Standardization and Patent Portfolios: Understanding Firms' Choices in Standard Projects

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Abstract

This paper studies the relationship between the participation decision of firms in standardization and the fit between the firm's technical knowledge and the standard's position in the technology space. Focusing on a set of firms that declare to own essential patents for several standards issued by different organizations, I study how firms allocate their contributions across standards, depending on a firm-standard similarity measure and the intensity of competition among participating firms. My findings suggest that the match between the technological fields of a standard and the firm's technical knowledge is positively related to the firm's decision to participate in standards development. In particular, I find empirical evidence that for a 1 percentage point increase in the technological fit between a firm and a standard, the probability that the firm participates in the technological development of the standard increases by 0.05 percentage points. Furthermore, my results support the hypothesis of a competition effect among participating firms. For a one-unit increase in the intensity of competition among firms in the same standard, either driven by an increase in the number of firms contributing to the standard or in the knowledge similarity among existing firms, the number of SEPs declared decreases by 32.7% on average.

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1 Introduction

In many technological fields, innovation activities have become increasingly complex, often requiring the collaborative efforts of a wide and diverse range of players. A prominent example of such collaborations is the development of technology standards, which have become an essential component of economic activities through the promotion of interoperability of inventions developed by different firms necessary for the production of complex products. Formal standards are developed in Standard Setting Organizations (SSOs) that are open to a broad range of stakeholders, including private firms and national and international institutions. Firms supply technologies and collaboratively develop technology standards in several SSOs. The participation decision to contribute to standards development by a firm is highly strategic and depends on the incentives the firm faces when deciding whether to participate and how much effort to exert in standardization.

There is a substantial recent literature studying the determinants for firms to participate in standards development. The existing research has particularly focused on the interplay between participation in standard organizations and patenting (Blind and Thumm, 2004; Gandal et al., 2004), with a notable effort devoted to the economic effects of standard essential patents (Rysman and Simcoe, 2008; Lerner and Tirole, 2015) and the motives affecting the strategic decision of firms to declare the ownership of intellectual property to standard organizations (DeLacey et al., 2006; Bekkers et al., 2011; Hussinger and Schwiebacher, 2013; Layne-Farrar et al., 2014). Standard essential patents (SEPs) are defined as intellectual property rights on the technologies necessary for the implementation of the standard (Shapiro, 2000; Lerner and Tirole, 2015; Baron and Spulber, 2018). Existing empirical studies have generally taken the form of case studies, focusing on a specific Standard Setting Organization (Farrell et al., 1992; Bekkers, 2001; DeLacey et al., 2006). To the best of my knowledge, the role of the match between the firms' technological knowledge and the standard's position in the technology space in shaping the firms' decisions to declare SEPs has not been studied so far.

My study contributes to this literature by providing empirical evidence regarding the role of the firm-standard match on firms' incentives to participate in standards development through SEPs declarations. In my research, I rely on a cross-sectional sample of 106 firms declaring essential patents to 539 standards issued by 8 standards organizations. By exploiting the heterogeneity across standards issued by several organizations, I analyze whether firms holding patent portfolios more similar to the standard-related technology classes are more likely to declare standard essential patents. My findings suggest that the match between the technological fields of a standard and the firm's technical knowledge is an important driver of the firm's participation decision in standards development. In particular, I find a positive relationship between the degree of the firm-standard technological similarity and the likelihood of the firm contributing to a standard. For a one percentage point increase in the technological fit between a firm and a standard, the probability that the firm participates in the technological development of the standard increases by 0.05 percentage points.

I complement my study by empirically analyzing how the competition among firms contributing to the same standard relates to standard-related patenting behavior. A growing body of research has focused on the role of the degree of complementarity and competition between technology contributors as determinants of the participation decision of firms in standards development. The literature has particularly paid attention to the interplay between the technological competition of firms developing the technologies necessary for the standard and the coordination effort with competitors for the development of the standard (Baron and Pohlmann, 2013; Bar and Leiponen, 2014; Delcamp and Leiponen, 2014; Rosa, 2019). As highlighted by Leiponen (2008) and Baron and Pohlmann (2013), in standards development, firms must coordinate their innovation activities with rivals in order to achieve a common standard while competing on the selection of standard's components. This stream of literature has studied the role of the technological distance between firms in the context of cooperative standard setting, focusing on the firm's membership in standard consortia (Baron and Pohlmann, 2013), in standard committees (Bar and Leiponen, 2014), and the firms' submission of technical contributions (Rosa, 2019) as measures of participation in standards development. None of these papers focuses on firms' essential patents declarations.

Lastly, a few empirical papers have focused on the role of R&D coordination and competition for the effort exerted by firms in developing standards. Some of these studies have investigated the effect of firms' cooperative arrangements on the overall number of standard-related patents (Bar and Leiponen, 2014) and the number of essential patents declared (Pohlmann and Blind, 2011). Closer to this paper is Rosa (2019), who studies the competition effect among firms participating in a standard group related to one organization on their standard-setting effort, measured by the number of technical contributions at the firm level. I contribute to this literature by providing empirical evidence regarding the role of the technological competition among firms declaring essential patents on standard-related patenting. Since I have to match firms' patenting behaviors with balance sheets information information I restrict my analysis to a sample of 411 standards issued by 8 organizations and 73 firms declaring SEPs. In contrast to the early studies, I account for the declarations of firms as a measure of standard participation and, building on this literature, I define a new competition measure that accounts not only for the technological distance between firms but also for the number of firms contributing to the same standard.

For this analysis, I define a measure of competition that allows me to characterize whether firms are closer competitors and the intensity of competition among them, such that depends on (i) the technology similarity between firms within a common standard and (ii) the number of firms contributing to the standard. Notably, firms with similar technological knowledge, which by definition have similar patents, are more likely to develop similar inventions and to compete on the technologies to be included in the standard. Thus in standards characterized by firms that supply technological substitutes, firms face tougher competition for developing standard-related technologies, either essential or non-essential. Furthermore, holding the importance and complexity of the standard fixed, firms participating in standards featuring a smaller number of firms are more likely to develop standard-essential technologies compared to firms contributing to standards characterized by a larger number of participants. To test the effect of the competition among participants of a standard, I estimate a fixed-effects model that relates the degree of competition among participating firms to the effort of firms in developing the standard. In particular, I include in my specifications standards' and firms' fixed effects to account for the unobservable factors that can affect the effort exerted by firms in the standards.

The joint analysis of patents and standards is not straightforward and has some limitations. Declared SEPs are not necessarily essential for a standard (Stitzing et al., 2017; Brachtendorf et al., 2020), and not all actual standard essential patents are necessarily declared either through blanket disclosures or firms can decide to stay out of the standardization process for strategic reasons (Bekkers et al., 2012; Baron et al., 2014). Finally, the population of patents directly related to standardization is much larger than the group of narrowly defined standard essential patents. Some patented inventions may be useful but not essential for implementing a standard. Those patents are called commercially essential patents. Therefore, because not all standard-related technologies are declared or become essential for a standard, I use two different variables to measure the effort of firms in standardization: the number of patents declared essential and the overall number of standard-related patents, either essential or not, filed by a firm in the technology classes associated with the standard.

My results show that firms declare fewer SEPs when participating in standards where the competition is more intense. For a one-unit increase in the intensity of competition among firms in the same standard, either driven by an increase in the number of firms contributing to the standard or in the knowledge similarity among existing firms, the number of SEPs declared decreases by 32.7% on average. The results are constant when I also account for the total number of standard-related patents filed, even if it weakens in magnitude. My results show a negative relationship between the intensity of competition among firms in a common standard and the number of patents filed in the standard-related technology classes. For an increase of 1 unit in the competition intensity among participating firms, firms file 15.7% fewer patents when I include the full set of fixed effects. The negative and significant relationship between the firm's standard-related effort and the intensity of competition supports the hypothesis of a *competition* effect, according to which when technologically similar firms want to participate in standardization through the ownership of intellectual property rights relevant to the standard, the competition over standard-related patents becomes more intense and firms are less likely to develop technologies that are relevant to the standard.

The remainder of the paper proceeds as follows. In Section 2, I provide an overview of the related literature. Section 3 describes the data sources and the sample used in the empirical analysis. I present the econometric methodology and the empirical results in Section 4. Lastly, in Section 5, I provide some concluding remarks.

2 Literature review

The existing economic literature has substantially studied the standard-setting process and the specific institutions in which standardx setting takes place. The standard-setting processes differ in the mechanisms followed to achieve compatibility. David and Greenstein (1990) provide a detailed description of the different types of standard-setting processes and their consequences for industry structure and welfare. Technology standards can result from the competition among firms that offer competing incompatible technologies. Katz and Shapiro (1985) analyze the social and private incentives for firms to achieve technical compatibility and standardization in the presence of network externalities. Farrell and Saloner (1985) focus on the benefit from standardization and study how communication can overcome the risk of trapping an industry in an inferior standard. Augereau et al. (2006) empirically study the standards war for the 56K modems and emphasize the role of internet service providers' competition and service differentiation in preventing the market from achieving standardization until the intervention of a Standard Setting Organization.

On the other hand, standards can result from voluntary coordination between competing agents. There are various organizational forms of such forums (Leiponen, 2008). These may be private alliances, industry consortia, or open standard-setting organizations. Farrell and Saloner (1988) model consensus standard setting as a war of attrition and compare its performance to a simplified market-based standards war. Farrell and Simcoe (2012) build on the war of attrition model to study the welfare implication of different consensus and licensing rules endorsed by Standard Setting Organizations. Lerner and Tirole (2006) focus on collaborative standards development and emphasize the fact that participants may be able to engage in forum shopping when there are multiple organizations. Spulber (2016) analyzes the bargaining process over patent licensing royalties between innovators and users of a technology standard and predicts that the interplay between voting in SSOs and competition in the market results in the selection of efficient innovation. Larouche and Schuett (2019) focus on the standard-setting process and show that repeated interactions among firms supplying technology to standards development generate the incentive to avoid excessive royalties by threatening to exclude other technology contributors from future rounds of standardization, if they charge royalties higher than FRAND.

A more recent literature on standardization has focused on the decision of firms to participate in the development of standards through participation at voluntary and consensus-based standard organizations. The literature has studied and identified an array of factors motivating firms' involvement in standards development. These include learning and knowledge diffusion, appropriating value from a portfolio of proprietary technologies, influencing technology development, networking, and R&D coordination. A number of studies analyze the role of patents in firms' decisions to be involved in standards development. Gandal et al. (2004) empirically examine the interaction between intellectual property and participation in standardization committee meetings in the modem industry. They find that while participation in standardization predicts future patenting, patents are not a good predictor for meeting attendance. By contrast, Blind and Thumm (2004) find that firms strongly relying on patents to protect their R&D investments are less likely to join the standard-setting process.

Another argument suggesting a link between patenting and standard-setting participation relates to standard essential patents. From the firms' perspective, having one intellectual property deemed essential to a standard can ensure a steady stream of licensing revenue in the future. Thus the impact of a firm from being included or excluded from an important standard can be substantial (DeLacey et al., 2006). Rysman and Simcoe (2008) show that the declared patents essential to standards increase their returns by affecting the future adoption of the patented technology. The expected additional return may incentivize firms to participate in standards development in order to have their patented technology included in the standard. Several economics studies have focused on the determinants of essential patent declarations (Farrell et al., 1992; Bekkers, 2001; DeLacey et al., 2006). Qualitative case studies, such as Bekkers (2001) and DeLacey et al. (2006), study the competitive behavior of firms in standard-setting organizations by examining the standardization process of respectively wireless standards and IEEE. Bekkers et al. (2011) show that the extent to which the firm participates in standard-developing activities is an important predictor of the likelihood of its patents being declared essential for the technology standard. Hussinger and Schwiebacher (2013) focus on a sample of firms declaring essential patents to open standard organizations and find that the disclosure of standard-relevant IP ownership is valued positively by financial markets if the disclosure refers explicitly to associated patents.

On the other hand, involvement in standards development is also associated with high costs for firms with valuable intellectual properties. Specifically, Standard Setting Organizations can require the patent holders for a price commitment on the owned standard essential patents. Lerner and Tirole (2015) focus on the economic effects of standard essential patents (SEPs) and study the inefficiencies attached to the lack of licensing price commitments for these types of patents. Layne-Farrar et al. (2014) focus on the relationship between licensing rules endorsed by SSOs and the participation decision of firms. They study the effects of a range of licensing rules on firms' participation decisions and R&D investment and show that firms holding essential technologies for a standard may decide to stay out of standardization when the standard is developed by an organization endorsing unfavorable (to SEP holders) licensing requirements. Neither paper considers the firm-standard match as a determinant of declarations. I extend the earlier literature and contribute to the understanding of firms' participation in standards development through essential patent declarations by studying how the firm-standard technology similarity affects this decision. Rosa (2019) develops a structural model to quantify the effect of the firm-standard match on the firm's participation decision in standards development. To do so, she focuses on the 3GPP working group, and she measures the participation decision of firms in terms of technical contributions submitted in the release of the standard and the firm-standard match in terms of the broadness of the standards on the one hand, and size of the patent portfolio of the firms on the other. What distinguishes my research is that, while this project aims to provide a descriptive analysis, I focus on a sample of 8 organizations to analyze the participation decision of firms in standards development through the declaration of essential technologies to the standard. In addition, my definition of the firm-standard similarity measure accounts for the technological similarity between a firm's and standard's patent portfolio.

A vast literature has highlighted the role of standard participation in R&D coordination. These studies focus on the firm's trade-off when participating in the standard-setting process between the R&D coordination effort among rivals for the creation of a common value and the competition between competing firms to appropriate the created value through the inclusion of their technologies in the standard. Leiponen (2008) focuses on the 3GPP working group to examine the roles of standard-setting committees, private alliances, and consortia in the competition among firms to influence formal standardization. Her results suggest that firms should identify both formal organizations and informal alliances where they can align their technical features in order to influence the evolution of their industry. Delcamp and Leiponen (2014) study the effect of industry consortia on the coordination of innovation strategy, focusing on the patent citation network, and find that firms participating in the same consortium are likelier to cite each other's patents.

Further research has extended this literature by analyzing the role of the technological position of firms for their involvement in standards development. Baron and Pohlmann (2013) use the correlation measure and the similarity score between firms' technological portfolios over the standard-related IPC classes to study whether firms participating in the standards development contribute complementary or substitutable technologies. Analyzing membership in standard consortia, they show that firms are more likely to participate in consortia with firms specializing in the same technology components (substitutes) of the standard, suggesting that consortia can reduce wars of attrition and duplicated R&D costs of technological rivals through upfront R&D coordination. Bar and Leiponen (2014) define the firms' patent portfolio as the share of U.S. patents held in each of the 15 most relevant wireless telecommunications technology classes and use the Euclidean distance between the firms' patent profile vectors to study whether firms form committees in a way that is aligned with complementarity or substitutability of their technological inputs. They find firms are more likely to cooperate in R&D development when they are technologically distant. Rosa (2019) studies how the knowledge similarity among firms, measured by the average cosine similarity, shapes firms' participation and effort decisions in 3GPP standardization groups. She provides evidence of cooperation and competition effects among participating firms. Her results suggest that, on the one hand, a cooperation effect generates incentives for firms to exert more effort in standards development when firms team up with rivals specialized in similar technological fields. On the other hand, the competition effect among similar firms generates incentives for firms to exert less effort in the standardization process.

These papers rely on firms' membership, either in formal organizations or informal alliances, and the firms' technical contributions to identify the firms participating in standardization. My research differs from the previous literature on technology development and standardization by relying on the firms' declarations of essential patents as a measure of the firm's participation. Furthermore, I build on this literature to define a measure of the technology similarity among firms under a common standard that captures the intensity of competition between those firms. Specifically, following Bar and Leiponen (2014) and Rosa (2019), I construct my competition measure as the aggregated cosine similarities among firms contributing to a common standard. This measure allows me to capture the intensity of the competition among those firms not only in terms of their technological similarities but also in terms of the number of firms competing for the development of standard-related technologies. My measure differs from previous papers since I aggregate the cosine similarities of participating firms instead of accounting for their average.

Lastly, a few empirical papers investigate the effect of R&D coordination and technology competition on the effort of firms in standards development. Pohlmann and Blind (2011) study the role of standards consortia and patent pools as determinants of the patent declarations of 250 patents owing firms in standard organizations. Their findings suggest that companies involved in R&D coordination among SEP holders tend to declare fewer standard essential patents. Baron et al. (2014) focus on ICT standards issued by 8 organizations and analyze the effect of participation in voluntary consortia on cooperation in developing technology standards and find that in cases of wasteful investment in standard-related R&D costs, consortia can efficiently reduce over-patenting. They define a novel measure of standard-related effort as the aggregated number of patents filed in standard-related technology classes. Rosa (2019) uses the number of technical contributions in a standard as a proxy of the effort exerted by firms in standards development and provides evidence that the efforts exerted by participating firms strongly complement the more technologically similar firms participating in a standard group. My paper contributes to understanding how competition among participating firms affects the effort exerted in standards development. Specifically, I study how the competition intensity over intellectual property rights, measured by the aggregated cosine similarities among firms, affects the standard-related effort at the firm level. I rely on the number of SEPs they declare to the standard and the overall amount of patents filed in the standard-related technology classes as proxies of the effort a firm exerts in standardization.

3 Data

In this section, I present two types of data. First, I use data on technology standards issued by 8 Standard Setting Organizations (SSOs) selected from the Searle Center Database (SCDB). The SCDB is the first large database developed by the Searle Center on Law, Regulation, and Economic Growth at Northwestern University Law School that includes data on quantifiable information on technology standards, SSOs characteristics, and standard essential patents (SEPs). Second, I use bibliographic and legal data of patents filed by firms to more than 100 patent authorities worldwide, from the European Patent Office's PATSTAT database[1]. My analysis is based on a cross-sectional dataset of 106 firms that declared patents essential to 539 standard projects issued by 8 SSOs between 1985 and 2015. The sample is selected such that all firms have declared essential patents to at least one standard.

[1]For a detailed description of the two databases and the methodology used to merge the data see Baron and Spulber (2018), Baron and Pohlmann (2018), and Bonani (2022a).

The Searle Center database consists of two different datasets: the first dataset contains detailed information on a large sample of standard documents issued by 598 SSOs[2], the standard issuing body, and the rules composing the Intellectual Property Rights policies of 36 SSOs; the second is a novel dataset of declared standard essential patents to a subset of 19 SSOs, the agents who declared the patent, the standard document to which the patent has been declared essential, the year of declaration, and the patent's related information such as the filed date, the granted date, and the associated International Patent Classification (IPC) classes. The Searle Center assigns a *standard document id* to each standard document which allows users of the database to link the data on standards and Standard Setting Organizations to the data on SEPs.

Standard documents in the SCDB are defined as technical specifications describing a complex technology system. Standard documents can either include both documents dealing with specific technical aspects and the documents listing and aggregating other documents to create more complex systems.[3] For this analysis, I focus on standard projects as large technology systems described by a set of standard documents. To aggregate all the documents referring to the same standard setting project, I rely on the standard document identifier, *doc-idn* and the variable *standard project*, both included in the SCDB, which allow me to identify all declarations to standard documents that are part of a broader standardization project.

Participation in standards development is not always related to obtaining a SEP for the standard (Gandal et al., 2004; Spulber, 2013). It can be the case that a large share of participants in the development of a standard are members of the Standard Setting Organization who do not get any SEPs nor develop any technologies relevant to the implementation of the standard. The main incentive this type of participants face in joining a standard-setting process concerns the voting right those individuals have on the approval of the standard. The final standard that is approved and issued by the organization is determinant in defining the benefit that participating members can have from their involvement in standardization through the sale of resulting products. Baron and Gupta (2018) focus on 3GPP and show that approximately one-third of all participating firms have not submitted a single contribution to 3GPP. This result suggests that only a small share of participating actors are responsible for the majority of the technical development of a standard. For the purpose of my analysis and since I cannot observe the full set of agents participating in each standard, I focus on the sample of firms that hold SEPs in the SCDB as being the active developers of the innovations that are necessary for the creation of the standard. Therefore, I start by collecting the set of firms that declared at least one patent as essential to a standard. Besides, there are several categories of SSO members; not only firms decide to join standards development, but also universities, research and government institutes, and other SSOs. The SCDB collects information on the disclosure made by several agents, including universities, national and international

[2] All SSOs in the SCDB are contractual organizations that have formal rules.

[3] "A standard document can describe the technical details of narrowly defined technologies, or they can define complex technological systems. In the latter case, standard documents typically reference other standard documents to deal with technical details", Baron and Spulber (2018).

institutes, and individuals. Since I am interested in the participation decision of firms and after merging the Searle Center datasets, I can retrieve information on a sample of 106 firms.

Moreover, I rely on two additional types of information that can be retrieved from the Searle Center Database: the standard related information and the standard's patent portfolio. Concerning standard projects, I collect information on the SSO issuing the standard, the year when the SSO published the standard, the number of standard specifications designing the standard project, the number of agents, both firms, universities, and national and international institutes, declaring to hold a patent as essential to the standard, and the number of SEPs declared prior to the declaration made by each firm in my sample. To construct the patent portfolio of each standard, I follow the methodology defined in (Baron et al., 2014) and presented in Bonani (2022a). Specifically, I rely on the 4-digit IPC classification of the set of essential patents declared to retrieve the standards' locations in the technological space[4]. Since several SSOs in my sample allow for blanket disclosures and I cannot observe the related IPC classes for some standards, I select only the standards for which I observe less than 10% of blanket disclosure. Although the SCDB contains information on the declarations made to 1,481 standard projects by the 106 companies, I am able to collect information on 539 standards issued by 8 SSOs.

The Searle Center Databases also provide information regarding the Intellectual Property Policy endorsed by each organization. Several aspects define the Intellectual Property Policy of a standard organization and affect how restrictive an IPR policy is for the standard's contributors and, thus, their decision to participate in the standards development[5]. Because the IPR policies vary over time and I cannot observe and collect detailed information on either the different aspects defining each SSO's policy or the patent policy variation, I construct *SSO-DeclarationYear* interactive fixed effects, which allow me to account for the heterogeneity in the IPR policies across SSOs and the policies changes over time.[6] While it is important for the analysis to have data on a wide range of SSOs since it allows me to exploit the variation of the several rules endorsed by different organizations, it is also important to recognize the limitation related to such a degree of heterogeneity. In an attempt to deal with a high degree of complexity across different organizations, I include information on IPR policies in my specification captured by the interactive terms.

[4] See Baron and Pohlmann (2018) for a detailed explanation of the methodology for matching standards with technology classes.

[5] The licensing and disclosure rules reported in the IPR policy are the major factors affecting the licensing revenues of SEP holders.

[6] There is limited variation between the 8 SSOs in my sample regarding the licensing rules. First, only one SSO requires licensing on reasonable and non-discriminatory terms (RAND). Second, 7 SSOs provide a menu of options SEP holders can choose among, including RAND and royalty-free. Third, one SSO offers a menu of licensing options where more binding terms (royalty-free and non-assertion) can be imposed. Nevertheless, not all SSOs impose licensing obligations on their members; only ETSI requires its members to license their SEPs. Concerning the standard contributors, who can differ from the members of an SSO but can still hold SEPs, there is no available information in the Searle Center databases. However, even though the licensing of essential patents is not mandatory for the members, the majority of SSOs define the Letter of Assurance as a necessary condition for the inclusion of the technology in the standard document, regardless of the membership status of the SEP holder.
Turning to the disclosure rules, the majority of the SSOs in my sample require the disclosure of patents that can be essential to a standard by their members. One SSO only encourages members to disclose SEPs, but the membership often requires members to make licenses on essential patents available. While the disclosure of essential patents is commonly required, 7 SSOs do not require a formal patent search, and one SSO does not specify any rule on the obligation of a patent search. Besides, SSOs differ on their stance with respect to blanket disclosures: blanket disclosures are not allowed by one SSO in the sample, 6 SSOs require the disclosure of specific patents, whereas, for one SSO, blanket disclosure is accepted but discouraged. Lastly, concerning the timing of the required disclosure, only two SSOs adopt more specific policies (ETSI and IEEE), while the majority of SSOs generally ask for as soon as possible disclosures. It is important to notice that this is not an exhaustive list of all the aspects included in the Intellectual Property Rights policy endorsed by an SSO.

Patents have been widely recognized as a measure of innovation at the firm level. Nevertheless, patents have limitations: not all inventions meet the patent authorities' criteria for patentability, and not all inventors seek to patent. There is a large number of patents that have not been declared essential but are still relevant for the development of a standard. In order to have a deeper understanding of the innovation process, it is important to analyze patenting and standards development as two different parts of a joint process (Baron and Pohlmann, 2018). Hence, using the information in PATSTAT, first of all, I collect information on the patents filed by a firm in the years prior to the declaration as a measure of a firm's patent portfolio. Due to the delay between application and issuance dates and since I am interested in the innovation activities at the firm level, I count patents using the years of application. Secondly, I again rely on the 4-digit IPC classification to identify standard-related patents that have not been declared as essential but are still important for developing a standard. I use the 4-digit IPC classes related to a standard to count the total number of patents filed by a firm in the standard-related technology classes as a measure of the firm's effort in standards development.[7]

Lastly, I construct two empirical measures that account for the technology similarity between a firm-standard pair and the competition intensity among firms contributing to a common standard. Both measures are built using the Cosine Similarity, which is a metric commonly used in machine learning to measure the similarity between two documents.

To analyze whether firms contribute to standards that are technologically closer to their technical knowledge, I build on the economic literature studying the technological position of firms (Rosenkopf and Almeida, 2003; Gilsing et al., 2008; Baron and Pohlmann, 2013; Bar and Leiponen, 2014; Rosa, 2019) and I compare the distribution of the firms' patents with the distribution of the standards' declared SEPs over the main 4-digit IPC classes. It is empirically challenging to model the firm-standard match due to the unobservability of the standard's technological fields and the endogeneity between the needs that the Standard Setting Organization tries to fulfill through the development of the standard and the interpretation of the consumers' needs by the rivals in an industry who are engaged in the technological competition. In order to define the standard's technical fields, I rely on the past technological accomplishments of the firms in standards development, measured by the SEPs IPC classes declared to the standard. Specifically, I follow Baron and Pohlmann (2013) who identify the standard-related technology fields as being the 4-digit IPC classes of the essential patents declared per standard, and Rosa (2019) who relies on the Cosine Similarity to measure the technological similarity between two firms contributing to a common standard. The cosine similarity between standard s and firm i is defined by:

$$Similarity_{i,s} = \frac{\vec{S}_s \cdot \vec{I}_i}{\|\vec{S}_s\| \|\vec{I}_i\|} = \frac{\sum_{j=1}^{J} \mathbb{1}\{IPC_{sj} = j\} \mathbb{1}\{IPC_{ij} = j\}}{\sqrt{\sum_{j=1}^{J} \mathbb{1}\{IPC_{sj} = j\}} \sqrt{\sum_{j=1}^{J} \mathbb{1}\{IPC_{ij} = j\}}} \tag{1}$$

[7]See Bonani (2022a) and Baron et al. (2014) for a detailed description of this measure.

Where $\vec{S}_s$ and $\vec{I}_i$ are, respectively, the standard's and the firm's patent portfolio. To analyze the technological position of a firm with respect to the remainder of the standard, I rely on the technology classes in which firms file patents, and standards have declared standard essential patents. Using PATSTAT data on filed patents, I identify the patents and the related 4-digit IPC technology classes filed by each firm, according to the International Patent Classification. I then use the IPC classes of the identified patents to map the patent portfolio of each firm. Using the SCDB data on essential patents, I construct the patent portfolio of a standard, taking into account the 4-digit IPC classes associated with each patent declared essential to the standard. After having identified the 4-digit IPC classes associated with a standard according to declared SEPs, and the 4-digit IPC classes associated with a firm, I then define the vectors of IPC classes where firms have patented, and standards have declared patents, accounting for all the classes associated to a firm and a standard. I, therefore, define the vector of IPC classes associated with firm i as $\vec{I}_i = (\mathbb{1}\{IPC_{i1} = 1\}, \ldots, \mathbb{1}\{IPC_{iJ} = J\})$, where $\mathbb{1}\{IPC_{ij} = j\}$ equals 1 if the technology class j is a technology class where firm i has filed patents to the years prior to declaring a patent as essential to a standard. Following the same approach, I define the vector associated with standard s as $\vec{S}_s = (\mathbb{1}\{IPC_{s1} = 1\}, \ldots, \mathbb{1}\{IPC_{sJ} = J\})$, where $\mathbb{1}\{IPC_{sj} = j\}$ equals 1 if the technology class j is associated to the SEPs declared to standard s in the years before the declaration made by firm i, and 0 otherwise. Lastly, I compute the cosine of the angle of the two defined vectors to retrieve the degree of technological similarity between firm i and standard s. Table (1) shows one stylized hypothetical firm and standard to exemplify the procedure.

Table 1
Similarity computation procedure - a stylized example

Step 1 - Patent Portfolio				
Firm 1	$[IPC1, IPC2, IPC4]$			
Standard 1	$[IPC2, IPC3, IPC4]$			
	IPC1	IPC2	IPC3	IPC4
Step 2 - Portfolio Vectors				
Firm 1	1	1	0	1
Standard1	0	1	1	1
Step 3 - Cosine Angle				
Firm 1 - Standard 1 similarity	0.8			

Concerning the competition intensity measure, since I am interested in the competition among firms contributing to a common standard, I create a measure that relates the technology closeness between a firm and all other firms holding standard essential patents for the same standard with the number of firms being active contributors of the standard in order to capture how fierce the competition is among those firms. In economics, the distribution of patents has been widely used to measure the technological distance between firms. Rosenkopf and Almeida (2003) and Gilsing et al. (2008) study the role of technology distances between firms in alliances, Baron and Pohlmann (2013), Bar and Leiponen (2014), and Rosa (2019) in the context of cooperative standard setting. Various methodologies are used in the literature to calculate the technological distance between firms participating in standardization based on the distribution vector of their patent portfolios over different technology classes. The measures used in the literature include the Min-Complement distance (Bar and Leiponen, 2012), the Euclidean distance (Bar and Leiponen, 2014), the cosine similarity (Rosa, 2019), and the correlation measure between portfolios (Baron and Pohlmann, 2013). Bar and Leiponen (2012) argue that the Min-complement distance is superior to other measures since it is insensitive to the distribution of patents in irrelevant classes. Rosa (2019) argues that the advantage of Cosine Similarity over the Euclidean distance is that it depends only on the direction, not the length, of the vectors, such that it allows considering the classes in which a firm has filed patents but not how many. I build on this literature, and I define the technology similarity between firms by accounting for the firms' patent portfolios over the main IPC classes. Specifically, following Bar and Leiponen (2014) and Rosa (2019), I construct the competition intensity measure as follows:

$$Similarity\text{-}Competition_{i,-i,s} = \sum_{a\neq i} CosineSimilarity_{i,a,s} = \sum_{a\neq i} \frac{\sum_{j=1}^{J} \mathbb{1}\{IPC_{ij}=j\}\,\mathbb{1}\{IPC_{aj}=j\}}{\sqrt{\sum_{j=1}^{J} \mathbb{1}\{IPC_{ij}=j\}}\sqrt{\sum_{j=1}^{J} \mathbb{1}\{IPC_{aj}=j\}}} \tag{2}$$

Where $Similarity\text{-}Competition_{i,-i,s}$ is the sum of the cosine similarities between the patent portfolio of firm i and all other firms $-i$ contributing to standard s. The term $CosineSimilarity_{i,a,s}$ measures the technology similarity between a firm i and any other firm a declaring SEPs to standard s, by accounting for the intensity of the competition among those firms. To measure the technology similarity between firms, and since the Cosine Similarity is a one-to-one measure, firstly, I compute the similarity between any 2 firms declaring SEPs for a specific standard s, where $\mathbb{1}\{IPC_{aj}=j\}$ equals 1 if any firm a declaring essential patents to standard s, which is different from i, have filed patents in j. Then, to account for the technology competition firm i faces when participating in standards development, I sum the Cosine Similarities between this firm and all the other firms in the standard project. This measure allows me to account for the number of firms within a common standard and, therefore, for the competition intensity. For instance, if two firms have declared SEPs for a common standard, the maximum value of the Cosine Similarity will be 1. While if the firms participating in the same standard are ten, the maximum value will be 9, capturing tougher competition.

Table (2) summarizes standards' and firms' characteristics in my sample. Concerning the standards, not all standards have equal weights. While the number of firms holding standard essential patents is quite balanced across standards, the number of disclosures made as well as the number of SEPs declared vary substantially between standards, as shown by the standard deviations of disclosures (347.4) and declared SEPs (12,373.4). Moreover, there are 3,315.8 essential patents declared on average in my sample and 104.8 disclosures made. This data suggests that firms tend to include a large amount of standard essential patents in the same disclosure[8].

[8]This information does not take into account blanket disclosures, suggesting that the number of declared SEPs included in one disclosure is higher compared to the reported data.

Table 2
Descriptive Statistics

	Mean	Standard Deviation	Min	Max
Standards' characteristics				
Total number of standards	539			
Number of contributors per standard	25.4	46.6	1	357
Number of disclosure made per standard	104.8	347.4	1	3,807
Number of essential patents declared per standard	3,315.8	12,373.4	0	122,712
Broadness of standard (Total number of IPC classes per standard)	27.6	77.1	1.0	529
Number of standard documents per standard	3109.0	8,936.3	1.0	84,955
Firm-Standard Similarity	0.7	0.2	0.0	0.9
Firms' characteristics				
Number of firms	106			
Number of standards contributing per firm	15.6	22.0	1.0	112
Number of SEPs per firm	201.4	729.7	1.0	12,919
Number of patents	14,936.3	39,425.2	1.0	386,667
Firms' knowledge similarity (average across firms)	0.5	0.1	0.1	0.9

Note: This table summarizes the characteristics of standards issued by 8 SSOs and 106 firms between 1985 and 2015.

To account for the heterogeneity across standards in terms of breadth and the complexity and importance of the systems described by a standard project, I use the information regarding the technology classes associated with each standard and the number of standard documents referring to a project. As reported in the table, standards also vary in the number of IPC classes they are related to, with a minimum of 1 IPC class to a maximum of 529, and in the number of documents designing a standard project- the values range from 1 to 84,955. Lastly, firms declaring essential patents to a standard have, on average, a patent portfolio similar to the standard's portfolio of 0.7, meaning that more than half of the patents filed by a firm are in the standard-related technology classes. One possible interpretation of the firm-standard similarity is that firms tend to contribute to the development of standards for which they have similar technological knowledge.

Concerning the 106 firms in my sample, firms are very active in standards development, declaring on average patents to 15.6 standards. Although the patents declared as essential are less than 1.5% of all the patents filed by a firm, the similarity between the firms' and the standards' patent portfolios is high. This result provides preliminary evidence that there is a large share of standard-related innovation that is not directly associated to the standard through its disclosure. Besides, firms that contribute to a common standard have similar knowledge, with a firm's knowledge similarity equal to 0.5 on average. This result points to a cooperation effect between firms that are technologically substitutes: firms might decide to participate in standards where other participants have substitute knowledge, supporting the idea that standards benefit from a coordination of firms among the standard-related research and development.

4 Empirical analysis

The following empirical analysis includes two subsections. In the first subsection, I analyze how firms decide to which standard they want to contribute and the role of the technological similarity between a firm and a standard in making this decision. I provide empirical evidence that firms are more likely to contribute to standards that have already developed technological knowledge similar to the ones owned by the firm. In the second subsection, I analyze how the intensity of competition among firms with similar knowledge affects the effort a firm exerts in standards development in terms of the number of SEPs declared and the overall number of standard-related patents. I show that firms that contribute to standards characterized by more intense competition exert less effort in standards development.

4.1 Firm-standard technological fit and participation

The participation decision in the development of a standard is not random, and the literature on standardization has shed light on the determinants affecting the firms' choices to participate in some standardization groups and not others. In an attempt to provide empirical evidence on the determinants that affect the firms' participation decision, I rely on the literature studying the decision to join a standard project and on the information provided in the Searle Center and PATSTAT Databases.

When firms decide whether to participate in the development of technology standards, they take into account the overall profits firms expect to get from participation in standardization and the costs associated with their involvement. Participating firms can benefit from their involvement in standardization through the sale of resulting products, taking the standards as inputs, or by licensing the patents protecting such technologies (SEPs). However, participation in standards organizations can also impose high costs on firms with valuable IP rights. In particular, standards organizations can oblige the standard's contributors to make SEPs available to standard users on specific licensing terms. In most cases, they require the owners of potential SEPs to commit to making licenses available on fair, reasonable, and non-discriminatory (FRAND) terms. Layne-Farrar et al. (2014) argue that the owner of a potentially standard-essential technology may choose to stay out of standards organizations stipulating strict licensing requirements and offer licenses to standard implementers on unconstrained terms. Therefore there is an economic trade-off firms need to account for when deciding whether to contribute to a standard project, and this trade-off is affected by the IPR policy endorsed by the Standard Setting Organization.

The match between firm and standard is another channel affecting the economic trade-off that arises when firms decide to participate in standardization. If firms are specialized in certain technologies, they are likely to have lower costs of participation. For instance, if a group is developing a new standard for a channel access method, then firms working in the fields related to network equipment are more likely to participate in that group. How relevant a standard is to a firm's technical expertise can lower the cost of participation for firms since they can take full advantage of the developed technologies and the pre-existing technological knowledge. Moreover, there is a large number of patents that are not declared essential but are still necessary for the implementation of the standard. Firms with technological knowledge similar to the standard's topic are likely to develop so-called commercially essential patents. Contributing to the standards development by owning patents that are essential and conditional on holding standard-related patents that are not essential can increase the firm's bargaining power in the licensing game and assure a larger share of the licensing revenues. Therefore, the firm-standard match affects the profitability of participating in the standards development by increasing the potential revenue streams, incentivizing firms to participate.

While the economic forces involved in the trade-off are endogenous to all firms' specific characteristics, the two effects generating this trade-off are determined by (i) the match between the technological fields of the standard and the technological knowledge of the firm and (ii) the Standard Setting Organization's IPR policy. I refer to the first point as the *firm-standard technological fit hypothesis*. Then, suppose the firm-standard technological fit hypothesis is true. I should observe that firms with technological knowledge more similar to the standard-related technological fields are more likely to contribute to standards development. To capture the technological fit between a firm-standard pair, I rely on the cosine similarity measure between a firm's and a standard's patent portfolio the year prior to the declaration of any SEPs by the firm in the standard, as defined in the Data section. To empirically test this hypothesis, I estimate the following linear probability model for participation at the firm-standard level:

$$y_{i,s,SSO} = \begin{cases} 1 & \text{with probability } P(Y=1|\mathit{Similarity}_{i,s}, X, \upsilon) \\ 0 & \text{with probability } (1 - P(Y=1|\mathit{Similarity}_{i,s}, X, \upsilon)) \end{cases} \tag{3}$$

where

$$P(Y=1|\mathit{Similarity}_{i,s}, X, \upsilon) = \beta_0 + \beta_t \mathit{Similarity}_{i,s} + \beta_p \mathit{Portfolio}_i + \beta_s X'_s + \beta_{SSO} dSSO_s * dDeclarationYear_i + \upsilon_i + \upsilon_s \tag{4}$$

Where $y_{i,s,SSO}$ is a dummy variable that equals one if firm i participates to standard s by declaring at least one essential patent, issued by the Standard Setting Organization SSO, whose value determines whether or not a firm contributes to standards development. $\mathit{Similarity}_{i,s}$ measures the technology similarity between the firm and the standard the year prior to the declaration of any SEP by firm i in standard s, $\mathit{Portfolio}_i$ is the number of patents in firm i's portfolio the year prior to the declaration of any SEP to standard s, X'_s is a set of proxy variables for the standard's characteristics observed at the time of declaration, and $dSSO_s * dDeclarationYear_i$ is an interaction term that allows me to account for the effect of the Intellectual Property Rights policy endorsed by the SSO on the participation decision. υ_i, υ_s capture the unobserved (to the researcher) determinants of the firm's participation decision and the standard's unobserved characteristics.

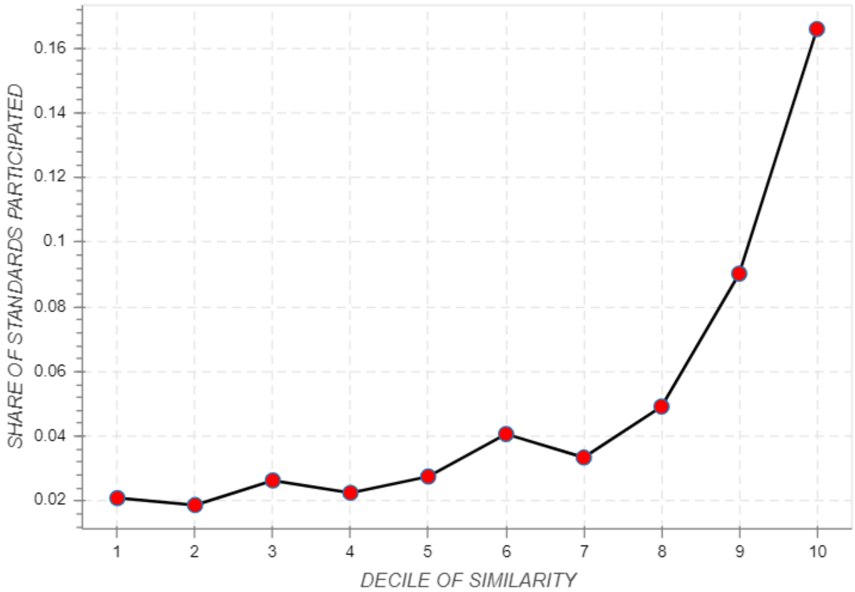
The dependent variable of my econometric equation is a binary outcome which takes the value of 1 if a firm declares a patent as essential for a standard s and 0 otherwise. Since for the 539 standards in my sample, a firm can either declare a patent essential, and therefore $y_{i,s,SSO}$ equals to 1, or not ($y_{i,s,SSO}$ will equal 0), and since I cannot observe the declaration year for the standards a firm does not declare any SEPs, I need to infer this information as it is relevant in order to match the covariates of my specification with the decision of the firm to not contribute to a given standard. Following the literature on Entry-Exit models, I assume that the year of a potential declaration of a firm in a standard to which it does not contribute is the difference between the median of all declaration years it makes and the standard's publication year.

In the vector X_s', I include the aggregated number of technology classes related to a standard and the total number of SEP holders in the years prior to the declaration made by a firm as proxies of the breadth of a standard. In the empirical analysis, I should observe that broader standards, which require a higher number of distinct technologies, are subject to higher participation. This is because if more technologies are required, it is more likely that one of them will be relevant to a given firm's interest and expertise. Besides, I also include the aggregated number of SEPs declared to a standard in the years before a firm makes a declaration of holding a SEP. As shown in Baron et al. (2014), the aggregate licensing revenues can be assumed to be split between firms according to their shares of essential patents. For a fixed level of the revenue derived by the licensing of SEPs, a larger number of essential patents declared to a standard implies a lower revenue per SEP holder. Therefore firms are less likely to contribute to standards associated with a high number of essential patents already declared. On the other hand, a large number of SEPs declared to a standard can imply the relevance of the standard, which can increase its attractiveness for firms developing standard technologies.

Moreover, if a firm works in several technological areas, it is more likely to be interested in more standards. To capture this empirically, I include the patent portfolio size of a firm $Portfolio_i$ to measure the firm's technological capacity. Therefore, I should observe that firms with bigger portfolios are more likely to participate in standardization groups.

To control for the unobserved firms' and standards' determinants that can affect the firm's participation decision in the development of a standard, I use a set of firm and standard fixed effects v_i and v_s. For instance, pure innovators are more likely to contribute to some standards and not others compared to vertically integrated firms that might be willing to contribute to several standards. Besides, specific standards might define complex technological systems of particular importance for the industry, making them more attractive to a larger share of firms. The set of standard and firm-specific dummies allows me to partially control for the endogeneity issues due to the firms' and standards' unobserved heterogeneity.

Figure 1
Participated Standards and Firm-Standard Similarity



This figure shows the average share of standards in which firms participate over the firm-standard similarity by deciles.

Lastly, to account for the effect of the IPR policies on the incentives firms face when deciding whether to contribute to standards development, I include in my specification an interaction term $dSSO_s * dDeclarationYear_i$, between the Standard Setting Organization $dSSO_s$ issuing standard s and the year $dDeclarationYear_i$ of the declaration by firm i. Specifically, the term equals one when the standard is issued by the Standard Setting Organization $dSSO_s$ and the declaration by the firm occurs in year $dDeclarationYear_i$. By accounting for an intertemporal dimension of the organization to which the firm declares any SEP, this variable allows me to identify the effect of the different licensing and disclosure rules on the contribution decision of a firm by exploiting the variation in the IPR policy between different SSOs in a given year and across years within the same SSO. As shown by Chiao et al. (2007), a standard organization can be more oriented towards the implementers of a standard, or it can favor the standard's innovators, i.e. the agents developing the technologies that are necessary for the implementation of a standard. Indeed, when SSOs choose the rules that compose their IPR policies, they indirectly define the maximum price SEP holders are allowed to charge for their essential patents. Firms might decide not to contribute to some standards if their return on the investment is not sufficient to cover R&D costs. On the flip side, even if the SEP royalties are too restrictive, some types of firms can decide to participate in standards development since they can still benefit from selling the standard-implementing products in the downstream markets. Even if this variable is invariant across firms and standards issued by the same organization, it varies for the same firm between standards issued by different SSOs and for declarations made to the same SSO but at different points in time. Therefore the $dSSO_s * dDeclarationYear_i$ term allows me to control for the variation at the IPR policy level.

I start my analysis on the firm-standard fit hypothesis by plotting the average share of standards a firm declares essential patents to over the total number of standards in my sample, my proxy for the participation decision of a firm as an active developer of the standard, on the technological similarity between firms and standards. I discretized the similarity measure in deciles. Figure 1 suggests a positive relationship between the number of standards a firm decides to contribute to and the fit between the firm's technological knowledge and the standard's technical fields. For instance, the number of standards a firm actively participate in exponentially increases for an increase in the technology similarity between the firm and the standard.

Though this figure points to an effect of the firm-standard similarity on the firm's participation decision in standards development, it does not account for the observed and unobserved heterogeneity across firms and standards. To control for these sources of heterogeneity, I estimate the econometric specification defined in Equation (4). Columns 1,2, 3, and 4 of Table (3) present the estimates of Equation (4) using OLS estimators. Given the dichotomous nature of my dependent variable, I also estimate a logit model for Equation (4) as robustness check.[9] The results are reported in Columns 5 to 8. I find a positive and significant β_t across all specifications, meaning that firms are more likely to actively contribute to standards in which the technological fit is closer. The coefficient of $Similarity_{i,s}$ is the estimated marginal effect of the technology similarity between a firm-standard pair on the probability that a firm contributes to the standard. Focusing on the estimates reported in Column 4, my model predicts that for a one percentage point increase in the technological fit between a firm and a standard, the probability that the firm contributes to the technological development of the standard increases by 0.05 percentage points, everything else constant. These results provide empirical evidence in favor of the firm-standard technological fit hypothesis.

The technology classes associated with patents declared essential to a standard are observed ex-post by firms, and the patents' technology classes are likely to match the classes of patents held by participating firms. Thus the similarity measure potentially includes a mechanical process of participation in standards development, such that the similarity between a firm's and a standard's patent portfolio increases when the firm participates in the standard. However, the rules concerning the declaration of SEPs are flexible, and firms declare standard essential patents at different points in time and at different stages of the standardization process. To mitigate any mechanical process included in the defined similarity measure, I construct a different standard patent portfolio for each firm, which is based only on the technology classes related to the SEPs that were declared the years before the declaration made by the firm. Therefore the decision of a firm to contribute to a standard does not depend on variables that are the realized outcomes of the standard but on variables that are in the firm's information set at the time of their participation decision.

Nevertheless, since there are several declarations associated with the same firm for a given standard in my sample, as I aggregate standard documents at the project level and firms declare several patents to different documents, it is likely that the similarity between a firm and a standard mechanically increases for subsequent

[9] As an additional robustness check, I estimate a probit model of Equation (4). The results are reported in Table (6) in the Appendix.

declarations. In this case, there is a technology path dependence in the firm's participation decision in standard amendments and revisions, which is captured by the increase in the technology similarity at the firm-standard pair. Notably, firms that have already contributed to a standard are more likely to participate in the following revisions of the same standard, reflected in the greater similarity. Thus, there might be a mechanical channel contributing to the estimated effect, such that the patents' technology classes of a firm are likely to match the technology classes where participating firms have filed SEPs.

Table 3
Estimates for participation decisions

	OLS Baseline	OLS Fixed Effects	OLS Fixed Effects	OLS Fixed Effects	Logit Baseline	Logit Fixed Effects	Logit Fixed Effects	Logit Fixed Effects
Independent Variables								
Similarity	0.086***	0.057***	0.066***	0.053***	1.134***	1.203***	1.266***	2.808***
	(0.004)	(0.005)	(0.005)	(0.006)	(0.101)	(0.114)	(0.167)	(0.271)
Portfolio size of the firm	0.009***	0.010***	0.018***	0.030***	0.226***	0.239***	0.396***	0.689***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.007)	(0.008)	(0.027)	(0.042)
SEPs declared per standard	0.079***	0.072***	0.060***	0.072***	0.619***	0.663***	0.662***	0.917***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.011)	(0.017)	(0.021)	(0.042)
Total firms declaring SEPs	0.246***	0.218***	0.205***	0.102***	1.276***	1.033***	1.434***	0.635***
	(0.003)	(0.003)	(0.003)	(0.005)	(0.068)	(0.083)	(0.104)	(0.222)
IPC classes per standard	-0.001***	-0.001***	-0.000***	-0.001***	-0.004***	-0.003***	-0.002***	0.165***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.015)
SSO*DeclarationYear FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Firm FE	No	No	Yes	Yes	No	No	Yes	Yes
Standard FE	No	No	No	Yes	No	No	No	Yes
N	70,337	70,337	70,337	70,337	70,337	67,400	67,400	66,073
adj. R^2	0.82	0.83	0.85	0.87	0.80	0.81	0.87	0.90

Note: All values are in log form for the OLS specification except for the Firm-Standard Similarity variable. In the logit model, I use the log transformation of the variables Portfolio size of the firm and SEPs declared per standard while the other variables are in level terms. Standard errors are reported in parentheses, and they are clustered at the firm level to account for possible correlation in the errors across different standards within the same firm. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Focusing on the other covariates of my specification, in line with my expectations, firms with larger patent portfolios are more likely to contribute to standardization. Regarding my proxies for the broadness of a standard (number of firms declaring SEPs and the number of IPC classes), only the number of firms declaring SEPs has a positive sign across all specifications, suggesting that the likelihood to contribute to a standard by a firm increases for broader standards. On the other hand, the sign of the number of IPC classes is not consistent across all specifications. Therefore it does not allow me to draw any conclusion concerning the effect of IPC technology classes on the firm's probability of participating in standards development. The number of essential patents declared has a positive effect on the probability of contributing to a standard project, suggesting that SEPs declared to a standard might imply the relevance of the standard, which in turn can increase its attractiveness for firms developing standard technologies. Besides, standards associated with a larger number of SEPs also imply a higher degree of importance of the standard for the next versions, thus putting firms contributing to the legacy technology in dominant positions. Thus, this can increase the firms' likelihood of participating in standard projects.

4.2 Competition and standard-related effort

In addition to deciding on which standard to contribute to, firms can also decide on the effort they want to put into a standard. The amount of innovation a firm invests in the development of a standard will determine the benefits the firm gains from its involvement in the standardization process. In this section, I analyze in more detail how the intensity of competition among firms contributing to a standard relates to standard-related patenting behavior. Because not all standard-related technologies are declared or become essential for a standard, I use two different variables to measure the effort of firms in standardization in my specifications: the number of patents declared essential and a broader innovation measure defined by the overall number of standard-related patents, either essential or not, filed by a firm in the technology classes associated with the standard (Baron et al., 2014). Moreover, for this analysis, since I am interested in the standard-related effort of firms contributing to standards development, I abstract from the participation decision in standardization, and I focus only on the set of firm-standard pairs for which I observe firms declare essential patents.

Firms with similar knowledge, which patent technology in similar technological classes, are close competitors for developing a technology essential for the standard and so for declaring a SEP. On the one hand, when firms with similar technical knowledge participate in the standard-setting process, they might increase padding (Dewatripont and Legros, 2013) due to more intense competition. Thus they might declare more patents as essential and file more patents in standard-related technology classes. On the other hand, as the probability of winning the patent race decreases for an increase in competition among firms, we might expect that firms invest less in innovation (Dasgupta and Stiglitz, 1980). The effect of competition on the firm's standard-related efforts is a priori ambiguous. Therefore, I empirically investigate the direction of the competition effect on the effort exerted in standards development. To measure the intensity of competition among firms participating to the same standard, I rely on the aggregated cosine similarities between a firm and all other firms declaring SEPs to the same standard, as defined in the Data section. To empirically study the direction of the competition effect on standard effort, I estimate the following fixed effects model at the firm-standard level:

$$log(SEP_{i,s}+1) = \beta_0+\beta_c Similarity\text{-}Competition_{i,-i,s}+\beta_n Rel-Port_{i,-i,s}+\beta_t Similarity_{i,s}+\beta_i X_i'+\beta_s X_s'+\upsilon_i+\upsilon_s+\epsilon_{i,s} \tag{5}$$

Where $SEP_{i,s}$ is the overall number of standard essential patents firm i declares to standard s, $Similarity\text{-}Competition_{i,-i,s}$ is the aggregated cosine similarities between a firm and all other firms that declare essential patents to standard s, $Rel-Port_{i,-i,s}$ is the relative portfolio size of a firm with respect to the size of the patent portfolios of all other firms contributing to standard s, $Similarity_{i,s}$ is the cosine similarity between a firm's and standard's patent portfolios ,X_i' is a vector of the firm's characteristics and X_s' is a vector which accounts for the standard's characteristics, υ_i and υ_s are respectively the firm and the standard fixed-effects, and $\epsilon_{i,s}$ is the error term which represents those variables that influence the firm's choice of the number of SEPs to declare to standard s and are unobserved by the econometrician.

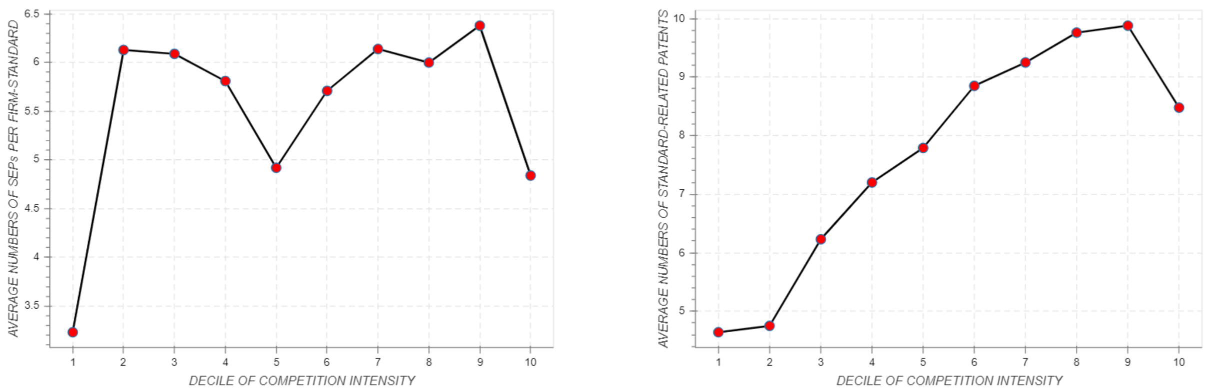
The firms' and standards' characteristics are constructed by aggregating the values observed in the years before the last declaration made by each firm. Since the declaration of standard essential patents is voluntary and firms declare SEPs to standards at different points in time, the covariates in the X_i' and X_s' vectors vary across firms and standards, respectively.

I include in my specification $Similarity_{i,s}$ and $Rel - Port_{i,-i,s}$, which are two covariates at the firm-standard pair level that measure the technological similarity of a firm-standard pair and the relative portfolio size of the firms respectively with respect to all other firms contributing to the standard. The first covariate tries to capture other mechanical channels that could drive the results. Specifically, if the standard is technologically close to the firms' field of expertise, firms declare more SEPs and file more standard-related patents. Moreover, since the intensity of competition between firms also depends on how the patent portfolio size of a firm compares to other firms' portfolio size, I control for the relative portfolio size of the firm compared to the size of the patent portfolios of all other firms in a common standard.

To control for the heterogeneity across firms, I include in the vector X_i' the portfolio size of the firms and its R&D expenditures. The values of these two covariates are computed by aggregating respectively the number of patents filed by the firm and the R&D expenditures in the years between the first and the last declaration made by the firm. Firms with a highly intensive patenting activity are more likely to have a larger number of SEPs compared to firms that file fewer patents. Besides, firms that invest a large amount in R&D are more likely to develop technologies essential for a standard. Nevertheless, participating in a standardization process might impact the firms' patents portfolio and their R&D activities. Since I focus on the set of firm-standard pairs for which I observe firms have at least one SEP for the standard, I abstract from the participation decision, and therefore this issue is not of any concern for my specification. I also include firm fixed-effects υ_i to account for the unobserved firm heterogeneity, such as membership, bargaining power, and the firm's business model, which may also affect the number of SEPs a firm can get.

The regressors included in the vector X_s' control for the number of SEPs declared for a given standard, the total number of standard documents referring to a common standard project, and the number of IPC classes related to the standard as a measure of the broadness of a standard. For instance, across different standards, with different broadness levels, a different number of SEP can be declared, which depends on the relevance of the standard for the industry and the overall licensing revenue firms can have. And this is something that must be accounted for to draw conclusions about competition within a standard project. Furthermore, a standard project associated with a higher number of documents defines more complex and important technological systems and so requires a larger number of essential technologies. Thus firms might be willing to contribute more in terms of SEPs declared and filed standard-related patents. Lastly, to capture the unobserved heterogeneity across standards that can affect the number of SEPs held by a firm, I also include standard fixed-effects measured by υ_s.

Even if patents declared essential depict the innovation directly related to a standard, there are non-essential intellectual property rights that are not necessary for the implementation of a standard but that are still relevant



(a) Standard-Essential Patents and Competition Intensity (b) Standard-Essential Patents and Competition Intensity

Figure 2

These figures show the average number of SEPs declared (left) and the average number of all standard-related patents (right) filed per firm-standard pair over the standard competition intensity.

for a standard, as documented by Bekkers et al. (2012) and Baron et al. (2014). Besides, since the declaration of standard essential patents is a voluntary decision of firms and SEPs are not subject to any scrutiny by third parties, firms can either under or over-declare the patents they own. Thus, the number of SEPs declared can be highly strategic. Stitzing et al. (2017) and Brachtendorf et al. (2020) show that the majority of declared SEPs are actually not essential for the declaring standard and that firms tend to over-declare the number of standard essential patents held. Therefore, it is restrictive to assume that the technological competition among firms would only affect the number of SEPs a firm decides to declare. To widen the understanding of the effect of the competition among firms with similar technological knowledge within a common standardization process, I rely on the same specification as defined in Equation (5) to estimate the effect of competition on the overall standard-related effort of firms. Specifically, I define the dependent variable of my specification as follows:

$$log(Patent_{i,s} + 1) = log\left[(\sum_{j \in J_s} PatentFile_{i,j}) + 1\right] \tag{6}$$

Where J_s is the set of technology classes defining standard s and $PatentFile_{i,j}$ is the total number of patents filed by firm i in technology class j at the time of the last declaration made for the standard[10].

As an initial exploitation of the effect of the competition intensity on the effort in standards development, I plot in Figure 2 the average number of SEPs declared and the average number of standard-related patents filed by a firm in each standard over the competition intensity among firms contributing to the standard. I discretized the competition measure in deciles also in these graphs. The left graph in Figure 2 shows a non-monotonic relationship of the competition intensity among contributors over the effort exerted in developing a standard. The figure suggests that firms in the mean ranks of the distribution declare more patents as essentials compared to firms in the tails, so firms that participate in less and more competitive standards, with an exception for the fifth decile. The right graph in Figure 2 shows a positive relationship between the number of standard-related patents and the degree of competition intensity among firms within a common standard. For instance, firms

[10]See Baron et al. (2014) and Bonani (2022a) for a detailed explanation on how this measure is constructed.

participating in standards characterized either by contributors who are specialized in similar technological fields or by a larger number of contributing firms increase their efforts, measured by the total number of patents filed in the technology classes related to a standard. However, also these graphs do not control for the variation across standards' and firms' observed and unobserved specific features.

To improve the understanding of the standard-related effort of firms with similar knowledge, I formalize my analysis by estimating the model defined in Equation (5). For the purpose of this analysis, I have to match the standard's information with the firm's characteristics, also in terms of R&D expenditure. Due to data availability, I restrict my analysis to a sample of 73 firms and 411 standards, and I only focus on the firm-standard pairs for which I observe firms have declared standard essential patents. The results are reported in Table (4) and Table (5). See the Appendix for the complete tables, including all estimates in Equation (5).

Focusing on Table (4), the table reports the estimates of the specification that has as the dependent variable the number of patents declared as essential. Looking at the last column, which is the preferred specification, the results are consistent with the idea that due to fierce competition firms exert less effort in standards development. An increase in the intensity of competition among firms by 1 unit, either driven by an increase in the number of firms in a standard or in the technological similarity among existing firms, decreases the number of declared SEPs by 32.7%.

Table 4
Standard-related effort and Competition intensity

	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Dependent Variable SEPs declared (log)								
Independent Variables								
Similarity-Competition	0.216***	-0.065***	0.313***	0.024	0.057***	-0.272***	-0.309***	-0.327***
	(0.011)	(0.004)	(0.011)	(0.015)	(0.006)	(0.024)	(0.030)	(0.031)
Firm FE	No	No	Yes	No	Yes	No	Yes	Yes
Standard FE	No	No	No	Yes	No	Yes	Yes	Yes
Firm-standard pair Characteristics (Firm-Standard similarity, Relative Portfolio Size)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm Characteristics (R&D, Portfolio size)	No	Yes	No	No	Yes	Yes	No	Yes
Standard Characteristics (IPC classes, Total SEPs, Total documents per standard)	No	Yes	No	No	Yes	Yes	No	Yes
Average SEP per firm-standard	585.96	585.96	585.96	585.96	585.96	585.96	585.96	585.96
Competition across standards	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32
N	1,245	1,166	1,245	1,245	1,166	1,166	1,245	1,166
adj. R^2	0.34	0.70	0.49	0.53	0.77	0.61	0.67	0.72

Note: The dependent variable is the logarithm of the aggregated number of SEPs declared in the years between the first and the last declaration made. The method of estimation is the fixed effect model. Standard errors are reported in parentheses, and they are robust to heteroskedasticity. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table (5) reports the estimations of the specification using the overall number of standard-related patents filed by firms as the dependent variable. Focusing on the last column, where both standards' and firms' fixed effects are included, the coefficient of interest is negative, suggesting that when the competition in the standard becomes more intense, either driven by an increase in the number of firms in the standard or by the similarity among existing firms, the effect of this increase on the overall number of patents filed is negative. Specifically, for 1 point increase in the competition intensity among participating firms, firms file 15.7% fewer patents in the standard-related technology classes. This evidence supports the hypothesis of a competition effect, according to which more intensive competition among participating firms leads to lower effort exerted in standards development. However, the number of patents filed by a firm in a technological field and the technology similarity between firms are jointly determined since firms might decide which technology field to enter. Therefore, there might be a mechanical channel contributing to the estimated effect, such that the patents' technology classes of a firm are likely to match the classes of patents where participating firms file since the classes are observed ex-post by the firm.

The negative coefficient of the variable of interest can be explained by the intense patent races among firms that are technological substitutes. Firms participating in voluntary Standard Setting Organizations develop different technologies as alternative technological solutions for a standard project, and they compete aggressively to include their technologies in the standard. When the technological similarities among firms participating in the same standard increase or more firms contribute to the same standard, holding the knowledge similarity constant, there is potentially tougher competition for including patented technologies. Since firms with similar knowledge are closer competitors for getting a SEP or developing technologies necessary for the implementation of the standard, the more intense the competition among those firms, the less likely they are to develop technologies that are essential or necessary for the implementation of the standard, and thus declare fewer SEPs and file fewer standard-related patents.

Table 5
Standard-related effort and Competition intensity

	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Dependent Variable								
Standard-related Patents (log)								
Independent Variables								
Similarity-Competition	0.174***	-0.035***	0.160***	0.697	0.037***	-0.112***	-0.131***	-0.157***
	(0.006)	(0.004)	(0.005)	(0.016)	(0.004)	(0.017)	(0.019)	(0.021)
Firm FE	No	No	Yes	No	Yes	No	Yes	Yes
Standard FE	No	No	No	Yes	No	Yes	Yes	Yes
Firm-standard pair Characteristics (Firm-Standard similarity, Relative Portfolio Size)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm Characteristics (R&D, Portfolio size)	No	Yes	No	No	Yes	Yes	No	Yes
Standard Characteristics (IPC classes, Total SEPs, Total documents per standard)	No	Yes	No	No	Yes	Yes	No	Yes
Average Patents per firm-standard	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24
Competition across standards	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32
N	1,245	1,166	1,245	1,245	1,166	1,166	1,245	1,166
adj. R^2	0.30	0.80	0.86	0.64	0.88	0.84	0.92	0.92

Note: The dependent variable is the logarithm of the aggregated number of standard-related patents in the years between the first and the last declaration made. The method of estimation is the fixed effect model. Standard errors are reported in parentheses, and they are robust to heteroskedasticity. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

However, the effect is not consistent across all specifications in both tables. When I omit a subset of the standards' and firms' fixed effects, the estimates of the coefficients of interest diverge, suggesting that the interesting variation may be included in the fixed effects. My results also suggest that the main source of variation in standard-related effort may be captured by individual, idiosyncratic standard aspects such that the different components of variance have different economic meanings. My findings highlight the presence of unobserved determinants that the model only captures once I include the full set of fixed effects. Indeed when I only account for the firm's observed and unobserved characteristics, the effect becomes positive. This result hints that some standard's specific factors, common to all firms, represent strategic incentives faced by the firms that overweight the firms' effects and boost competing firms to declare and file fewer SEPs and standard-related patents, respectively.

Since standard-specific factors mainly drive the changing sign, the fixed effects may capture the interesting mechanisms affecting the standard-related effort that each firm invests in standards development. On the one hand, in SSOs, firms not only compete in the selection of standard components but also coordinate with rivals for the development of the standards (Leiponen, 2008). Companies have the incentive to cooperate with their technological rivals. First, companies often develop substitutable patented technologies for selection into a standard, and only the selected technology benefits from a strong increase in its value (Rysman and Simcoe, 2008). The non-selected alternatives are abandoned. Therefore, firms can benefit from coordination with competitors to reduce the risk related to R&D activities and avoid over-patenting. Second, while the technological competition among firms contributing to the same standard may generate costly R&D duplications and delays in the development of the standard (Farrell and Simcoe, 2012), the coordination of firms with similar technological knowledge can lower coordination costs. Indeed, R&D coordination among technological rivals can efficiently reduce wasteful R&D duplication (Irwin and Klenow, 1996). This is true not only for coordination in standards development but for any R&D cooperation among competing firms.

Rosa (2019), in her research, shows that firms with similar technological knowledge provide complementary efforts in the development of a standard and that the efforts are stronger complement the more similar firms that are providing it. Moreover, Bar and Leiponen (2014) find that companies form committees in a way that's aligned with the complementarity of their technological inputs. According to these findings, there might be a coordination effect among firms with similar technological knowledge such that an increase in the technological similarities among firms or in the number of firms contributing to the same standard leads to less competition and higher coordination since firms may benefit from the positive externalities from working with other firms specialized in the same technological area. Therefore, some standard unobserved specific factors common to all firms can facilitate the coordination of firms and reduce R&D duplications. In this case, the coordination effect can reduce the wasteful over-investment in R&D and excess patenting spurred by the technological competition (Baron et al., 2014). In contrast, decreasing excessive resources in the development of competing technologies can induce an efficient allocation of resources in the development of complementary technologies that are necessary for the standard.

Notably, standards in my sample can be characterized by informal alliances that supplement formal standards development, in which firms coordinate standard-related R&D and streamline standards development. Baron and Pohlmann (2013) show that firms specializing in the same technological components of the standard are significantly more likely to be members of the same consortium. Through upfront coordination, technological competitors can reduce duplication in the development of technologies for selection into the standard. Baron et al. (2014) find that in cases of wasteful over-investment in standard-related R&D, consortia can efficiently reduce the extent of related patents. If this is the case, the results driven by standards fixed-effects suggest that standards in which the composition of contributing firms are technological rivals are exposed to less over-declaration of essential patents and development of non-essential competing standard-related technologies since the declaration of SEPs does not assure the actual essentiality of the patent neither that the technology will be included in the standard.

On the other hand, the standards fixed effects can identify groups where firms can appropriate from a smaller part of the total common value created, such that they are less incentivized to invest more standard-related effort and so to declare fewer standard essential patents and file fewer patents in standard related technology classes. In this case, this interpretation would imply that the firms in my sample primarily rely on the licensing of patents as the mainstream of revenue from standardization. However, suppose the coordination effect dominates the competition one. In that case, an increase in the number of participants holding the firm-firm similarity constant or in the technology similarity among contributing firms can avoid high R&D costs and thus increase the marginal licensing revenues for those firms. Further research that exploits the standard heterogeneity and how these different components interact with firm-specific characteristics is required to understand the economic effect of the standard-related features on firms.

5 Conclusion

Over the decades, technology standards have increased in importance as a required feature to ensure interoperability among independently designed products. Besides, modern standards have become quite complex, embodying a large number of patents held by many firms. Understanding the incentives firms face when deciding on which standard to contribute is key to promoting new innovation and stimulating markets' growth. This paper contributes to the stream of literature on standard participation by empirically studying the firms' participation decisions in standards development. To this end, I use data from the Searle Center Database and PATSTAT over a sample of 106 firms declaring essential patents to 539 standards issued by 8 SSOs.

In my first analysis, I analyze how the firm-standard technological match affects the firm's decision to contribute to the standardization process. The results show that the more the firms are technologically close to the standard's technological fields, the higher the probability they contribute to standards development. The technological match between the standard's and the firm's technical knowledge is an important factor when firms decide on their participation in standardization.

Since firms not only decide on whether to contribute to standardization but they also decide on how much standard-setting effort to invest in the standard development, I wider my analysis by studying how the competition over intellectual property rights among firms under a common standard affects the standard-related effort they exert. In particular, I rely on the number of SEPs they declare to the standard and the overall amount of patents filed in the standard-related technology classes as proxies of a firm's standardization effort. For this model, I use the overall cosine similarity between a firm and all other firms in a standard to measure the intensity of competition among those firms. By estimating a fixed effects model, I find a negative and significant relationship between a firm's standard-related effort and the intensity of competition among firms declaring standard essential patents to a common standard. This evidence supports the hypothesis of a *competition effect*, according to which firms invest less in standards development, either by declaring SEPs or filing patents in the standard-related technology classes when the competition among firms within a standard becomes more intense.

This research presents a new descriptive analysis of firms' choices to contribute to standardization. However, various issues are left for future research. First, when firms decide whether to contribute to standards development, they weigh their decision on the potential overall profits that firms expect from their participation in standardization. The expected profit is endogenous to all firms' characteristics, and it depends on two different revenue channels: the licensing of the intellectual property rights protecting the technologies included in the standard and the downstream sale of end products using the standard. The scarcity of data on IP rights revenues and other sources of standardization profits makes quantifying the effect of those sources of revenues on firms' participation decisions difficult. Secondly, firms also account for standardization costs when deciding whether to contribute to standards development. The costs related to standard participation represent another factor affecting the firms' decision that is difficult to estimate. Lastly, the competition effect results suggest some unobserved forces influence the number of patents filed in the standard-related technology classes. This can create endogeneity problems that may bias my estimates. By exploiting the heterogeneity across standards, further research can shed more light on the economic mechanisms contributing to the estimated effect and understand the economic effect of the standard-related features on firms.

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6 Appendix

Table 6
Estimates for participation decisions

	Probit Baseline	Probit Fixed Effects	Probit Fixed Effects	Probit Fixed Effects
Independent Variables				
Similarity	0.684***	0.669***	0.661***	1.356***
	(0.052)	(0.059)	(0.085)	(0.135)
Portfolio size of the firm	0.116***	0.125***	0.206***	0.360***
	(0.004)	(0.004)	(0.015)	(0.022)
SEPs declared per standard	0.331***	0.339***	0.342***	0.472***
	(0.006)	(0.008)	(0.010)	(0.019)
Total firms declaring SEPs	0.693***	0.617***	0.772***	0.343***
	(0.035)	(0.041)	(0.053)	(0.106)
IPC classes per standard	-0.002***	-0.002***	-0.001***	0.082***
	(0.000)	(0.000)	(0.001)	(0.008)
SSO*DeclarationYear FE	No	Yes	Yes	Yes
Firm FE	No	No	Yes	Yes
Standard FE	No	No	No	Yes
N	70,337	67,400	67,400	66,073
adj. R^2	0.80	0.81	0.87	0.90

Note: In the probit model I use the log transformation of the variables Portfolio size of the firm and SEPs declared per standard while the other variables are in level terms. Standard errors are reported in parentheses and they control for heteroskedasticity. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table 7
Standard-related effort and Competition intensity

	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Dependent Variable												
SEPs declared (log)												
Independent Variables												
Similarity-Competition	0.216***	0.225***	-0.065***	0.313***	0.266***	0.074 ***	0.024	-0.317***	0.057***	-0.272***	-0.309***	-0.327***
	(0.011)	(0.011)	(0.004)	(0.011)	(0.011)	(0.006)	(0.015)	(0.023)	(0.006)	(0.024)	(0.030)	(0.031)
Relative Portfolio size of the firm	-4.053***	-2.635***	1.304***	-1.350***	-0.680***	1.107***	1.169***	-1.182***	1.000***	0.419**	-1.356 ***	-0.968***
	(0.135)	(0.169)	(0.096)	(0.163)	(0.173)	(0.106)	(0.146)	(0.176)	(0.106)	(0.173)	(0.180)	(0.181)
Firm-standard similarity	1.693***	2.791***	-3.004***	4.394***	4.397***	-1.438***	-1.312***	-1.749***	-2.230***	-1.157***	1.783***	1.053***
	(0.263)	(0.281)	(0.160)	(0.279)	(0.278)	(0.171)	(0.196)	(0.218)	(0.181)	(0.221)	(0.289)	(0.309)
R&D expenditure (log)		0.203***	0.162***		1.173***			0.277***	0.008	0.141***		0.198**
		(0.015)	(0.010)		(0.086)			(0.010)	(0.065)	(0.012)		(0.085)
Portfolio size of the firm (log)		-0.283***	0.062***		0.563***			0.356***	0.804***	0.169***		0.965***
		(0.017)	(0.011)		(0.184)			(0.020)	(0.115)	(0.021)		(0.120)
IPC classes per standard (log)			0.354***			-0.084**			0.070			0.105***
			(0.036)			(0.041)			(0.043)			(0.007)
Total SEPs declared per standard (log)			0.869***			0.824***			0.846***	-0.177**		0.133
			(0.019)			(0.019)			(0.019)	(0.084)		(0.087)
Total documents per standard (log)			0.139***			0.149***			0.069***	1.606***		0.374**
			(0.026)			(0.022)			(0.022)	(0.136)		(0.159)
Firm FE	No	No	No	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes
Standard FE	No	No	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes
Average SEPs per firm-standard	585.96	585.96	585.96	585.96	585.96	585.96	585.96	585.96	585.96	585.96	585.96	585.96
Competition across standards	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32
N	1,245	1,166	1,166	1,245	1,166	1,245	1,245	1,166	1,166	1,166	1,245	1,166
adj. R^2	0.34	0.39	0.70	0.49	0.55	0.75	0.53	0.55	0.77	0.61	0.67	0.72

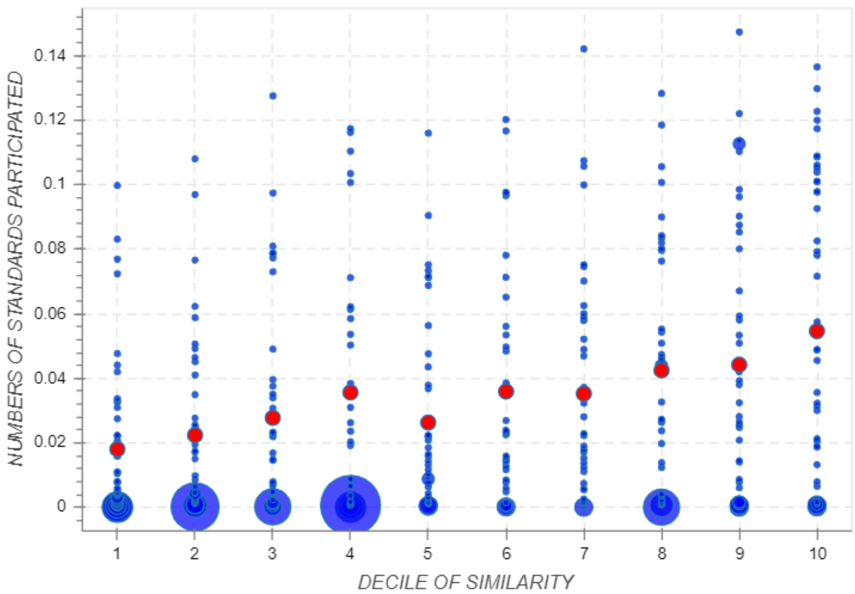
Note: The dependent variable is the logarithm of the aggregated number of SEPs declared in the years between the first and the last declaration made. The method of estimation is the fixed effect model. Standard errors are reported in parentheses and they are robust to heteroskedasticity. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Table 8
Standard-related effort and Competition intensity

	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Dependent Variable												
Standard-related patents (log)												
Independent Variables												
Similarity-Competition	0.174***	0.087***	-0.035***	0.160***	0.141***	0.048***	0.697	-0.152***	0.037***	-0.112***	-0.131***	-0.157***
	(0.006)	(0.005)	(0.004)	(0.005)	(0.005)	(0.004)	(0.016)	(0.016)	(0.004)	(0.017)	(0.019)	(0.021)
Relative Portfolio size of the firm	4.464***	-1.680***	0.353***	-1.117***	-0.847***	0.449***	7.711***	-0.513***	0.404***	0.562***	0.174	0.358***
	(0.136)	(0.102)	(0.082)	(0.098)	(0.103)	(0.080)	(0.197)	(0.134)	(0.082)	(0.136)	(0.123)	(0.121)
Firm-standard similarity	9.443***	3.146***	0.648***	3.852***	3.638***	1.017***	1.807***	1.251***	0.186	1.582***	2.440***	1.763***
	(0.133)	(0.166)	(0.107)	(0.154)	(0.163)	(0.122)	(0.218)	(0.187)	(0.122)	(0.183)	(0.186)	(0.191)
R&D expenditure (log)		0.094***	0.068***		0.216***			0.118***	-0.296***	0.026***		0.026
		(0.008)	(0.007)		(0.055)			(0.006)	(0.052)	(0.008)		(0.049)
Portfolio size of the firm (log)		0.962***	1.101***		1.147***			1.222***	1.132***	1.091***		1.469***
		(0.011)	(0.009)		(0.089)			(0.015)	(0.074)	(0.017)		(0.084)
IPC classes per standard (log)			0.396***			0.262***			0.391***			0.257***
			(0.035)			(0.033)			(0.035)			(0.037)
Total SEPs declared per standard (log)			0.080***			0.065***			0.091***	-0.324**		-0.032
			(0.014)			(0.012)			(0.012)	(0.058)		(0.059)
Total documents per standard (log)			0.411***			0.444***			0.389***	1.328***		0.026
			(0.019)			(0.015)			(0.015)	(0.085)		(0.115)
Firm FE	No	No	No	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes
Standard FE	No	No	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes
Average Patents per firm-standard	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24	7,442.24
Competition across standards	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32
N	1,245	1,166	1,166	1,245	1,166	1,245	1,245	1,166	1,166	1,166	1,245	1,166
adj. R^2	0.30	0.79	0.80	0.86	0.87	0.87	0.64	0.84	0.88	0.84	0.92	0.92

Note: The dependent variable is the logarithm of the aggregated number of SEPs declared in the years between the first and the last declaration made. The method of estimation is the fixed effect model.Standard errors are reported in parentheses and they are robust to heteroskedasticity. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ significant levels.

Figure 3
Participated Standards and Firm-Standard Similarity



This figure shows the normalized number of standards in which firms participate over the firm-standard similarity by deciles. The firms participating to the same number of standards in each decile is grouped into bins. The circular area of each bin depicts the count of firms. The red points represent the average number of standards by each decile.