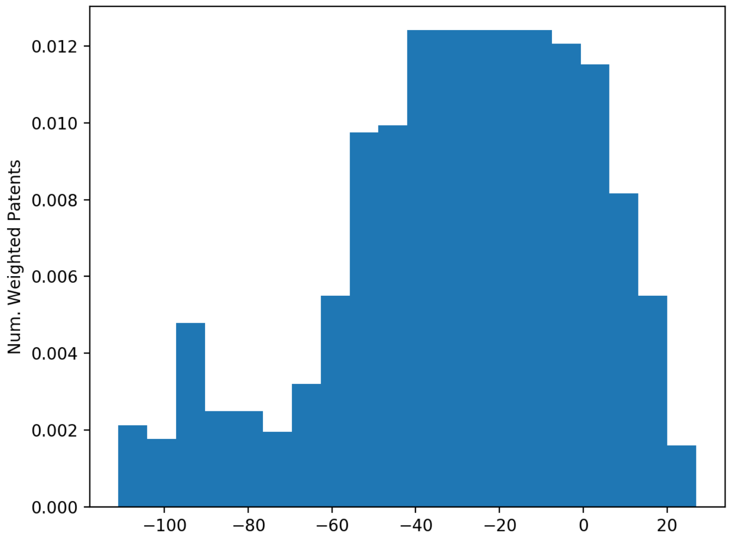
C Additional Figures and Tables

Figure 9
Technological Similarity (γ) by Firm Type



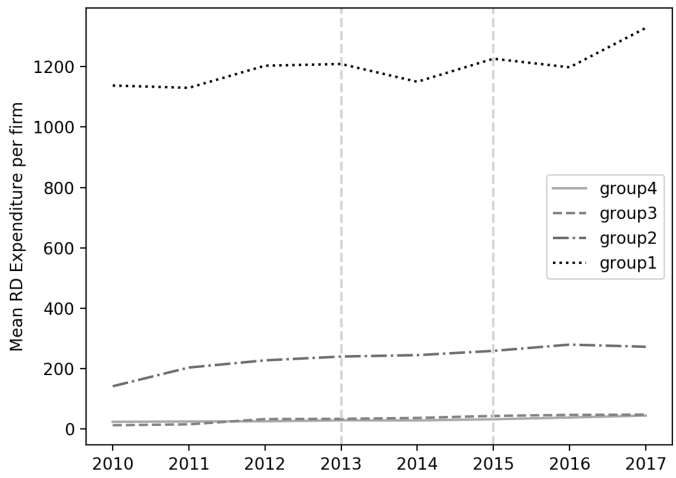
The figure shows the correlation between the technological similarity of a firm with its type. There are 11 firms that can be classified as pure upstream innovators, 38 as vertically integrated, and 111 as downstream-only.

Figure 10
Weighted Number of Patents per Standard over the standard's lifetime



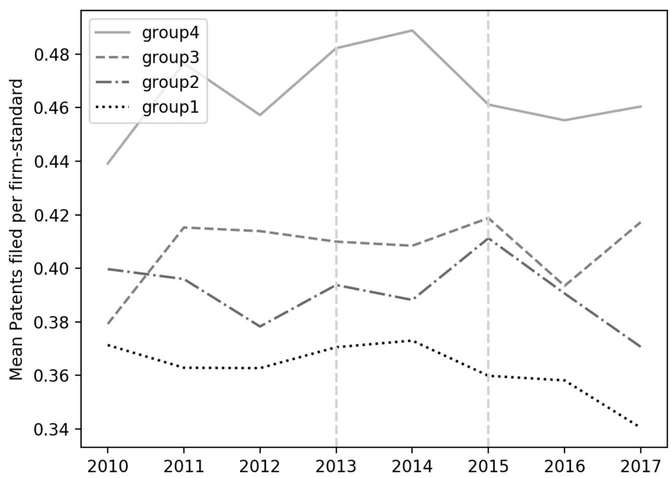
The figure shows the total number of weighted patents filed per standard in the years preceding and following the standard's publication.

Figure 11
R&D expenditures per firm before and after IEEE policy revision



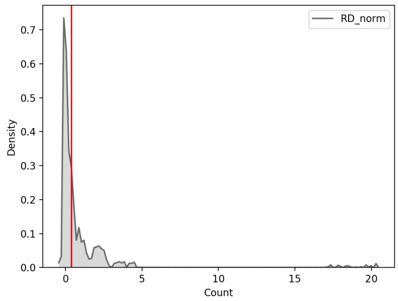
The figure shows the average R&D costs per firm over time, comparing the distribution across the four quartiles. The dashed light grey vertical lines denote 2013 and 2015, the year when the policy revision was announced and the year when it was endorsed by the organization. The black line plots the firms in the first quartile (control group), those that are technologically closer to IEEE's standards. The dark grey point-dashed line plots the firms in the second quartile, the grey dashed line firms in the third, and the light grey line firms in the fourth quartile.

Figure 12
Share of standard-related patents per firm before and after IEEE policy revision

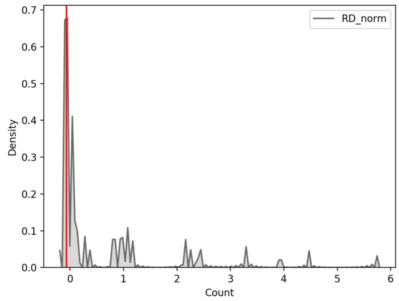


The figure shows the average ration of standard-related patents (not weighted) over total patenting per firm over time, comparing the distribution across the four quartiles. The dashed light grey vertical lines denote 2013 and 2015, the year when the policy revision was announced and the year when it was endorsed by the organization. The black line plots the firms in the first quartile (control group), those that are technologically closer to IEEE's standards. The dark grey point-dashed line plots the firms in the second quartile, the grey dashed line firms in the third, and the light grey line firms in the fourth quartile.

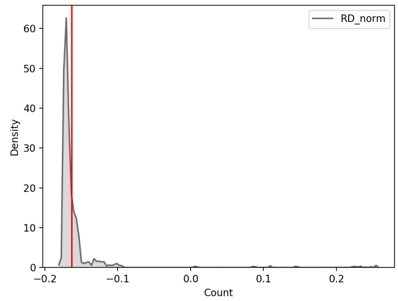
Figure 13
Heterogeneity Across Firms - R&D Expenditures



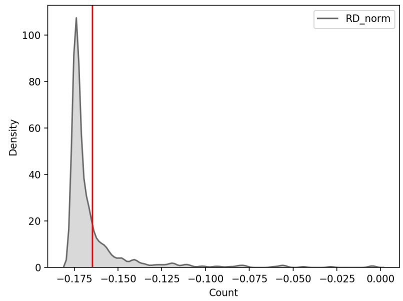
(a) 1st Quartile



(b) 2nd Quartile



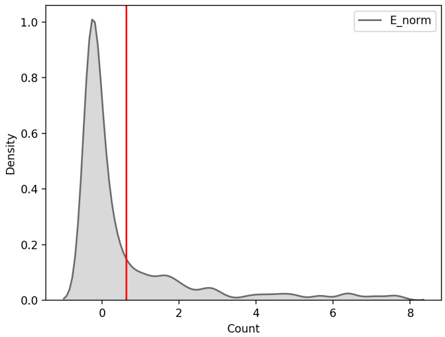
(c) 3rd Quartile



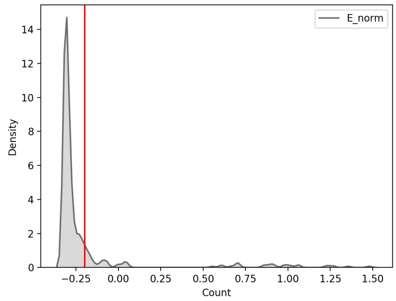
(d) 4th Quartile

These figures plot the distribution of R&D expenditures across firms within the four groups. Each observation represents a firm, and R&D costs are normalized across all firms in all quartiles. The red line denotes the average expenditure within each group.

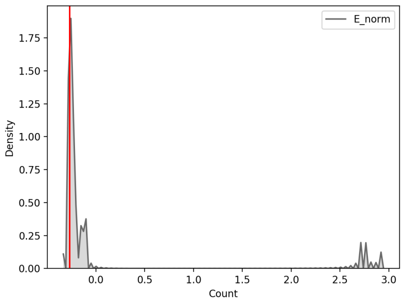
Figure 14
Heterogeneity Across Firms - Number of Employees



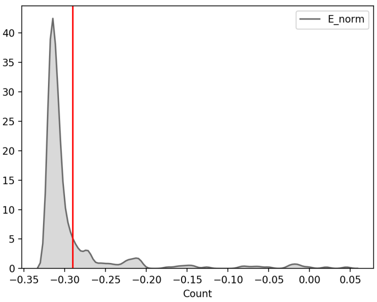
(a) 1st Quartile



(b) 2nd Quartile



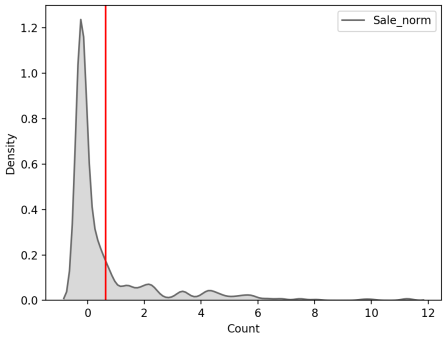
(c) 3rd Quartile



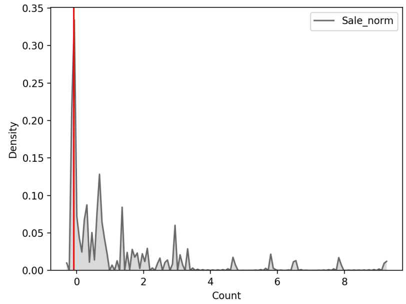
(d) 4th Quartile

These figures plot the distribution of the number of employees across firms in the four groups. Each observation represents a firm, and the number of employees is normalized across all firms in all quartiles. The red line denotes the average number of employees within each group.

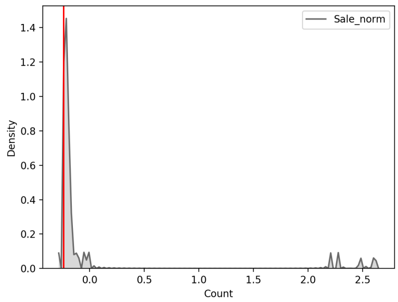
Figure 15
Heterogeneity Across Firms - Sales



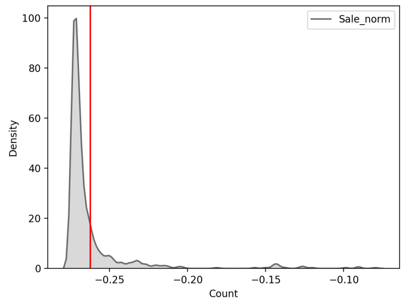
(a) 1st Quartile



(b) 2nd Quartile



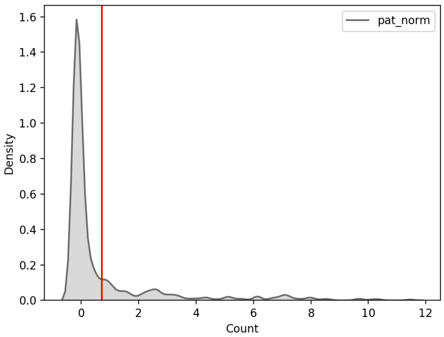
(c) 3rd Quartile



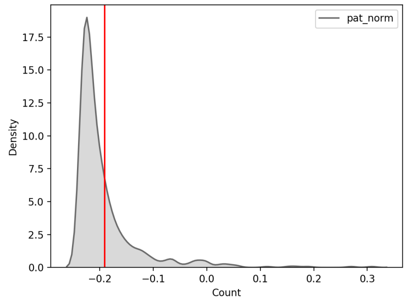
(d) 4th Quartile

These figures plot the distribution of sales across firms in the four groups. Each observation represents a firm, and sales are normalized across all firms in the quartiles. The red line denotes the average sales within each group.

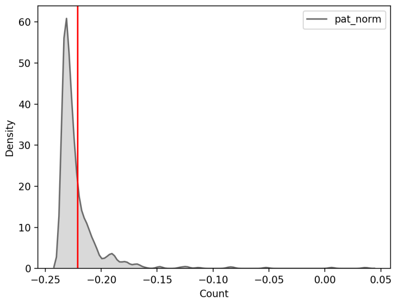
Figure 16
Heterogeneity Across Firms - Total Patenting



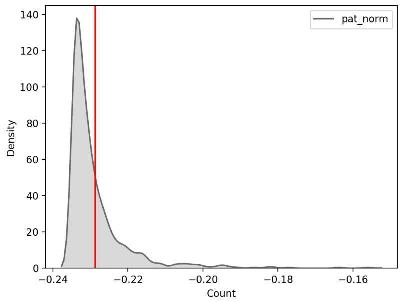
(a) 1st Quartile



(b) 2nd Quartile



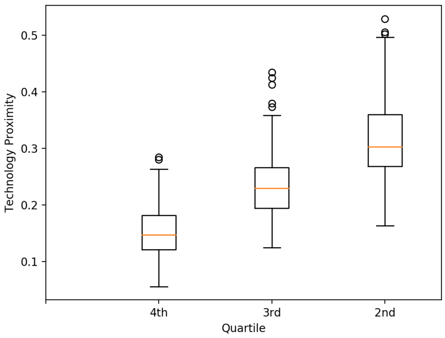
(c) 3rd Quartile



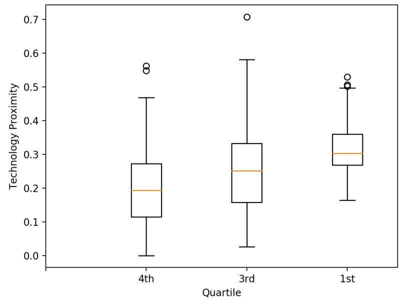
(d) 4th Quartile

These figures plot the distribution of patent counts across firms in the four groups. Each observation represents a firm, and patent counts are normalized across all firms in the quartiles. The red line denotes the average number of patents within each group.

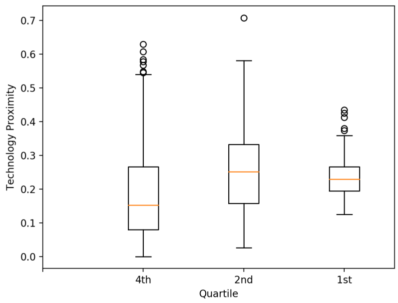
Figure 17
Technology Proximity across Quartiles



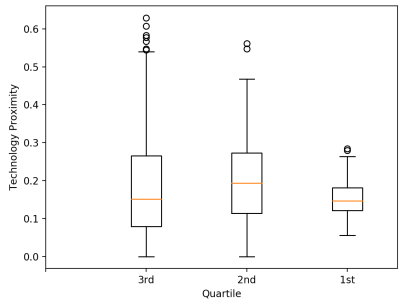
(a) 1st Quartile



(b) 2nd Quartile



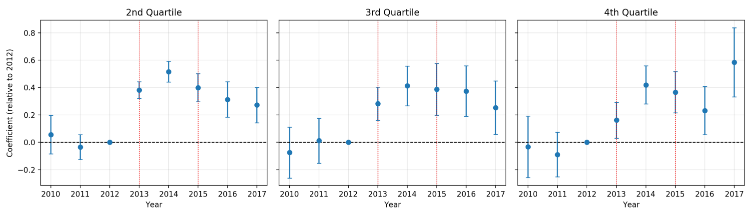
(c) 3rd Quartile



(d) 4th Quartile

These figures show the box plots illustrating the technology closeness between firms in the first (top-left), second (top-right), third (bottom-left), and fourth (bottom-right) quartiles compared to firms in the other groups. The technology proximities are computed as the cosine similarities between a firm and all other firms in the remaining groups.

Figure 18
Estimates of the Effect of IEEE Policy Change- Event Study



The figures illustrate the results from regressions reported in Table 17 across three treatment groups: firms in the second, third, and fourth quartiles. Each observation corresponds to a firm-standard pair in a given year. The baseline period is set to 2010, with the control group comprising firms in the first quartile, which are technologically closer to the IEEE. The top-left figure shows the results for the second quartile, the top-right for the third quartile, and the bottom figure for the fourth quartile. The dashed light grey lines indicate the years 2013 and 2015, marking the announcement and endorsement of the policy revision by the organization, respectively. Vertical bars represent 95% confidence intervals.

Table 3
Summary Characteristics of IEEE Standards Before and After Policy Revision

	Pre-period		Two-years Anticipation		Post-period	
	Mean	Std	Mean	Std	Mean	Std
Total number of standards	10		10		10	
Standards characteristics						
Number of SEP holders per standard	25.6	25.9	26.6	27.5	29.4	27.3
Number of disclosures made per standard	34.4	35.7	35.6	37.1	38.4	36.6
Number of essential patents declared per standard	112.7	128.5	112.9	132.8	120.4	129.7
Number of standard documents per standard	33.9	40.9	37.1	45.7	42.2	49.2
Number of technology classes per standard	76.8	134.6	68	137.6	68	136.4
Age of the standard at the time of declaration (mean)	8.9	7.3	11.40	7.4	13.9	7.3

Note: This table summarizes the characteristics of standards issued by IEEE, comparing cumulative numbers from 2012 and 2014 (pre-policy revision) to 2017 (post-policy revision). The ages of the standards are computed as the mean age before and after the policy change. For each standard, I compute cumulative values using data from the Searle Center Database, covering the period from the earliest available year to 2012 (Column 1), 2014 (Column 2), and 2017 (Column 3). This approach offers a comprehensive representation of each standard's characteristics over time, allowing for a comparison between the period before and after the policy change.

Table 4
Firms' Accounting Characteristics and Patent Portfolio Composition

	SEP Holders	Non-SEP Holders
Total number of firms	36	507
Firms characteristics		
Average R&D expenditures per year (millions)	4,178.7	125.2
Average number of employees per year (thousands)	107.6	7.6
Patent portfolio		
Average number of patents filed per firm per year	3,021.3	130.0
Average number of standard-related patents filed per firm per year	1,410.9	45.7
Total standard-related patents/total patents, average per firm (%)	47.2	42.2

Note: This table summarizes the characteristics of firms and their patent portfolios based on firm type (SEP holders vs. non-SEP holders) for the period 2010–2017.

Table 5

Top 10 Firms in First and Fourth Quartiles According to Their Technology Proximity

	Firm's Name	Technology Proximity
Top 10 Firms in the First Quartile		
	HANWANG TECH CO LTD	0.602
	PANASONIC CORPORATION	0.595
	SONY CORPORATION 7 0.591	
	TEXAS INSTRUMENTS INC	0.590
	LG ELECTRONICS	0.588
	SEIKO EPSON CORP	0.587
	NEC CORPORATION	0.586
	HON HAI PRECISION IND CO LTD	0.584
	IBM	0.583
	AT&T INC.	0.583
Top 10 Firms in the Fourth Quartile		
	ACEPLUX OPTOTECH INC	0.042
	INALWAYS CORP	0.072
	TIGERLOGIC CORP	0.072
	CLEARFIELD INC	0.072
	TSEC CORP	0.072
	GRUBHUB INC	0.072
	MAXPOINT INTERACTIVE INC	0.072
	MINDBODY INC	0.072
	TAINERGY TECH CO LTD	0.083
	SHUTTERSTOCK INC	0.083

Note: This table presents the ten firms with the closest and furthest proximity to the standards' technology space.

Table 6

Distribution of Firms across Industries

	1st Quartile	2nd Quartile	3rd Quartile	4th Quartile
Machinery Manufacturing	5	2	4	1
Computer and Electronic Product Manufacturing	81	95	95	66
Electrical Equipment, Appliance, and Component Manufacturing	4	9	0	6
Transportation Equipment Manufacturing	2	2	0	0
Merchant Wholesalers, Durable Goods	1	1	0	0
Electronics and Appliance Stores	1	0	0	0
Publishing Industries (except Internet)	4	8	10	38
Telecommunications	10	5	9	2
Other Information Services	4	2	13	31
Lessors of Nonfinansial Intangible Assets (except Copyrighted Works)	2	1	1	2
Professional, Scientific, and Technical Services	6	4	4	13

Note: This table presents the distribution of firms across NAICS code industries and quartiles for the period 2010-2017.

Table 7

Firms' Accounting Characteristics and Patent Portfolio Composition per Quartile

	1st Quartile		2nd Quartile		3rd Quartile		4th Quartile	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Total number of firms	120		129		136		150	
Firms characteristics								
Average R&D expenditures per year (millions)	1,337.5	4,310.4	281.0	1,235.2	36.6	108.5	33.9	62.8
Average number of employees per year (thousands)	52.6	92.1	7.1	17.5	2.8	15.5	1.8	3.3
R&D/SALE (%)	1.06	18.5	0.19	0.82	0.19	0.82	0.18	0.27
Patent portfolio								
Average number of filed patents per firm per year	1,305.0	2,764.4	65.3	105.4	20.2	36.2	10.2	20.0
Average number of filed standard-related patents per firm per year	556.8	1,518.2	28.4	66.9	8.5	21.1	5.1	13.0
Total number of standard-related patents/total number of patents, average per firm (%)	0.37	0.29	0.40	0.33	0.43	0.35	0.53	0.38
IEEE Technology distance	0.46	0.08	0.29	0.03	0.22	0.02	0.14	0.03
Total number of firms holding SEPs	30		5		1		0	

Note: This table summarizes the characteristics of firms and their patent portfolios across quartiles for the period 2010-2017.

Table 8
Effect of IEEE Policy Change on firm-standard patenting - 2nd Quartile

	Standard-related Patents		Standard-related Patents		Standard-related Patents	
	(1)	(2)	(3)	(4)	(5)	(6)
Anticipation-Period		0.397^{***}		0.398^{***}		0.388^{***}
		(0.042)		(0.042)		(0.042)
$dPOST * dGroup_{i,IEEE} = 2$	0.169^{***}	0.270^{***}	0.168^{***}	0.270^{***}	0.104^{*}	0.206^{***}
	(0.056)	(0.063)	(0.055)	(0.062)	(0.057)	(0.063)
Standard-firm technology distance	-1.323^{***}	-1.324^{***}	-1.323^{***}	-1.324^{***}	-1.456^{***}	-1.452^{***}
	(0.486)	(0.486)	(0.484)	(0.484)	(0.499)	(0.500)
Sales (log)	0.513^{***}	0.510^{***}	0.510^{***}	0.506^{***}	0.513^{***}	0.510^{***}
	(0.039)	(0.039)	(0.040)	(0.040)	(0.039)	(0.039)
N of SEP holders (log)	−0.028	−0.036	−0.044	−0.045	−0.027	−0.036
	(0.029)	(0.028)	(0.035)	(0.035)	(0.029)	(0.028)
Standard's documents (log)	0.100	0.045	0.144^{*}	0.145^{*}	0.100	0.046
	(0.099)	(0.105)	(0.081)	(0.081)	(0.099)	(0.105)
Standard Age FE	Yes	Yes	No	No	Yes	Yes
Year FE	No	No	Yes	Yes	No	No
Quartile_Time_trend	No	No	No	No	Yes	Yes
Standard FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Num.Obs.	18598	18598	18598	18598	18598	18598
Log-L	-85008.25	-84740.39	-85013.02	-84831.37	-84899.69	-84639.46

Note: The dependent variable is the weighted number of patents per firm-standard. The method of estimation is maximum likelihood for the Poisson model. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table 9
Effect of IEEE Policy Change on firm-standard patenting - 3rd Quartile

	Standard-related Patents		Standard-related Patents		Standard-related Patents	
	(1)	(2)	(3)	(4)	(5)	(6)
Anticipation-Period		0.313^{***}		0.314^{***}		0.308^{***}
		(0.061)		(0.061)		(0.062)
$dPOST * dGroup_{i,IEEE} = 3$	0.169^{***}	0.271^{***}	0.168^{***}	0.272^{***}	0.130^{*}	0.232^{***}
	(0.064)	(0.079)	(0.064)	(0.079)	(0.069)	(0.084)
Standard-firm technology distance	-1.514^{**}	-1.514^{**}	-1.511^{**}	-1.511^{**}	-1.542^{**}	-1.542^{**}
	(0.594)	(0.595)	(0.594)	(0.594)	(0.599)	(0.600)
Sales (log)	0.522^{***}	0.521^{***}	0.519^{***}	0.518^{***}	0.522^{***}	0.521^{***}
	(0.040)	(0.040)	(0.042)	(0.042)	(0.040)	(0.040)
N of SEP holders (log)	−0.026	−0.035	−0.044	−0.044	−0.026	−0.035
	(0.029)	(0.029)	(0.036)	(0.036)	(0.029)	(0.029)
Standard's documents (log)	0.107	0.047	0.142^{*}	0.142^{*}	0.107	0.047
	(0.103)	(0.109)	(0.083)	(0.083)	(0.103)	(0.109)
Standard Age FE	Yes	Yes	No	No	Yes	Yes
Year FE	No	No	Yes	Yes	No	No
Quartile_Time_trend	No	No	No	No	Yes	Yes
Standard FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Num.Obs.	18436	18436	18436	18436	18436	18436
Log-L	-77926.11	-77800.47	-77950.26	-77921.40	-77914.32	-77789.48

Note: The dependent variable is the weighted number of patents per firm-standard. The method of estimation is maximum likelihood for the Poisson model. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table 10
Effect of IEEE Policy Change on firm-standard patenting - 4th Quartile

	Standard-related Patents		Standard-related Patents		Standard-related Patents	
	(1)	(2)	(3)	(4)	(5)	(6)
Anticipation-Period		0.378^{***}		0.377^{***}		0.373^{***}
		(0.058)		(0.058)		(0.058)
$dPOST * dGroup_{i,IEEE} = 4$	0.288^{***}	0.417^{***}	0.288^{***}	0.417^{***}	0.225^{***}	0.352^{***}
	(0.083)	(0.085)	(0.082)	(0.084)	(0.086)	(0.089)
Standard-firm technology distance	-1.582^{***}	-1.583^{***}	-1.574^{***}	-1.574^{***}	-1.595^{***}	-1.596^{***}
	(0.579)	(0.579)	(0.578)	(0.578)	(0.574)	(0.575)
Sales (log)	0.523^{***}	0.522^{***}	0.520^{***}	0.519^{***}	0.523^{***}	0.522^{***}
	(0.040)	(0.040)	(0.042)	(0.042)	(0.040)	(0.040)
N of SEP holders (log)	-0.026	-0.035	-0.044	-0.044	-0.025	-0.035
	(0.029)	(0.029)	(0.036)	(0.036)	(0.029)	(0.029)
Standard's documents (log)	0.107	0.046	0.140^{*}	0.140^{*}	0.107	0.046
	(0.103)	(0.110)	(0.084)	(0.084)	(0.103)	(0.110)
Standard Age FE	Yes	Yes	No	No	Yes	Yes
Year FE	No	No	Yes	Yes	No	No
Quartile_Time_trend	No	No	No	No	Yes	Yes
Standard FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Num.Obs.	18522	18522	18522	18522	18522	18522
Log-L	-76686.94	-76562.64	-76713.02	-76686.96	-76664.60	-76540.79

Note: The dependent variable is the weighted number of patents per firm-standard. The method of estimation is maximum likelihood for the Poisson model. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table 11
Effect of IEEE Policy Change - Anticipation Effect Specifications

		Standard-related Patents	
		Extended	Pooled
Anticipation-Period			
	2nd Quartile (2013)	0.377***	
		(0.044)	
	2nd Quartile (2014)	0.514***	
		(0.052)	
	3rd Quartile (2013)	0.295***	
		(0.069)	
	3rd Quartile (2014)	0.428***	
		(0.075)	
	4th Quartile (2013)	0.195***	
		(0.071)	
	4th Quartile (2014)	0.456***	
		(0.079)	
	2nd Quartile (Pooled)		0.446***
			(0.045)
	3rd Quartile (Pooled)		0.363***
			(0.065)
	4th Quartile (Pooled)		0.332***
			(0.072)
Post-Period			
	2nd Quartile	0.332***	0.331***
		(0.071)	(0.071)
	3rd Quartile	0.353***	0.351***
		(0.094)	(0.093)
	4th Quartile	0.436***	0.433***
		(0.096)	(0.096)
Covariates		Yes	Yes
Standard Age FE		Yes	Yes
Quartile_Time_trend		Yes	Yes
Standard FE		Yes	Yes
Firm FE		Yes	Yes

Note: The dependent variable is the weighted number of patents per firm-standard. Column (1) shows results from the extended specification with separate coefficients for 2013 and 2014 anticipation effects. Column (2) shows results from the pooled specification with a single coefficient for the 2013-2014 anticipation period. All coefficients represent interaction effects between the treatment group and time periods. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table 12
Effect of IEEE Policy Change on Non-standard-related Patents

		Non-std Patents	
		(1)	(2)
Anticipation-Period			
	2nd Quartile		0.252^{***}
			(0.040)
	3rd Quartile		0.093^{*}
			(0.048)
	4th Quartile		0.349^{***}
			(0.057)
Post-Period			
	2nd Quartile	0.101^{*}	0.165^{***}
		(0.052)	(0.058)
	3rd Quartile	0.084	0.106
		(0.064)	(0.073)
	4th Quartile	0.454^{***}	0.555^{***}
		(0.065)	(0.075)
Covariates		Yes	Yes
Quartile_Time_trend		Yes	Yes
Standard Age FE		Yes	Yes
Standard FE		Yes	Yes
Firm FE		Yes	Yes

Note: The dependent variable is the number of non-standard-related patents per firm-standard. The method of estimation is maximum likelihood for the Poisson model. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table 13
Mechanism Analysis: Effect of IEEE Policy Change on Innovation Channels

		Non-std Patents	R&D	Total Patents
		Anticipation	Anticipation	Anticipation
Anticipation-Period				
	1st Quartile - SEP Holders	-0.060	-0.025	-0.037
		(0.054)	(0.022)	(0.048)
	2nd Quartile - Non-SEP holders	0.229^{***}	-0.042^{***}	0.266^{***}
		(0.056)	(0.015)	(0.051)
	2nd Quartile - SEP Holders	0.867^{***}	-0.170^{***}	0.832^{***}
		(0.099)	(0.045)	(0.097)
Post-Period				
	1st Quartile - SEP Holders	0.061	-0.189^{***}	0.069
		(0.084)	(0.038)	(0.073)
	2nd Quartile - Non-SEP holders	0.289^{***}	-0.072^{***}	0.287^{***}
		(0.082)	(0.024)	(0.073)
	2nd Quartile - SEP Holders	-0.523^{*}	-0.125^{***}	-0.367^{*}
		(0.268)	(0.037)	(0.197)
Covariates		Yes	Yes	Yes
Standard Age FE		Yes	Yes	Yes
Quartile_Time_trend		Yes	Yes	Yes
Standard FE		Yes	Yes	Yes
Firm FE		Yes	Yes	Yes

Note: This table shows the effect of IEEE policy change on different innovation channels. Column (1)) shows results for non-standard-related patents, column (2) for R&D expenditure, and columns(3) for total patents. The method of estimation is maximum likelihood for the Poisson model for patents and OLS for R&D. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table 14
Effect of IEEE Policy Change on ETSI Standard-related Patents

		ETSI Standard-related Patents	
		(1)	(2)
Anticipation-Period			
	2nd Quartile		0.378^{***}
			(0.007)
	3rd Quartile		0.299^{***}
			(0.007)
	4th Quartile		0.312^{***}
			(0.009)
Post-Period			
	2nd Quartile	0.228^{***}	0.324^{***}
		(0.006)	(0.007)
	3rd Quartile	0.252^{***}	0.352^{***}
		(0.006)	(0.008)
	4th Quartile	0.247^{***}	0.356^{***}
		(0.009)	(0.009)
Covariates		Yes	Yes
Standard Age FE		Yes	Yes
Quartile_Time_trend		Yes	Yes
Standard FE		Yes	Yes
Firm FE		Yes	Yes

Note: The dependent variable is the weighted number of ETSI standard-related patents per firm-standard. Column (1) shows results from post-only specifications, and column (2) shows results from specifications including anticipation effects. The method of estimation is maximum likelihood for the Poisson model. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table 15
Effect of IEEE Policy Change - Robustness checks I

	Bluetooth	Standard-related Patents (w0)	Tech Distance 2012	
Post-Period				
	2nd Quartile	0.205	0.207^{***}	0.219^{***}
		(0.158)	(0.061)	(0.063)
	3rd Quartile	-0.187	0.215^{***}	0.182^{**}
		(0.159)	(0.079)	(0.080)
	4th Quartile	0.090	0.348^{***}	0.370^{***}
		(0.145)	(0.087)	(0.096)
Covariates		Yes	Yes	Yes
Standard Age FE		Yes	Yes	Yes
Quartile_Time_trend		Yes	Yes	Yes
Standard FE		Yes	Yes	Yes
Firm FE		Yes	Yes	Yes

Note: The dependent variable is the weighted number of patents per firm-standard. The first column reports the results for Bluetooth standards. In the second column, the dependent variable is weighted to account for zeros in the IPC classes related to the standard. In the third column, firms are clustered based on their patent portfolios from 2000 to 2012. The method of estimation is maximum likelihood for the Poisson model. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table 16
Effect of IEEE Policy Change - Robustness checks II

		Standard-related Patents	
		(1)	(2)
Anticipation-Period			
	2nd Quartile		0.387^{***}
			(0.042)
	3rd Quartile		0.310^{***}
			(0.062)
	4th Quartile		0.376^{***}
			(0.058)
Post-Period			
	2nd Quartile	0.101^{*}	0.203^{***}
		(0.057)	(0.064)
	3rd Quartile	0.133^{*}	0.235^{***}
		(0.069)	(0.084)
	4th Quartile	0.229^{***}	0.358^{***}
		(0.085)	(0.088)
Covariates		Yes	Yes
Standard Age FE		Yes	Yes
Quartile_Time_trend		Yes	Yes
Standard FE		Yes	Yes
Firm FE		Yes	Yes

Note: The dependent variable is the weighted number of patents per firm-standard. The method of estimation is maximum likelihood for the Poisson model in the multiple regression, accounting for all groups in a single specification. The control group is the first quartile, and the baseline period is 2010-2014. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table 17
Effect of IEEE Policy Change on firm-standard patenting - Event Study

		2nd Quartile	3rd Quartile	4th Quartile
Pre-Period				
	2010	0.056	−0.075	−0.033
		(0.072)	(0.095)	(0.115)
	2011	−0.035	0.012	−0.090
		(0.046)	(0.084)	(0.083)
	2013	0.381^{***}	0.282^{***}	0.162^{**}
		(0.031)	(0.062)	(0.067)
Anticipation-Period				
	2014	0.516^{***}	0.412^{***}	0.419^{***}
		(0.039)	(0.074)	(0.071)
Post-Period				
	2015	0.399^{***}	0.387^{***}	0.366^{***}
		(0.052)	(0.097)	(0.077)
	2016	0.313^{***}	0.374^{***}	0.232^{***}
		(0.066)	(0.094)	(0.090)
	2017	0.272^{***}	0.253^{**}	0.585^{***}
		(0.066)	(0.100)	(0.129)
Covariates		Yes	Yes	Yes
Quartile_Time_trend		Yes	Yes	Yes
Standard FE		Yes	Yes	Yes
Firm FE		Yes	Yes	Yes

Note: The dependent variable is the weighted number of patents per firm-standard. The baseline period is 2012. Standard errors are presented in parentheses and allow for serial correlation through clustering by firm-standard. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.