Participation in Standards Organizations: The Role of R&D Expenditures, Patents, and the Product-Market Position

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Abstract

This paper examines the determinants of firms' participation in the standardization process. Using information about R&D, patent, and trademark activities of the world's largest R&D corporate investors and their membership in standards organizations, we find a highly robust positive association between a firm's R&D expenditures and its involvement in standardization. Our results indicate that a causal effect of R&D on membership in standards organizations is conditional upon the firm's patenting and/or product-market position and varies across distinct types of organizations. A strong patenting position amplifies the effect of R&D in upstream organizations whereas the product-market position strengthens the role of R&D in downstream organizations. We corroborate the existence of a positive causal effect of the patent position using variations in the preferential tax treatment of patent-related revenue. Finally, our findings also underscore the role of the product-market position – reflected in trademarking intensity, brand value, and the number of standards-compliant end products – in incentivizing R&D-intensive firms to join standards organizations.

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1 Introduction

In many technological fields, as innovation activities become increasingly modular, technological advancements often necessitate collaboration between a diverse range of businesses and organizations (Nalebuff et al., 1996; Rochet and Tirole, 2002). A salient example of such collaborative efforts is the development of technology standards, which play a particularly important role in the information and communication technology (ICT) sectors. Notwithstanding its rising economic significance, ICT standardization is often mired in distributive conflicts between technology contributors (i.e. sponsors of technologies necessary for the implementation of standards) and implementers (i.e., firms developing products or services conforming to standards) regarding the role and remuneration of Intellectual Property Rights (IPR). A significant body of literature points to the potential tension between the goal of standards organizations to develop open standards available for general use and the inclusion of proprietary technology subject to exclusive rights such as patents (Farrell et al., 2007; Lerner and Tirole, 2015).

These highly contentious issues have significant policy and managerial implications. Many standards organizations have patent policies requiring the owners of standard-essential patents (SEP) to make licenses available to standard implementers (Lemley, 2002; Lerner and Tirole, 2015; Baron and Spulber, 2018). Some organizations further restrict the inclusion of patent-protected technologies into their standards or bar SEP owners from collecting royalties from standard implementers. A number of important technology standards[1] have been developed under royalty-free licensing policies, where standards development relies entirely on the incentives of potential users who adopt the standards to provide the necessary R&D efforts. While many other technical standards are subject to royalty-bearing SEPs, there is a significant debate at a number of standards organizations whether there should be additional restrictions on the inclusion and/or enforceability of such SEPs.[2] These debates extend beyond the governance of single standards organizations, as governments and regulatory authorities around the world seek to provide guidance on principles for the inclusion and licensing of SEPs that balance the need to provide incentives for R&D-intensive firms to participate in the development of standards and the goal to make the standards as widely available as possible.[3]

From a business perspective, the extent to which IPRs are compatible with the open nature of standards development also raises important questions for managers of R&D-intensive firms seeking to appropriate a return on their R&D investments (Teece, 1986). The owners of proprietary technologies, for instance, may choose to retain a greater degree of control over the process of further developing and commercializing their technologies, as

[1] e.g., the Bluetooth standard for wireless communication, the USB standard for connections between computers and peripheral devices, and various Internet standards such as XML or HTTP.

[2] The Institute of Electrical and Electronics Engineers, IEEE, is a prominent standards organization that amended its patent policy in 2015 to tighten restrictions on the licensing and enforcement of SEPs.

[3] E.g., the European Commission in its 2017 Communication on the EU approach to Standard Essential Patents states two main objectives for a policy framework for SEPs: "incentivising the development and inclusion of top technologies in standards, by preserving fair and adequate return for these contributions, and ensuring smooth and wide dissemination of standardised technologies based on fair access conditions". The Communication further states that "FRAND valuation should ensure continued incentives for SEP holders to contribute their best available technology to standards."

an alternative to joining standards development. The emerging literature on platforms and innovation networks documents an array of strategies that allow a firm to elicit contributions from other firms to the further development of its technology, while retaining exclusive control over key proprietary assets (Boudreau, 2010; Ceccagnoli et al., 2012; Laursen and Salter, 2014; Alexy et al., 2018). Firms that heavily invest in R&D related to technology standards may also seek to strengthen their product-market position as an alternative means of appropriating a return on their investment in contributing to open standards development.

Central to these debates is the important question whether patents incentivize R&D-intensive firms to participate in collaborative standards development, or whether firms are more likely to participate if their R&D efforts are motivated by the prospect of using the technology in their products.[4] Despite the significance of this question to debates on policy and business strategy, there is a surprising dearth of reliable evidence on how a firm's patent and product-market positions influence its participation in open standards development. Put differently, what are the (distinct) roles of patent-based and product-based orientations in motivating the innovating firm to contribute its R&D input to technology standardization?

We tackle this question using a large longitudinal database of membership in 177 standards organizations (Baron and Spulber, 2018), which allows us to quantify the intensity of participation in standards development in a sample of large R&D-intensive firms. Existing studies have often focused on binary measures of membership or participation in single organizations. In addition to providing a measure of standardization that exhibits meaningful variations even among large and R&D-intensive firms, the large number of standards organizations in our data allows us to identify the distinct motives for participation in different types of organizations. The extant literature examining standards organizations has largely concentrated on upstream (technically oriented) organizations that develop standards, whereas scant attention has been devoted to the roles of scores of downstream organizations or marketing-oriented committees that certify newly developed standards and actively promote design compromises (Lerner and Tirole, 2006). We argue that these downstream standards organizations provide a crucial bridging capacity between the development of technical standard *specifications* and effective standardization through industry coordination on a single standard. We analyze whether the impact of a firm's patent or product-market positions differs between upstream and downstream standards organizations. Our findings provide insights into the modularity of standards development, where different firms participate in different parts of the process, depending on the relative strengths of their patent and product-market position (Simcoe, 2015).

Our work also relates to the literature that analyzes firms' membership decisions in standards organizations as a choice between different bodies with different features (e.g., Lerner and Tirole, 2006; Chiao et al., 2007). While prior research has investigated how firms choose between different standards organizations offering competing venues to develop a standard, we observe the determinants of participation in a large number of organizations playing different, complementary roles in a complex ecosystem of ICT standardization.

[4] This question is also related to the growing recognition of the significance of user-driven innovation (Von Hippel, 2005; Baldwin and Von Hippel, 2011; Gambardella et al., 2016; Harhoff and Lakhani, 2016).

Stacking memberships in multiple organizations has been found to provide coordination benefits to the participating firms, and facilitate standards development (Leiponen, 2008; Delcamp and Leiponen, 2014; Baron et al., 2014).

We find a highly robust association between R&D investments and participation in standards organizations, which increases in both the firm's patent and trademark intensity. While we use trademarks as an indicator of product-market position, we find that other measures of product-market position (such as brand value and the number of certified standard implementations) similarly strengthen the association between R&D and participation in standards organizations. Nevertheless, using R&D tax subsidies to identify the causal effects of R&D, we find that only patents increase the positive causal effect of R&D on membership in standards organizations across all organizations. Our findings reveal that product- and patent-based R&D appropriation strategies are associated with membership in different types of organizations. While the causal effect of R&D on membership in standards-developing organizations increases in a firm's patent intensity, the effect of R&D on membership in standards-promoting organizations increases in its product-market position. We also use favorable tax treatment of revenue from patents (commonly known as "patent boxes") to corroborate a causal interpretation of our results regarding the patent position.

Our results have significant managerial and policy implications. We reveal a robust positive effect of patent protection on the strategic complementarity between R&D investment and participation in open standards development. A policy change resulting in an increased profitability of patents is associated with increased participation of R&D-intensive firms in open standards organizations. While product-market factors can motivate R&D-intensive firms to participate in standards organizations that offer no specific patent-related incentives, this effect is limited to standards-promoting organizations, and does not extend to organizations where standards are developed. The interaction among firms whose R&D investments are primarily driven by these two different types of incentives is an important topic for future research and ongoing policy discussions within standards organizations.

The remainder of the paper is organized as follows. We provide an overview of related literature in Section 2. Section 3 describes the data sources and sample utilized in the empirical investigation. We present our econometric strategies and results in Section 4, alongside a set of robustness checks. Section 5 further discusses the implications of our findings, and we draw concluding remarks in the final section.

2 Literature review

2.1 Participation in standards organizations

A seminal literature analyzes the strategic decision of firms to make their products and/or services interoperable with those of their competitors by using common technology standards (Katz and Shapiro, 1985; Besen and Farrell, 1994). This literature emphasizes e.g. the role of the installed customer base and the firm's relative technological advantage over competitors. A more recent literature looks at the decision of firms to participate in the *development* of technology standards as, for example, a member of standards organizations.

While these decisions are interrelated, the decision to participate in the collaborative development of a technology standard is distinct from the firm's choice to make its product offerings interoperable with those of competitors (which could imply a variety of strategies in addition to the implementation of collaboratively developed standards).

Many standards are developed and defined in a complex ecosystem of private, voluntary, and open standards organizations. The functions of standards organizations encompass the preparation of technical standards or technical specifications published as or incorporated into other organizations' standards, the coordination R&D toward the definition of future standards, the resolution of commercial or policy conflicts arising in standards development, the promotion of fully developed standards, as well as the certification of compliance of products or services with existing standards. In our analysis, we distinguish between organizations that develop and publish technical standards,[5] and organizations that promote technology standards or participate in standards development in a variety of other roles (such as certification). Our distinction is akin to the distinction between technically oriented and marketing oriented consortia used by Delcamp and Leiponen (2014).

While some studies analyze the interplay between memberships in different standards organizations (Leiponen, 2008; Bar and Leiponen, 2014; Baron et al., 2014), the existing literature generally looks at the decision of firms to join a standards organization as a choice between different organizations providing alternative venues for standardization (Lerner and Tirole, 2006; Chiao et al., 2007). This *forum shopping* literature emphasizes the role of the standards organizations' patent policy for the venue choice of patent-intensive firms.[6]

In addition, a smaller number of studies has investigated the firm-level determinants of the degree of participation in standard development. While this research has analyzed the role of R&D expenditures and patents, there is to date no causal evidence based on exogenous variation, and the existing studies generally use binary measures of participation based on surveys or membership in single organizations. While these settings can be informative about the participation decisions of smaller or peripheral firms, they are of more limited use for analyzing the intensity of participation in standardization among large and R&D-intensive firms.

2.1.1 The role of R&D expenditures

There are two competing hypotheses for the impact of R&D expenditures on a firm's decision to participate in standards-developing activities. On one hand, joining the standardization process may help an innovating firm ensure that there is a product-market demand for its R&D contribution. On the other hand, participation in standard development may entail a risk of knowledge leakages to competitors (see Blind and Thumm, 2004).

[5] The literature often distinguishes between formal standards development organizations (SDOs) developing *de jure* standards; as well as more informal consortia (Simcoe, 2007). We analyze the determinants of participation in different standards organizations by their role in the standardization ecosystem, regardless of their degree of formality.

[6] As an extension to this framework, Lerner and Tirole's work further suggests that if the property/technology owner is also a user that receives a payoff in case of adoption, then its downstream presence also influences its choice of a standards organization.

Existing empirical studies - limited by the absence of causal identification - have produced mixed evidence regarding the role of R&D for firm participation in standards development. For example, Blind and Thumm (2004) analyze 149 European firms and find no statistically significant relationship between R&D intensity and the likelihood of joining the standardization process. Similar results were obtained for German (Blind, 2004; Rauber, 2014) and Dutch (Meeus et al., 2002) firms. Blind (2006) finds an inverted-U relationship between R&D intensity and the firm's decision to join the standardization process, and argues that meaningful participation in standards-developing activities requires the firm to have enough capacity to process and internalize the discussed knowledge, while leading R&D performers may limit their involvement in the standardization process because of the risk of knowledge leakages. Based on a survey of 375 firms in the German electrical engineering and machinery industry, Blind and Mangelsdorf (2016) find that a firm's R&D intensity is positively associated with seeking new knowledge or attempting to facilitate market access as motives for participation in standardization.

Despite the lack of definitive empirical support for the firm-level relationship between R&D expenditures and membership in standards organizations, some indirect evidence points to possibly significant complementarities between the two activities. Delcamp and Leiponen (2014) study patent citation networks among firms joining standards consortia and find that those firms who co-participate in the same consortia are more likely to cite each other's patents. This finding can be interpreted as an indication that firms use the knowledge exchanged during the standardization process to inform their own R&D. Likewise, when examining the effect of participation in open standards development on the success of start-ups, Fleming and Waguespack (2009) find that standards development benefits these firms mostly by providing them with information on new technological advances. Finally, according to Baron et al. (2014), informal consortia accompanying the standards-developing process taking place in formal SDOs provide a venue for their members to coordinate the level of standards-related R&D efforts, thus also alleviating problems of over- or under-compensation of patented contributions to the standard.

2.1.2 The role of patents

As noted earlier, the risk of technology leakages may deter R&D-intensive firms from joining collaborative technology development processes. Formal IPR protection mechanisms, and especially patents, may limit the ability of a third party to appropriate private knowledge, and thus increase the willingness of R&D-intensive firms to collaborate in technology development (Blind and Thumm, 2004).

In addition to the role of patents in protecting against unintended knowledge spillovers, patents may provide an incentive for firms to participate in the standardization process because of the value and relevance of SEPs.[7] Inclusion of a patented technology into a standard may significantly increase the value of the patents associated with it (Rysman and Simcoe, 2008) and provide additional financial returns to their owners (Hussinger and Schwiebacher, 2015; Pohlmann et al., 2016). The prospect of these additional returns may

[7]There is a sizeable an growing literature on SEPs, (see Shapiro, 2001; Lerner and Tirole, 2015; Baron et al., 2016).See Baron and Pohlmann (2018) for a review of this literature and a new database with declared SEPs.

serve as an incentive for patent holders to actively participate in standards development in order to improve the chances that their patented technology is included into the standard. Bekkers et al. (2011) show that the extent to which the firm participates in standards-developing activities is an important predictor of the likelihood of its patents being declared essential for the technology standard. Kang and Motohashi (2015) observe a similar pattern at the inventor level: there are more chances for a patent to be declared standard-essential if the technology inventor regularly attends meetings of standards organizations.[8]

At the same time, membership in standards organizations can also impose significant costs on firms with valuable IPR. In particular, standards organizations can oblige their members 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.

Empirical evidence on the relationship between patenting and participation in standardization is similarly ambiguous. Blind and Thumm (2004) find that firms strongly relying on patents to protect their R&D results are less inclined to join the standardization process. Gandal et al. (2004) describe a positive correlation between patenting and participation in standards committees (meeting attendance) in the modem industry, but find that it is committee participation that leads to more patenting, whereas patenting appears not to be a significant predictor of committee participation.

Survey-based evidence points to a complementarity between patenting and contributing to open standards. Fischer and Henkel (2013) apply a conjoint analysis to a survey of low- to high-level managers of a communications equipment firm to investigate the interactions among different strategies to appropriate benefits from technological innovation. The survey respondents identify patenting and contribution to open standards as mostly complementary strategies. While the benefits of patent protection increase inasmuch as the firm contributes to open standards, the effect turns insignificant or even negative at higher levels of patenting and contribution to standards.

2.1.3 The role of the product-market position

Among other reasons for why firms might steer clear of standards-developing activities is a strong product-market position which allows them to achieve commercial success alone, without leveraging the capacity of a standards organization (see Blind and Thumm, 2004). For example, a firm may opt to promote a technology as a proprietary *de facto* industry standard. This strategy is, however, feasible only if the firm has enough market power to turn its own technology into a standard generally accepted in the marketplace. Product-market leaders may thus be less likely to join the standardization process. Furthermore, firms maintaining their product-market position by engaging in product differentiation –

[8]Berger et al. (2012) note that a large number of patent applications resulting in declared SEPs undergo amendments that seem to be specifically designed to ensure that these patents' claims correspond with the standard specification. Firms participating in the standardization process may thus obtain information on the progress of the standard to tailor their strategies aiming at the acquisition of IP rights.

either by investing heavily in advertising and/or R&D – may be reluctant to standardize their products because having compatible elements often reduces product uniqueness in the eyes of consumers (see Lecraw, 1984). Advertising-based brand differentiation can also make standardization redundant, as both brands and standards can be used to overcome information asymmetries between producers and consumers about product quality.

These arguments point to a negative effect of a firm's strong product-market position on participation in collaborative standards development. Nevertheless, several authors argue that a strong product-market position should induce firms to increase their participation in standards organizations. Teece and Sherry (2003) observe that contributors of patented technologies and the manufacturers that are poised to implement the novel standard in their products frequently participate together in standardization. Similarly, Spulber (2013) emphasizes the existence of both product- and patent-related incentives for participation in standards organizations, and argues that coordination among inventors and producers is a crucial function of these organizations. Prufer and Larrain (2018) develop a theoretical model analyzing the distinct incentives of upstream and downstream firms to join standards development processes. In their model, patent-owning upstream contributors join standards organizations in order to increase the chance of their technology being selected into a standard, and downstream implementers join standards organizations in order to benefit from knowledge spillovers arising in standards development. Teece and Sherry (2003) point to the important implications of the interplay between firms with these different incentives for SDO governance and the antitrust approach to standardization.[9]

In addition to directly influencing the incentives to participate in standards organizations, a firm's product-market position can be expected to have a mediating effect on the relationship between R&D and participation in standards development. A large literature in industrial economics has studied the relationship between firm size and R&D, revealing the role of a firm product-market's position as incentive for innovation. More recently, technology development in such fields as genomics and open source software offers salient examples of *appropriability regimes* in which the decision to pursue R&D in an open and collaborative effort is primarily driven by product-market incentives (Pisano, 2006).

Similar incentives are often likely to be at play in standards development. Internet standards published by the World Wide Web Consortium (W3C), the Bluetooth Wireless communication standard, or the USB standard for connections between computers and peripheral devices are just some prominent examples of standards developed under policies requiring that all essential IPRs are licensed royalty-free to standards implementers. While firms contributing costly R&D to the development of these standards must recoup this investment entirely in the market for standards-related products or services, product-market incentives in most SDOs coexist with the incentives provided by patents. There is little empirical evidence shedding light on the relative importance of product- and patent-based incentives for standards-related collaborative R&D, and the interactions between these appropriability mechanisms. Using evidence collected by a survey of employees from one firm, Fischer and Henkel (2013) document that employees regard their product-related patents as complementary to the firm's contributions to open standards. Nevertheless, no

[9] Contreras (2013) presents a case study of the policy implications of this interplay; describing the opposing interests of *product-* and *patent-*centric firms regarding a change in an SDO's patent policy.

comprehensive study has empirically addressed the role of incentives unrelated to patents in the development of open standards.[10]

2.2 Collaborative innovation and complementary assets

Our research also contributes to the more general literature on open and collaborative innovation processes (Von Hippel, 1998; Chesbrough, 2006; Harhoff et al., 2003; West et al., 2014). Firms participating in such processes face significant challenges in coordinating their efforts with those of other participants, while securing a return on their investments (Laursen and Salter, 2014). Control over key complementary assets can thus be an important requirement for firms seeking to profitably engage in collaborative technology development (Teece, 1986; Arora and Ceccagnoli, 2006). Recent development in this literature offers a more subtle take on the interplay between openness and appropriability (Laursen and Salter, 2014; Henkel et al., 2014). For instance, Laursen and Salter (2014) highlight a concave relationship between firms' engagement in open innovation and the strength of their appropriability strategies.

The literature on technology platforms has shed further light on the relationship between appropriation and open innovation. According to Gawer and Cusumano (2014), technologies developed by firms can provide foundational platforms upon which a larger number of firms can build further complementary innovations. Existing research has mostly focused on the incentives of the innovating firm to open the platform or retain exclusive control to appropriate the returns on innovation (West, 2003; Gawer and Henderson, 2007; Eisenmann et al., 2009; Boudreau, 2010). More recent research also investigates the factors determining the incentives of other firms to join a proprietary platform. These firms face the threat of expropriation of their contributions to technology development by the platform owner (Gawer and Henderson, 2007). Huang et al. (2013) find that both formal IPR (patents and copyrights) and downstream capabilities (as measured by trademarks and consulting services) are associated with increased platform participation. Both mechanisms thus seem to be effective in protecting firms from expropriation of their contributions to a collaborative technology development process on a platform.

There are important parallels between the platform participation decision of say software vendors and the decision of firms to join open standards development organizations in ICT domains. Indeed, Gawer and Henderson (2007) and Boudreau (2010) refer to standards organizations as a model of fully open technology platform development. Despite the research on proprietary or sponsored platforms gaining traction in recent years, there is a dearth of knowledge on the characteristics and strategies of firms developing standards-based open platform.

[10]In a different context, existing studies analyze the role of downstream capabilities, measured by trademarks, for the decision of software vendors to join proprietary or open-source platforms (Fosfuri et al., 2008; Huang et al., 2013; Ceccagnoli et al., 2012).

3 Data and measures

3.1 An overview of the main data sources

3.1.1 The data on memberships in standards organizations

We obtain information about membership in standards organizations from the Searle Center Database on Technology Standards and Standard Setting Organizations (see Baron and Spulber, 2018). This database contains membership data for 191 standards organizations, including formal standards development organizations (SDO), informal consortia, and organizations that participate in the standardization process in a variety of ancillary roles (e.g., coordination, certification, or advocacy). It particularly focuses on the organizations that operate in the ICT sector, with yearly observations covering the period 1997-2015.

The standards organizations in the Searle Center Database are membership-based. Depending on the organization, membership can be open to individuals or other organizations – firms, universities, public administrations, trade associations, and standards bodies.[11] The Searle Center Database contains membership information on standards organizations with organizational membership. The standards organizations in this database are also *open*, which means that any organization complying with the general criteria for membership and agreeing to abide by the standards organization's policies can become its member. Nonetheless, the majority of member entries in the database are commercial firms.

Although membership is often not required for participation in the standardization process at a standards organization, members are usually given additional rights, such as privileged voting rights on standardization decisions; the right to participate in elections of the standards organization's leadership; and the right to define the rules and policies of the organization. Most standards organizations charge a membership fee, which can vary with the size of the participating organization and the tier of membership. Furthermore, standards organization members have to enter into a membership agreement: it may define, *inter alia*, obligations concerning the disclosure of potential SEPs and the requirement to make licenses for SEPs available to standards implementers. Therefore, firms have to choose carefully in which standards organizations they wish to obtain membership. The firm with the largest number of membership records in the Searle Center Database is IBM Corporation – it is listed as a member of 112 standards organizations.

3.1.2 The data on R&D expenditures, patents, and trademarks

The information on firms' innovation outcomes and other characteristics is extracted from two waves of the OECD Database on the IP Bundles of the World's Top R&D Investors [henceforth 'OECD database'] (see Dernis et al., 2015; Daiko et al., 2017). This database contains annual statistics on the patent and trademark activities of the world's Top 2,000 corporate R&D performers, including their subsidiaries, for the period between 2010 and 2014. The selection of firms to add in the OECD Database is guided by the EU Industrial

[11] Several international standards developing organizations (e.g., ISO, IEC, CEN, or CENELEC) restrict membership only to national standards bodies.

R&D Investment Scoreboard (see Guevara et al., 2015), which also serves as the source of economic and financial data. The IP statistics for these 2,000 firms is derived from the five major IP offices (IP5) located in the European Union, the United States, Japan, South Korea, and China. To avoid double counting because of patent applications being filed at different IP offices, the patent data in each of the waves is further consolidated in "[families] of patent applications with members filed at least in one of the IP5, excluding single filings" (Dernis et al., 2015, p.20). Overall, the firms included in the OECD database own 66% of all IP5 patent families; trademark ownership is more dispersed, with about 8% of all applications being filed in the European Union, the United States, Japan, and Australia (Dernis et al., 2015).

As the list of the firms ranked among the world's Top 2,000 R&D investors changed from the first wave (published in 2015) to the second wave (published in 2017), we retained only those firms that appeared in both waves. Having controlled for name and ownership changes over the sample period, as well as for other discrepancies to ensure data consistency, we were able to identify 1,633 firms that appeared in each wave, amounting to almost 82% of the Top 2,000 corporate R&D performers considered in the original 2015 wave.

3.2 The construction of the sample

To construct the sample for our empirical analysis, we match the 1,633 firms obtained from the intersection of both waves of the OECD Database to the Searle Center Database. For the observation period, we establish matches between the firms in the OECD database and the membership records of 177 standards organizations. We use the name harmonization file supplied by the Searle Center Database to perform the matching, while also significantly extending it to improve the compatibility with the OECD database. In few instances, the name harmonization procedure results in several firms from the OECD database collapsing into a single observation (e.g., "Mitsubishi Electric" and "Mitubishi Materials" are harmonized as "Mitsubishi") – we aggregate all the statistics for such firms. This matching procedure yields a sample of 1,609 firm matches.

It should be noted that the OECD database includes R&D-intensive firms across many industries. To verify whether it provides good coverage of the firms which are most intensely involved in the ICT-related standardization, we assess it against the information in the Searle Center Database. Our assessment shows that the average firm in the OECD database is a member of 5.36 standards organizations. The OECD database firms collectively account for 9.3% of all firm-standards organization membership observations. The share of these firms among the entities with a particularly large number of memberships found in the Searle Center Database is much higher: for example, 42 of the Top 50 entities with the highest number of standards organization memberships are included in both waves of the OECD database.

Using the Database of Declared SEPs (see Baron and Pohlmann, 2018), we also find that out of 144,521 declared SEPs, 124,846 patents (86.4%) belong to the firms included in both waves of the OECD database. This database particularly contains 36 of the Top 50 entities declaring SEPs (and all of the Top 10 ones).[12] We further draw on two databases of certified standard implementations to calculate the number of different standards-compliant products each firm offers.[13] We identify 36,831 unique products that comply with standards developed by ICT standards organizations, of which 26,257 products (72.2%) are offered by the firms included in the intersection of both waves of the OECD Database. Overall, this analysis leads us to conclude that the OECD Database contains a significant majority of the top standards organization members, SEP owners, and implementers of ICT standards.

Industry	Total number of firms Ind. Sam. 1	Total number of firms Ind. Sam. 2	Avg. num. of SOs	SO_50	SEP holders	SEP_50	Producers	Prod_50
Broadcas. & Entertain.	5	5	14.00	0	0.40	2	0.40	1
Consumer Electronics	17	17	19.23	3	0.41	4	0.47	3
Electron. & Elec. Equip.	144	144	8.56	7	0.20	9	0.15	7
Fixed Line Telecom.	15	15	31.33	6	0.60	7	0.47	3
Mobile Telecom.	4	4	15.75	0	0.75	0	0.25	1
Tech. Hardw. & Equip.	232	232	14.41	23	0.31	20	0.26	28
Aerospace & Defense	0	43	6.83	1	0.12	1	0.05	0
General Industrials	0	60	5.22	3	0.10	3	0.03	2
Publishing	0	3	7.33	0	0.00	0	0.00	0
Software & Comp. Serv.	0	154	7.69	7	0.13	3	0.03	2
Support Services	0	17	4.71	0	0.06	0	0.00	0
Total	417	694	10.66	50	0.22	49	0.16	47

Note. SO_50 denotes the Top 50 entities with the highest number of standards organization memberships. SEP_50 denotes the Top 50 entities declaring SEPs. Prod_50 denotes the Top 50 producers that offer products complying with the standards developed by ICT standards organizations. The "Top" statistics shown above refer to the firms in the OECD database, not the entire Searle Center Database: for example, all 50 firms in the OECD database with the highest number of standards organization memberships in the Searle Center Database are classified in one of the 11 industries of *Industry Sample 2*, but only 42 of the Top 50 entities – in both waves of the OECD database.

Table 1: Sample construction: An industry breakdown

The second stage of sample construction is to restrict the matched sample to the firms in the industries that are particularly relevant to ICT standardization. This is done by first adopting the FTSE's Industry Classification Benchmark (ICB) to define industries, and then selecting the industries of interest by drawing on the same data and applying the same criteria (i.e., membership counts, declared SEPs, and standards-compliant products; see Table 1 for more details) as above.[14] We thus create two samples: first, a narrower sample covering six industries that are most involved in developing ICT standards: such as Broadcasting and Entertainment, Consumer Electronics, Electronic and Electrical Equipment, Fixed Line Telecommunications, Mobile Telecommunications, and Technology Hardware and Equipment (*Industry Sample 1*). In each of these six industries, the average number of memberships per firm is higher than 10, apart from the Electronic and Electrical

[12]Given that both the membership data and the data on SEPs also contain universities, research institutions, and public administrations, the firms in both waves of the OECD database account for an even larger share of the corporate entities involved in ICT standardization.

[13]To search for the information about devices incorporating the standardized wireless connection technology, we use *GSM Arena* (www.gsmarena.com) and *Wi-Fi Alliance* (www.wi-fi.org/product-finder) websites.

[14]Although we define industries on the ICB Sector level, ICB Sectors 3740 (Leisure Goods, which include not only Consumer Electronics, but also Toys and Sport Goods) and 5550 (Media, including Broadcasting, Media Agencies, and Publishing) are observed to be highly heterogeneous regarding the extent of their involvement in ICT standards development; so, we use ICB Subsector classifications for these industries.

Equipment sector; at least 20% of the firms have declared one or more SEPs; and at least 15% of the firms sell standards-compliant products. 417 firms from the intersection of the two waves of the OECD Database are included in this industry sample. Recognizing that the above six industries do not encompass all of the most significant corporate entities participating in standards development, we also construct a larger sample of 11 industries that covers 694 firms (*Industry Sample 2*). This sample is selected to account for all the most relevant stakeholders in ICT standardization among the firms in the OECD database, but it includes industries that are more heterogeneous with respect to the relevance of ICT standardization.[15]

3.3 The description of variables

Dependent variables. To capture the extent of a firm's participation in various types of standardization activities, we calculate the number of standards organizations in which the firm has membership in a given year (we use its log-transformed form).[16] Moreover, we differentiate standards organizations with respect to their prevailing role in the standardization process. We design and adopt the following classification:

- *Standards developers*: organizations added in this group develop technology standards or technical specifications (e.g., Bluetooth SIG, Consumer Electronics Association, UPnP Forum, Peripheral Component Interconnect SIG, and ASTM International);
- *Standards promoters*: organizations of this type promote standards developed by other organizations (e.g., Healthcare Information and Management Systems Society, Internet2, Wi-Fi Alliance, WiMAX Forum, and Smart Card Alliance);
- *Other organizations*: this group includes organizations that can't be classifed into either of the groups above (e.g., TM Forum, Workgroup for Electronic Data Interchange, LonMark International, DVD Forum, and VoiceXML Forum).

In addition, we also distinguish between standards developers that receive and publish at least one SEP disclosure, and other standards developers.

When creating our classification, we relied on each organization's self-description of its tasks and activities published on the organization's official website (websites were consulted from February to April 2018). Since the distinction was not always straightforward,[17]

[15] For some firms, the financial statistics contains missing observations. Therefore, the actual number of firms included in the econometric analysis is slightly lower – see the tables below for more details.

[16] For a small number of standards organizations, the membership information in the Searle Center Database has gaps, i.e. missing years. In these cases, we use an *interpolated* membership count. A firm is classified as member of a standards organization in a given year if there is no information on membership in this standards organization and year in the data, and if the firm was member in the year before and the year after the year with missing information.

[17] The case of the *Wi-Fi Alliance* is a telling example of how the roles of standards organizations can overlap and change over time. Among the functions the Wi-Fi Alliance is responsible for is the certification of the compliance of a product with IEEE 802.11 wireless connection standards. As part of this process, the Wi-Fi Alliance develops a "shared interpretation of the 802.11b standard – contained in a dense 400 page document – that would avoid interoperability issues." (DeLacey et al., 2006, p.10) This "interpretation" can itself be considered as a technology standard. Nevertheless, recognizing that this function is ancillary to the Alliance's main role of promoting Wi-Fi technology, we classified this organization as a standards promoter and, thus, included it in the standards promoters group.

we refined the classification by using additional sources of information. For example, an organization was classified as a standards developer if the standards developed by it were included in the Searle Centre Database; if it was listed among the developers accredited by the American National Standards Institute; or if it had disclosed SEPs. In order to identify standards organizations that have received and published at least one SEP disclosure, we used the data from Baron and Pohlmann (2018).[18]

Overall, our analysis suggests that among the 177 standards organizations included in our sample, 58% should be classified as standards developers, 23% – as standards promoters, and 19% belong to other organizations. As far as the distribution of the sampled firms by the type of standards organizations is concerned, about 41% of them have at least one membership associated with standards developers, 17% – with standards promoters, and 15% – with other organizations (all numbers are on average across 6 years).

Explanatory variables. To measure the level of R&D investment, we use the natural logarithm of the firm's reported R&D expenditures in a given year (lnRD). Patent-intensive firms are captured by a dummy variable that takes the value of one if the firm's ratio of patent counts to the number of employees is above the sample median, and zero otherwise (PT_High). Similarly, we identify firms with a strong product-market position by introducing a dummy variable that takes the value of one if the trademark-counts-to-employees ratio is greater than the sample median (TM_High).[19] We draw on trademark statistics to reveal the product-market position, largely owing to the variety of functions trademarks can perform: along with differentiating the product offering of one producer from that of another, trademarks are also shown to be a reliable proxy for innovation and, more generally, new product development activities, especially at the commercialization stage (see Mendonça et al., 2004; Helmers and Rogers, 2010; Sandner and Block, 2011; Crass et al., 2016). Given the diversity of market-related information trademark statistics tends to incorporate, we are confident that this approach provides us with a suitable proxy for the firm's product-market position.[20]

Control variables. We include several firm-level characteristics to control for the factors that can potentially affect the firm's decision to participate in the standardization process. We particulalry control for the total number of employees (lnEmployees), the amount of net sales (lnSales), and the firm's capital intensity (measured as capital expenditures over net sales; lnCapital_Int). Each of these variables is log-transformed. We also control for year fixed effects and regional trends. The latter are controlled for by adding interaction terms between year (as continuous variable) and six regional dummies (i.e., North America, Europe, China, Japan, South Korea, and other).[21] We thus attempt to capture any notable

[18]It should be noted that using the SEP disclosure data to identify the organizations which develop standards with an essential patented technology is likely to result in false negatives. That is, other standards organizations in our sample may also develop standards that are potentially subject to SEPs, but do not require the disclosure of such SEPs or do not make disclosure letters publicly available.

[19]We have experimented with different dummy specifications to ensure that our results are not affected by the way these dummies are constructed. For example, we have computed these dummies based on each industry's median, as well as used the total amount of sales for scaling. Despite these alterations, the results we observed were largely consistent with our baseline specifications.

[20]In recent studies, Ceccagnoli et al. (2012) and Huang et al. (2013) also employ a trademarks-based indicator to proxy the product-market position, or downstream capabilities, in the software industry.

[21]To assign firms to regions, we largely rely on the country of incorporation information provided in the OECD Database. In some cases, these firms are incorporated in tax havens and are unlikely to have

shifts in the patterns of patenting and standardization participation in different regions of the world. For example, the increased participation of emerging market actors in global technological development may induce spurious correlations between innovation activities and standards development, which are not controlled for if only firm fixed effects are used.

4 Empirical analysis

4.1 Descriptive statistics

In Table 2, we provide descriptive statistics for standards organizations and their members. For each indicator, we first calculate its yearly averages (or totals if the membership data is used) for a given standards organization and then find the mean over the period 2010-2014.

	All organizations	Standards developers	Standards promoters	Other organizations	Organizations with SEPs
Any members					
mean	238.76	314.54	92.66	131.59	233.04
[s.d.]	[1,061.66]	[1,325.40]	[127.08]	[176.31]	[177.95]
Members from Ind. Sam. 1					
mean	21.89	24.96	14.57	18.85	35.20
[s.d.]	[28.17]	[31.60]	[20.51]	[18.26]	[23.65]
Members from Ind. Sam. 2					
mean	27.40	31.76	18.07	22.02	47.16
[s.d.]	[33.31]	[37.63]	[22.92]	[20.68]	[28.16]
PT intensity					
mean	0.0649	0.0673	0.0562	0.0668	0.0703
[s.d.]	[0.0871]	[0.1028]	[0.0481]	[0.0465]	[0.0358]
TM intensity					
mean	0.0064	0.0072	0.0059	0.0039	0.0041
[s.d.]	[0.0343]	[0.0425]	[0.0106]	[0.0030]	[0.0017]
PT counts					
mean	1,404.17	1,430.35	1,221.20	1,541.44	1,563.05
[s.d.]	[1,001.39]	[944.04]	[1,067.35]	[1,113.48]	[788.36]
TM counts					
mean	44.73	47.67	36.92	42.97	46.14
[s.d.]	[24.14]	[24.85]	[20.32]	[23.59]	[11.95]
Total organizations	132	84	27	20	10

Note. Patent/trademark indicators are calculated based on the sample of the firms which are included in the intersection of the two waves of the OECD Database.

Table 2: Descriptive statistics: By the type of standards organizations

In the 2010-2014 period, the average standards organization listed in the Searle Center Database had 239 members, with about 10% of this number being due to the firms from one of our industry samples. Organizations that developed standards or technical specifications had significantly larger membership counts than other types of standards organizations, both in terms of the overall membership counts and among the firms included in the OECD

significant business activities in those locations. If so, we searched for additional information in publicly available sources to assign the firm to the region where it conducts most of its business.

Database. In turn, the average member of a standards-developing organization filed 1,430 patent and 48 trademark applications per year. Although these figures were slightly lower for standards promoters and other standards organizations, the latter type had the highest average patent counts among all types of standards organizations. Finally, standards organizations with SEP disclosures had the highest number of members when the firms from the OECD Database were considered. Members of these standards organizations also had the highest average patent count compared to members of other standards organizations.

4.2 Econometric analysis

4.2.1 Baseline models

In this section, we present the results of the OLS regression analysis examining the effect of a firm's R&D expenditures, patent, and trademark activities on the number of standards organizations in which the firm participates. We present the results from the narrower and more homogeneous *Industry Sample 1* throughout the analysis. However, the results from the larger *Industry Sample 2* are very similar (see Table 12 in Appendix A).

The main explanatory variables of interest are is the amount of the firm's R&D spending (Model 1), depending on its IP positions. Given that we utilize the fixed-effects estimation technique, the time-invariant variables, such as IP dummies, cannot be estimated on their own. We therefore interact R&D spending with each IP dummy variable separately (Models 2-4), as well as include a three-way interaction term based on all the three variables (Model 5). The results of this analysis are reported in Table 3.

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5
lnRD	0.040*	0.014	0.003	-0.005	-0.001
	(0.068)	(0.460)	(0.860)	(0.779)	(0.956)
lnRD#PT_High		0.155***		0.093*	0.055
		(0.005)		(0.095)	(0.456)
lnRD#TM_High			0.196***	0.154***	0.118**
			(0.000)	(0.003)	(0.048)
lnRD#PT_High#TM_High					0.085
					(0.454)
lnEmployees	0.062**	0.042*	0.039*	0.032	0.034
	(0.018)	(0.091)	(0.093)	(0.176)	(0.135)
lnSales	0.048***	0.044***	0.040***	0.040***	0.039***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnCapital_Int	0.058	-0.028	-0.041	-0.072	-0.067
	(0.534)	(0.752)	(0.633)	(0.410)	(0.440)
Constant	-48.993*	-27.884	-6.635	-3.003	-5.292
	(0.088)	(0.315)	(0.800)	(0.909)	(0.842)
Year dummies	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes
R-squared	0.104	0.116	0.121	0.124	0.125
Observations	1,893	1,893	1,893	1,893	1,893
Number of companies	404	404	404	404	404

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 3: Fixed-effects models with IP positions

We find a strong and statistically significant positive association between the firm's R&D spending and the count of its standards organization memberships (Model 1). Furthermore, this association is also found to depend on the firm's IP intensity in the sense that it significantly increases for the firms with patent and trademark intensities above the sample median (Models 2-3). Both types of IP intensity increase the positive association between R&D expenditures and the firm's participation in standards organizations even when included simultaneously (Model 4). We find no evidence for significant interactions between the effects of patents and trademark positions on the association between R&D and standards organization membership (Model 5).

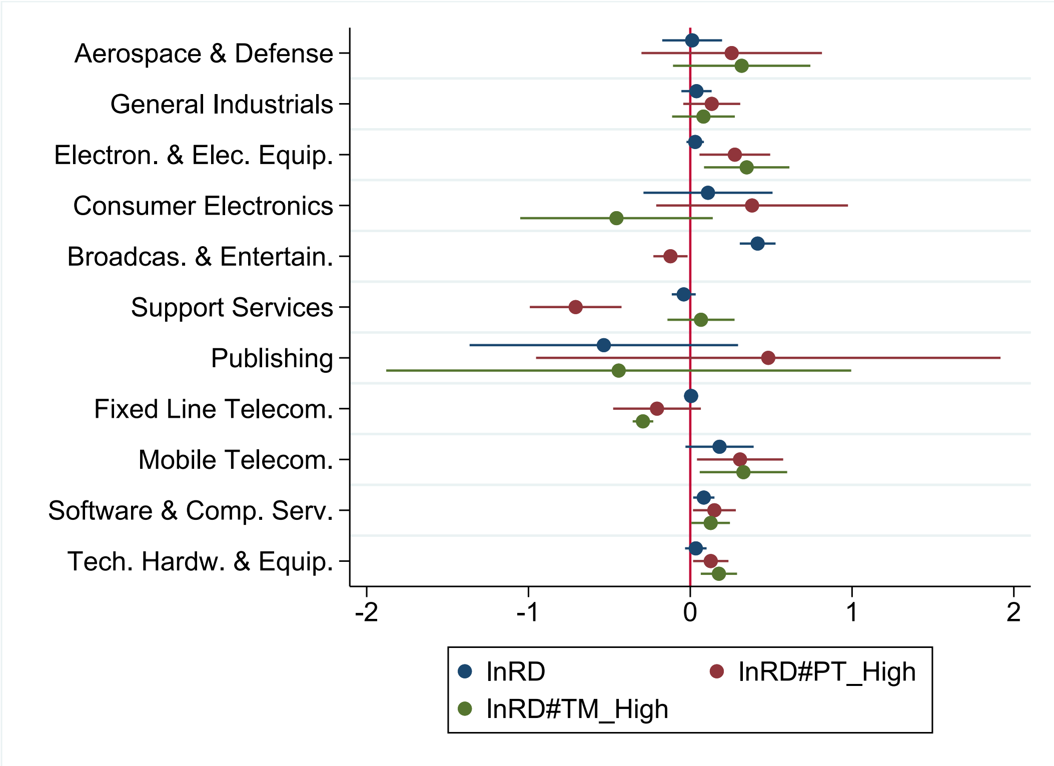
To gain more insight into the results, we allow the coefficients of interest to vary by industry. Figure 1 shows industry-specific coefficients and their 95% confidence intervals. The point estimate for the association between the firm's R&D spending and the count of its standards organization memberships is positive in nine out of eleven industries in *Industry Sample 2*, and in all six industries included in our narrower *Industry Sample 1*, even though this association is individually significant at 95% only in Broadcasting and Entertainment and Software and Computer Services. The interactions between the firm's R&D spending and patent and trademark positions receive positive support from eight and seven industries, respectively, and both are individually significant and positive in the same four industries: Electronic and Electrical Equipment, Technology Hardware and Equipment, Mobile Telecommunications, and Software and Computer Services.

Overall, these findings suggest that the associations of interest are very robust. The association between R&D and membership in standards organizations is highly robust, with no evidence of inter-industry heterogeneity; and while there are statistically significant negative coefficients for the interaction terms between R&D and IP positions in some industries, these are industries with only small numbers of firms among the top R&D performers in the OECD database.

We attribute the discrepancies observed in our by-industry results to the fact that in most industries, only a small number of firms is included in the OECD database. These small samples lead to less precise estimates. This reasoning is supported by the results for the industries with the largest number of firms (i.e., Electronic and Electrical Equipment, Technology Hardware and Equipment, and Software and Computer Services), which turn out to be similar in terms of both the sign of the coefficient and the level of significance to the average coefficients across industries.

While the results presented so far are based on binary measures of IP intensity, in Table 4, we present the results from estimating models with continuous counts of patents and trademarks. In Models 1-4, we include *pre-determined* counts based on the number of IP applications in 2010, the first year of our sample period. Similar to the previously used IP dummies, these pre-determined counts are time-invariant; thus, the interaction terms in the fixed effect specification can be regarded as variations in the effect of the time-variant R&D measure depending on the firm's IP intensity. In Models 5-7, we use time-variant patent and trademark counts based on the flow of applications over time. These specifications draw on richer information, because we also take into account variations in IP intensity over time. However, the interaction terms are more difficult to interpret in this case: they can indicate variations in the effect of either the extent of R&D spending by IP intensity

Figure 1: Coefficients for R&D and R&D-IP interactions:
An industry breakdown; Industry Sample 2



Note. Coefficients and 95% confidence intervals. Coefficients for RD#TM in Broadcasting and Entertainment dropped.

or IP intensity by the extent of R&D spending. The baseline effect of IP counts without interactions is included in Model 5.

The results are broadly in line with those obtained from the baseline specifications with IP dummies. The association between the firm's R&D spending and its standards organization memberships significantly increases in the firm's number of patents (pre-determined). The number of trademarks also has an amplification effect on the R&D-participation association, even though this effect vanishes when patent counts are simultaneously included in the model (yet, not for time-invariant trademark counts). As before, we find no evidence for significant complementarity between both types of IP counts.

While including time-variant IP counts allows us to test for direct effects of IP, we find these to be insignificant. This can suggest that IP counts influence the participation decision of only particular R&D-intensive firms. It is also plausible that the within-variation over less than 6 years is not highly informative of the main effect of IP counts. This is because the flow of IP applications is often subject to significant stochastic shocks, while the firm's participation decision is more likely to be driven by the overall size and value of its IP stock rather than within-variations in IP applications over time.

4.2.2 The heterogeneity among standards organizations

Next, we divide our sample into standards developing, standards promoting, and other standards organizations. Among standards developers, we further distinguish between the organizations with standards being potentially subject to SEPs, and without thereof. In

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	Predetermined IP counts				Time-variant IP counts		
lnRD	0.028	0.054**	0.040**	0.034*	0.128***	0.110**	0.100*
	(0.195)	(0.011)	(0.032)	(0.070)	(0.005)	(0.030)	(0.071)
lnPT_count					-0.012	-0.014	-0.010
					(0.282)	(0.653)	(0.784)
lnTM_count					-0.002	-0.068*	-0.051
					(0.823)	(0.093)	(0.473)
lnPT_count#lnTM_count							-0.011
							(0.427)
lnRD#lnPT_count	0.016**		0.012*	0.013**		0.000	0.001
	(0.010)		(0.055)	(0.021)		(0.963)	(0.882)
lnRD#lnTM_count		0.022**	0.015	0.010		0.014*	0.016
		(0.012)	(0.130)	(0.280)		(0.071)	(0.303)
lnRD#lnPT_count#lnTM_count				0.002			0.001
				(0.438)			(0.729)
lnEmployees	0.050**	0.059**	0.051**	0.050**	0.018	0.017	0.019
	(0.042)	(0.021)	(0.038)	(0.041)	(0.480)	(0.507)	(0.452)
lnSales	0.044***	0.046***	0.044***	0.043***	0.039***	0.038***	0.038***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.005)	(0.005)
lnCapital_Int	0.007	0.045	0.010	0.006	-0.112	-0.116	-0.107
	(0.939)	(0.623)	(0.911)	(0.946)	(0.222)	(0.196)	(0.232)
Constant	-26.209	-33.342	-20.900	-23.675	-78.798**	-71.367**	-69.441**
	(0.341)	(0.234)	(0.458)	(0.389)	(0.019)	(0.033)	(0.039)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.111	0.110	0.113	0.113	0.126	0.128	0.130
Observations	1,893	1,893	1,893	1,893	1,510	1,510	1,510
Number of companies	404	404	404	404	403	403	403

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 4: Fixed-effects models with predetermined/time-variant IP counts

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
	Standards developers		Standards promoters		Other organizations		With SEPs		Without SEPs	
lnRD	0.018	-0.019	0.079***	0.049**	0.024	0.008	0.014	0.004	0.016	-0.026*
	(0.339)	(0.243)	(0.001)	(0.021)	(0.270)	(0.681)	(0.374)	(0.787)	(0.405)	(0.070)
lnRD#PT_High		0.106**		-0.006		0.033		0.085*		0.087*
		(0.023)		(0.913)		(0.532)		(0.050)		(0.073)
lnRD#TM_High		0.094**		0.163***		0.058		-0.026		0.143***
		(0.040)		(0.007)		(0.302)		(0.565)		(0.003)
lnEmployees	0.032	0.007	0.031	0.013	0.074**	0.063*	0.003	-0.005	0.041*	0.013
	(0.190)	(0.765)	(0.225)	(0.580)	(0.039)	(0.080)	(0.893)	(0.815)	(0.090)	(0.591)
lnSales	0.080***	0.074***	0.001	-0.005	-0.002	-0.005	0.053**	0.052*	0.052***	0.044***
	(0.000)	(0.002)	(0.922)	(0.593)	(0.873)	(0.665)	(0.046)	(0.054)	(0.000)	(0.000)
lnCapital_Int	0.012	-0.096	0.023	-0.056	-0.125	-0.173	-0.124	-0.159*	0.095	-0.027
	(0.894)	(0.264)	(0.801)	(0.509)	(0.303)	(0.160)	(0.161)	(0.059)	(0.308)	(0.774)
Constant	-16.134	18.627	-59.403**	-25.045	-34.932	-17.870	-0.049	5.885	-24.338	18.470
	(0.548)	(0.463)	(0.011)	(0.256)	(0.129)	(0.494)	(0.998)	(0.743)	(0.421)	(0.522)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.125	0.141	0.036	0.049	0.036	0.039	0.043	0.048	0.127	0.147
Observations	1,893	1,893	1,893	1,893	1,893	1,893	1,893	1,893	1,893	1,893
Number of companies	404	404	404	404	404	404	404	404	404	404

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 5: Fixed-effects models with IP positions:
By the type of standards organizations

Table 5, we show the results from testing our baseline specification for membership counts within each of the five types of standards organizations. We particularly find that there is a positive effect of R&D investment in determining the extent of the firm's participation in standards promoting organizations, while the effect turns insignificant for other types.[22] As for the conditioning role of the firm's IP positions in the R&D-participation association, rather heterogeneous patterns emerge among different types of standards organizations: both patent and trademark intensities significantly interact with the firm's R&D spending in determining its membership counts in the organizations developing standards (Model 2). Furthermore, the patent position substantially enhances the effect of the firm's R&D expenditures on its participation in the organizations that develop standards linked to SEPs (Model 8). In contrast, the firm's trademark position is found to have a positive moderating effect on its participation in standards promoting organizations (Model 4). Thus, the product-market position appears to provide an incentive to R&D-intensive firms to participate in standards organizations that do not offer explicit patent-based rewards.

4.2.3 The endogeneity of R&D expenditures

It is plausible that the firm that participates in standards development may increase its internal R&D expenditures due to knowledge exchange and learning taking place in open standards development and innovation collaboration. We thus need to address this potential endogeneity bias arising from reverse causality. Another possible source of endogeneity pertains to various confounding factors (i.e., omitted variables) that may simultaneously lead to higher levels of business innovation activities and more profound demand for technological standardization. Such unobserved factors range from macroeconomic environment, business growth, and corporate strategies to technological evolution over time and new opportunities corresponding with it.

To identify the causal effect of R&D investment on the extent of the firm's participation in standards organizations, we adopt an instrumental variable (IV) approach in conjunction with the fixed-effects models outlined before. Following Bloom et al. (2013), we use firm-specific R&D tax support to instrument for firms' R&D spending. A large body of literature provides strong evidence that national and/or state R&D tax support have a positive effect on firms' R&D spending (Bloom et al., 2002; Hall and Van Reenen, 2000; Rao, 2016). We use the OECD data on implied tax support for R&D, with the specific focus on large firms in a profit-making scenario. In line with the literature (Griffith et al., 2006; Bloom et al., 2013), we use the listed country of residence of inventors from the firms' patents (obtained from the OECD Database) to build a firm-specific measure of the total weighted tax support, which sums over the tax support in each country where the firm operates weighted by the share of the firm's R&D being conducted in this country.

While we draw on the literature in using R&D tax support as an IV for the firm-level R&D spending, there are some caveats with this approach. First, R&D tax support may be endogenous to the factors that also influence the firm's functioning, such as macroeconomic conditions or the political environment. Nevertheless, some recent evidence suggests that

[22]The coefficient is positive, albeit insignificant, for standards organizations associated with SEPs. This can most likely be attributed to the fact that the small number of such organizations leads to more imprecise estimates.

the endogeneity of R&D tax support leads to a downward bias, thereby underestimating its causal effect on R&D spending (Chang, 2018). We are therefore confident that, if relevant, potential confounding factors should bias us against finding a significant first-stage effect. Second, there is evidence for variations in the effect of R&D tax credits by industry and firm size (Castellacci and Lie, 2015), leading to bias in the estimation of instrumented interaction terms. While R&D tax credits are generally found to be more significant in affecting R&D spending by smaller firms, this effect should once again bias us against finding a significant first stage effect in our sample of large firms. We provide a thorough analysis of the validity of our chosen IV (see Appendix B), concluding that the firm-specific total weighted R&D tax support significantly predicts R&D spending by the firms included in our sample, and there is no evidence that this effect depends on the firm's IP intensity.

Independent variables	Model 1	Model 2	Model 3	Model 4
lnRD	-0.653	-1.488*	-0.738	-1.494*
	(0.146)	(0.055)	(0.187)	(0.059)
lnRD#PT_High		1.069*		1.058*
		(0.055)		(0.058)
lnRD#TM_High			0.185	0.033
			(0.701)	(0.949)
lnEmployees	0.275*	0.272*	0.264*	0.270*
	(0.088)	(0.091)	(0.079)	(0.095)
lnSales	0.115	0.148	0.109*	0.147
	(0.107)	(0.117)	(0.096)	(0.123)
lnCapital_Int	0.786	0.741	0.738	0.733
	(0.175)	(0.194)	(0.171)	(0.203)
Constant	111.975	319.073	150.967	323.871
	(0.425)	(0.176)	(0.440)	(0.196)
Year dummies	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes
Observations	1,128	1,128	1,128	1,128
Number of companies	289	289	289	289

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Note. The instrumental variable is the amount of indirect government support via R&D tax incentives (as % of GDP) at time T-1.

Table 6: 2SLS fixed-effects models with IP positions: The 2$^{\text{nd}}$ stage

Table 6 reports the results from estimating the second stage structural model of the extent of participation using the IV outlined above. Taking into account the potentially endogenous link between the firm's R&D spending and its memberships in standards organizations, Model 1 identifies no statistically significant effect of R&D expenditures, whereas Models 2 and 4 show that this effect is transmitted via the firm's patent intensity. In Table 7, we present the analysis exploring the heterogeneous patterns across various types of standards organizations. It particularly suggests that the firm's patent intensity is also a conditioning factor for the effect of R&D investment on participation in organizations that develop standards (Model 2). By contrast, the trademark position is found to positively moderate the effect of the firm's R&D spending on its participation in organizations that promote standards developed elsewhere (Model 4).

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
	Standards developers		Standards promoters		Other organizations		With SEPs		Without SEPs	
lnRD	-0.342	-0.789	0.048	-0.243	0.170	0.182	-0.054	-0.264	-0.261	-0.679
	(0.300)	(0.108)	(0.919)	(0.779)	(0.429)	(0.643)	(0.757)	(0.434)	(0.431)	(0.161)
lnRD#PT_High		0.782*		-0.047		-0.142		0.357		0.705*
		(0.052)		(0.926)		(0.607)		(0.172)		(0.072)
lnRD#TM_High		-0.358		0.712*		0.215		-0.152		-0.289
		(0.367)		(0.095)		(0.516)		(0.540)		(0.454)
lnEmployees	0.139	0.158	0.050	0.008	0.030	0.018	0.050	0.057	0.115	0.130
	(0.229)	(0.228)	(0.746)	(0.953)	(0.691)	(0.819)	(0.429)	(0.362)	(0.314)	(0.314)
lnSales	0.093**	0.129*	0.007	-0.016	-0.014	-0.025	0.018	0.034	0.085**	0.116*
	(0.046)	(0.083)	(0.889)	(0.768)	(0.587)	(0.481)	(0.390)	(0.287)	(0.047)	(0.082)
lnCapital_Int	0.376	0.437	0.050	-0.134	-0.286	-0.336	0.006	0.030	0.352	0.398
	(0.363)	(0.351)	(0.928)	(0.766)	(0.279)	(0.211)	(0.980)	(0.888)	(0.395)	(0.395)
Constant	76.707	152.908	-89.279	51.613	-57.193	-39.375	-5.388	31.813	48.471	124.201
	(0.469)	(0.299)	(0.532)	(0.844)	(0.456)	(0.765)	(0.928)	(0.764)	(0.674)	(0.412)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,128	1,128	1,128	1,128	1,128	1,128	1,128	1,128	1,128	1,128
Number of companies	289	289	289	289	289	289	289	289	289	289

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Note. The instrumental variable is the amount of indirect government support via R&D tax incentives (as % of GDP) at time T-1.

Table 7: 2SLS fixed-effects models with IP positions: The 2^{nd} stage; by the type of standards organizations

4.2.4 The policy change: An analysis of patent boxes

The instrumental variable models presented above elucidate that the effect of R&D spending on standards organization memberships is particularly strong for firms with larger patent portfolios. At the same time, the latter finding does not necessarily imply a causal effect of the patent system. Indeed, a positive coefficient on the interaction term could well be induced by unobserved factors correlated with patent counts such as R&D *productivity* (e.g., inventions per R&D dollar). It is also possible that non-linear effects of R&D induce a positive interaction between R&D spending and patent position (which strongly correlate with R&D investments). Finally, we cannot rule out reverse causality since the extent of the firm's involvement in standards development may also increase the value of its IP assets, especially patents (Rysman and Simcoe, 2008), and/or necessitate its increased use of IP to protect the firm's knowledge assets against unintentional spillovers.

To further assess the mechanisms underpinning our findings, we exploit the introduction of *patent boxes* – fiscal regimes that grant favorable tax rates to revenue derived from patents. We hypothesize that the introduction of a patent box has a twofold impact on affected firms. On the one hand, a patent box regime makes patent ownership more attractive and, as such, induces firms to file an increased number of patent applications, or acquire patents from other firms not benefiting from the patent box. On the other hand, the lower tax rate on revenue derived from patents increases the value of both existing and new patents, rendering firms more responsive to the strategic incentives provided by patents. If patents provide incentives for firms to participate in standards organizations, we should find a positive effect of the introduction of patent box regimes on standards organization memberships of the affected firms. Naturally, this effect should increase in the extent to which the firm relies on patents to protect its technology.

We do not, however, observe the precise extent to which firms are affected by patent boxes. Patent boxes are national tax instruments, and most of the firms in our sample are large multinational corporations paying taxes in multiple jurisdictions. Having said that, we hypothesize that, on average, the introduction of a patent box in country A has a larger effect on multinationals headquartered in country A than those with affiliates in country A, but headquartered elsewhere. We thus use a simple difference-in-difference approach, where we observe standards organization membership counts of firms headquartered in patent box countries before and after the introduction of patent boxes compared to other firms in the sample. We still acknowledge that other firms may also be affected, either because they already hold patents in this country or because they may relocate patents from other jurisdictions (see Ciaramella, 2017). For greater robustness, we also carry out a difference-in-difference-in-difference comparison, where we compare patent-intensive firms in patent box countries with non-patent-intensive firms and with firms headquartered in other countries.

Using information from PwC (2013) and Ciaramella (2017), we identify 16 countries which introduced patent box regimes in the period 1973-2015. We exclude Ireland and Italy where the first introduction of a patent box occurred outside of the observation period in our standards organization membership data. We also exclude patent box regimes that apply to both patents and trademarks because we seek to reliably attribute the empirical results to patents.[23] So, we are left with eight patent box regimes introduced between 2000 and 2014. They affect 92 firms in *Industry Sample 1*: under a half of them (41 firms) are from China, while the remainder – in Europe (Table 8).

Country	Introduction year	TM included	# sampled firms
Ireland	1973	N	-
France	2000	N	14
Hungary	2003	Y	-
Belgium	2007	N	4
Netherlands	2007	N	9
China	2008	N	41
Luxembourg	2008	Y	-
Spain	2008	N	1
Malta	2010	Y	-
Cyprus	2011	Y	-
Liechtenstein	2011	Y	-
Switzerland*	2011	Y	-
United Kingdom	2013	N	18
Portugal	2014	N	1
Turkey	2014	N	2
Italy	2015	Y	-

Table 8: Patent box regimes in different countries

We estimate the effect of patent box introductions in a fixed-effects setting over a panel spanning across a longer period of time than our 5-year sample period. We subsequently interact the dummy variable indicating the patent box being introduced with time-invariant firm-level variables (i.e., average R&D expenditures and IP dummies). We continue to control for year dummies and regional trends. The results are displayed in Table 9. We

[23]We thus exclude Hungary, Luxembourg, Malta, Switzerland, Cyprus, and Liechtenstein. The excluded countries are also too small to provide information that we can use to identify the effects of trademarks in addition to patents.

find a statistically significantly positive effect of patent box introduction on standards organization membership counts (Model 1). The effect of patent box introduction is stronger for patent-intensive firms (Models 3 and 5). As for magnitudes, the introduction of a patent box increases the count of standards organization memberships of a firm that is patent-intensive by approximately one organization.

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5
box_active	0.303*	0.183	-0.112	0.108	-0.079
	(0.086)	(0.308)	(0.469)	(0.651)	(0.669)
box#av_RD		0.001*	-0.000	0.001*	-0.000
		(0.050)	(0.976)	(0.060)	(0.959)
box#PT_High			1.273***		1.316***
			(0.000)		(0.001)
box#TM_High				0.215	-0.123
				(0.506)	(0.711)
Constant	-98.711**	-92.662**	-58.004	-86.227*	-60.504
	(0.034)	(0.043)	(0.154)	(0.082)	(0.160)
Year dummies	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes
R-squared	0.390	0.391	0.398	0.392	0.398
Observations	7,984	7,984	7,984	7,984	7,984
Number of companies	499	499	499	499	499

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 9: Fixed-effects models with IP positions: The Patent box analysis

We next distinguish between the effect of a patent box on membership counts in different types of standards organizations. We focus on the difference-in-difference-in-difference comparison between patent-intensive firms in patent box countries and other firms in the sample as the most robust estimation of the effect of the patent box regime. The results are shown in Table 10. As expected, the introduction of a patent box has a positive effect on memberships of the affected firms with a higher intensity of patent applications across all but other standards organizations.

4.2.5 Alternative measures of the product-market position

So far, we have observed that the product-market position tends to enhance the willingness of an R&D-intensive firm to engage in standardization activities. Throughout the analysis, we have used trademark intensity to capture this position, even though it is likely to be a multidimensional concept. To account for its alternative dimensions, we supplement our analysis with two additional measures: the first measure is a dummy variable that takes the value of one if the firm is on the list of the Top 500 most valuable corporate brands (as estimated by The Brand Finance Group; see www.brandfinance.com), and zero otherwise. The second measure is the number of ICT standards-compliant products offered by the firm; to count these products, we use the information from the GSM Arena website (see Section 3.2 for more details). Since we draw on annual surveys of the corporate brand value, and the GSM Arena website provides product release dates, we are able to compute both time-variant and time-invariant measures. We employ time-variant brand

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
	Standards developers		Standards promoters		Other organizations		With SEPs		Without SEPs	
box_active	0.135	-0.121	0.031	-0.124	0.110	0.026	-0.092	-0.136	0.055	-0.196
	(0.437)	(0.511)	(0.814)	(0.403)	(0.399)	(0.861)	(0.523)	(0.329)	(0.739)	(0.281)
box#av_RD	0.001***	0.000	0.001***	0.000	0.000*	0.000	0.001***	0.001***	0.001***	0.001*
	(0.005)	(0.297)	(0.002)	(0.107)	(0.080)	(0.312)	(0.000)	(0.003)	(0.001)	(0.052)
box#PT_High		1.270***		0.666*		0.440		0.890**		1.150***
		(0.000)		(0.056)		(0.162)		(0.012)		(0.001)
box#TM_High		-0.108		0.003		-0.052		-0.467*		-0.044
		(0.740)		(0.990)		(0.827)		(0.069)		(0.893)
Constant	-101.451**	-70.121*	-45.610	-27.385	6.949	17.362	-1.348	-8.924	-103.250**	-73.269*
	(0.018)	(0.084)	(0.153)	(0.398)	(0.836)	(0.609)	(0.964)	(0.755)	(0.013)	(0.070)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.386	0.393	0.161	0.165	0.080	0.082	0.113	0.121	0.392	0.398
Observations	7,984	7,984	7,984	7,984	7,984	7,984	7,984	7,984	7,984	7,984
Number of companies	499	499	499	499	499	499	499	499	499	499

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 10: Fixed-effects models with IP positions:
The Patent box analysis; by the type of standards organizations

value indicators and product counts to test for their direct effects, whereas pre-determined variables are used to test for interactions with time-variant R&D expenditures.

As such, we argue that both measures also reflect the firm's product-market position. Similar to trademarks, the corporate brand is part of the firm's differentiation effort. Differentiation by means of the corporate brand can be a substitute for product-based differentiation captured by trademarks (Agostini et al., 2015). However, valuable corporate brands can also serve as yet another, reputation-based mechanism through which the firm retains its existing and attracts new customers. In this case, some degree of complementarity is expected between the corporate brand value and the intensity of trademark activities. In turn, the number of ICT standards-compliant products represents a measure of the breadth of the firm's product offering. Given that the firm's trademark intensity reflects not only the number of different products that the firm offers, but also the depth of trademark protection that it seeks for its products, using product counts and trademark intensity at the same time should help us disentangle the effects of the breadth of product offering and the depth of product differentiation.

The results of this analysis are presented in Table 11. First of all, each of the additional measures enhances the effect of R&D spending on memberships in standards organizations (Models 3-4). Such an outcome supports the argument that the firm's ability to appropriate its R&D investment by leveraging the product-market position can provide an incentive for joining the standardization process. Notably, the positive effect of trademark intensity on the association between R&D spending and standards organization membership remains significant even after controlling for other dimensions of the firm's product-market position.

Second, our analysis of time-varying product counts identifies a positive relationship between the firm's product counts and its counts of standards organization membership. This finding may indicate that the firm's product-market position (particularly, in the relevant end-product markets directly implementing the standards under development) provides incentives to participate in standards organizations that are independent of the firm's R&D effort. The observed effect can be specifically attributed to the firm's desire to participate in shaping the standards developed for its products, the importance of timely

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
lnRD	0.041*	0.041*	0.035	-0.005	-0.005	-0.008
	(0.061)	(0.067)	(0.105)	(0.760)	(0.793)	(0.650)
Prod_count	0.008***					
	(0.000)					
Top500		0.013				
		(0.612)				
lnRD#Prod_count_ti			0.002***	0.002***		
			(0.008)	(0.002)		
lnRD#Top500_ti			0.119*	0.026		0.213**
			(0.083)	(0.738)		(0.040)
lnRD#PT_High				0.088	0.090	0.111*
				(0.139)	(0.133)	(0.078)
lnRD#TM_High				0.153***	0.164***	0.139**
				(0.003)	(0.003)	(0.013)
lnRD#Producer					0.222*	
					(0.064)	
lnRD#PT_High#Producer					-0.111	
					(0.352)	
lnRD#TM_High#Producer					-0.261**	
					(0.020)	
lnRD#PT_High#Top500_ti						-0.300**
						(0.011)
lnRD#TM_High#Top500_ti						0.066
						(0.544)
lnEmployees	0.061**	0.062**	0.059**	0.031	0.030	0.034
	(0.019)	(0.019)	(0.022)	(0.194)	(0.194)	(0.158)
lnSales	0.046***	0.048***	0.047***	0.040***	0.040***	0.040***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
lnCapital_Int	0.053	0.057	0.046	-0.077	-0.077	-0.065
	(0.572)	(0.545)	(0.622)	(0.377)	(0.373)	(0.465)
Constant	-54.445*	-48.935*	-48.305*	-3.672	-5.183	-1.263
	(0.056)	(0.088)	(0.091)	(0.889)	(0.846)	(0.963)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.106	0.104	0.107	0.125	0.125	0.126
Observations	1,893	1,893	1,893	1,893	1,893	1,893
Number of companies	404	404	404	404	404	404

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Note. Top500 denotes the time-variant position of the corporate brand value. Top500_ti denotes the time-invariant (as of 2009) position of the corporate brand value. Prod_count denotes the total number of ICT standards-compliant products offered by the firm each year. Prod_count_ti denotes the time-invariant (the total for the period before 2009) number of ICT standards-compliant products offered by the firm. Producer is a dummy variable that takes the value of one if the firm offered at least one ICT standards-compliant product in the period before 2009, and zero otherwise.

Table 11: Fixed-effects models with IP positions:
Alternative measures of the product-market position

information about future technology development, and the aspiration to benefit from knowledge spillovers from firms contributing new technologies to standards development. Nevertheless, there can also be other interpretations for this positive relationship, such as reverse causality when increased participation in standardization induces a greater extent of implementation of technology standards developed in standards organizations.

Lastly, regarding the interaction between IP positions and these two extra dimensions of the product-market position (Models 5-6), there is some evidence of a potential trade-off (or substitution) between trademark intensity and being a producers of standards-compliant products, as well as between patent intensity and the value of the corporate brand. Put differently, the previously observed role of patent and trademark positions for the incentives of R&D-intensive firms to participate in standards organizations seems less relevant for firms that have a stronger corporate brand and/or that directly offer standards-related products. These findings thus lend some support for the hypothesis that formal IPRs encourage modularity in technology development, and provide participation incentives that are particularly relevant for the R&D-intensive firms without a large number of own products incorporating the developed standards.

5 Discussion

In this paper, we advance the understanding of firms' motivations for partaking in open standards development by examining the role of R&D expenditures, patents and product-market position.

We document a significant and positive association between a firm's R&D investments and its intensity of participation in standards organizations, which is robust across many ICT industries within our sample, but appears largely driven by membership in downstream standards organizations that promote standards developed elsewhere. This association between R&D effort and membership in marketing-based standards organizations is significantly stronger for firms with a stronger product-market position. Our IV estimations fail to corroborate a positive causal link between business R&D expenditures and membership in standards organizations *on average*. However, we find robust evidence that this relationship is contingent upon the existence of appropriation mechanisms, which allow the firm to reap a return on the investment in contributing to standards development.

The most robustly significant R&D appropriation mechanism revealed by our analysis is patent protection. This finding contrasts with recent policy debates centering on the conflicts and tensions at the interface between patent and standardization systems. Our IV estimations show that the positive interaction between R&D and patenting position in determining firms' participation in standards organizations is most salient in organizations that set and develop their own standards, as opposed to those tasked with promotion, certification, or other ancillary functions. The effect of patents does not appear to be specific to membership in organizations that develop standards subject to declared SEPs.

The results of our analyses using exogenous changes in the tax treatment of patent revenue further corroborate a causal interpretation of our findings with respect to the role of patents. We find direct evidence that policies with the effect of strengthening patent protection result in a stronger role of the patent position in boosting the membership of R&D-intensive firms. This effect is once again most pronounced in the organizations developing standards.

The robust evidence on the role of patents for participation in open standards organizations underscores the high degree of strategic complementarity between patenting and engagement in collaborative standards development. Both patenting and collaborative standards development are associated with a modular and distributed form of technology development, where different firms can develop individual pieces of a complex technology, and use licensing to generate a return on investment. Compared with other informal and common means of appropriating a return on R&D investments, such as secrecy, complexity, and lead time (Cohen et al., 2000), our findings imply that patenting may offer higher levels of compatibility with the processes adopted by open standards organizations.

As one of our most novel findings, the association between firms' R&D efforts and membership in standards organizations is reinforced not only by patenting, but also by a strong product-market position. Our results do not support the view that highly innovative firms with a leading product-market position are more likely to market their products without the reliance on collaborative standardization. In the empirical analysis, we use trademark intensity, as well as measures of brand value and counts of standards-compliant product models to capture multiple dimensions of a firm's product-market position. Our findings attest to the significance for open standards development of a strong product-market position, or the underlying downstream complementary assets (such as capabilities in manufacturing, distribution, or marketing). Such complementary assets can serve as yet another appropriation mechanism that allows firms to profit from their R&D contributions to organizations providing little patent-based incentives (Teece, 1986; Pisano, 2006).

Our IV estimations further suggest that the causal effect of a firm's R&D input on participation in standards organizations only increases in patent intensity with respect to technically oriented upstream standards organizations, as opposed to marketing-oriented downstream organizations. In contrast, the causal effect of R&D investments is amplified by the firm's product-market position only for downstream standards organizations. Our study, therefore, sheds some light on this large body of downstream organizations that bring these already developed standards closer to the market. A diverse range of standards, sometimes competing, exist to tackle a variety of technical needs and the implementation of such technology standards is usually voluntary. The development of a high quality technical specification *per se* is thus no guarantee for achieving effective standardization in an industry. A large number of standards-related industry associations exist to facilitate industry coordination on a single set of standards, and to promote standards adoption through education, certification, and other related activities. Such organizations may also develop detailed interpretations of standards developed elsewhere to support certification of standard compliance, and administer the licensing of standard certification marks.

In spite of the paucity of evidence about their activities, these marketing-oriented standards organizations appear to play a pivotal role in diffusing standardized technologies and facilitating *effective* standardization in the marketplace, thus constituting an integral part of the ecosystem of technology standardization. For instance, despite having developed the early IEEE 802.11 standard (now known as the Wi-Fi technology), IEEE did not have provision for testing equipment for compliance with this standard and thus widespread interoperability issues in products followed. Wireless Ethernet Compatibility Alliance

(WECA, the predecessor of Wi-Fi Alliance) was formed in 1999 to promote the adoption, perform testing and certify product compatability with Wi-Fi standard, which has evolved into one of the most valued and widely adopted technologies globally. The MPEG Industry Forum, for another example, is tasked with promoting MPEG standards, developing MPEG certification for products and collaborating on developing new *de facto* MPEG standards. In doing so, it connects an extensive network of content creators, developers, manufacturers, service providers and end users.

6 Conclusion

This study presents, to the best of our knowledge, the most extensive and robust evidence to date on the firm-level determinants of participation in standards organizations. Using the Searle Center Database (Baron and Spulber, 2018), we analyze membership of the world's top corporate R&D performers in 177 ICT-related standards organizations.

We have found robust evidence for a strategic complementarity between R&D and standards organization membership. The correlation between R&D efforts and membership counts of standards organization increases in the size of a firm's patent and trademark portfolios. We further corroborate a causal interpretation of the effect of patents on the appropriability of R&D in standardization using preferential tax treatment of patent revenue as an exogenous source of variation. Our findings also underscore trademarks as capturing a salient dimension of a firm's product-market position alongside the firm's brand value and number of standards-compliant products. Nevertheless, patents and product-market position are observed to provide differing incentives to join distinct types of standards organizations.

Most notably, our findings juxtapose the effect of R&D efforts on membership in upstream organizations which increases in the patent intensity with the effect of R&D on membership in downstream organizations which is significantly bolstered by the product-market position. While little researched in the literature, the activities of downstream standards-promoting organizations are instrumental to the development and implementation of high quality standards specifications while playing a critical role in the commercialization of products incorporating standardized technologies. We further show that many of these activities are similarly dependent on the technological resources and inputs voluntarily provided by their member firms. This resonates with the increasingly modular organization of standards-based technology development. The development of standardized interfaces, and the existence of technology markets enabled by IPR, allow each firm to contribute its R&D effort to those tasks in the standards development process that are best aligned with the firm's assets and capabilities.

These results have important implications for business strategy, innovation research, and standardization policy. Importantly, our findings highlight the role of the patent system for the functioning of standards development. This is in line with existing research that documents the link between patents and engagement in collaborative technology development (e.g., participation by independent software vendors in software platforms - see Huang et al. (2013)). Policies increasing the value of patents will thus provide a strong incentive for firms' participation in standards organizations. Our analysis of distinct types of standards organizations further allows a finer-grained understanding of the diverse roles of patents. We find that patents induce participation in standards organizations both due to the increased returns to innovation (i.e. appropriation mechanism) as well as the protection against the risk of unintended spillover of technology to other participants of the standardization processes (i.e. legal protection).

We have documented the coexistence of different types of appropriation mechanisms providing incentives for R&D-intensive firms to participate in standards organizations. Thus one promising future avenue is to investigate the interactions among firms driven by patent- and product-centric incentives in the course of standards development. The governance of standards organizations is often characterized by debates opposing *contributors* and *implementers*. We believe that data on patent and trademark portfolios may indicate the relative importance of patent- and product-centric incentives, and help future research shed light on the interactions at play in standardization.

It is plausible to also expect some degree of interaction in the use of patents and trademarks in appropriating value of innovation (Somaya and Graham, 2006; Fischer and Henkel, 2013; Fisher and Oberholzer-Gee, 2013; Huang et al., 2013). Fischer and Henkel (2013), for instance, observe that a firm's number of product-related patents (as a proxy for product-market position) complement the size of its overall patent portfolio. However, such complementarity seems to exist only among high levels of both mechanisms. In the context of partnership formation in the software industry, Huang et al. (2013) demonstrate a strong substitution (via a significant negative interaction) between IP protection and downstream capabilities in determining participation in innovation alliances. Nevertheless, we find no evidence that the effect of either appropriation mechanism depends on the other in determining the firm's engagement in standards development. One explanation is that such complementarity is likely to be contingent on industry settings.

There are several limitations to this study, which open up opportunities for future research development. First, as our sample consists of large R&D-intensive firms, some of our findings may have more limited application to small firms involved in the standardization processes. Simcoe et al. (2009) for example depict notable disparity between incumbents and entrepreneurial start-ups in standardization. Second, our measure of product-market position may not capture some dimensions such as product sales or detailed counts for lack of products data for all firms in our sample. Third, IP positions are mostly treated as time-invariant in our empirical analyses, which does not consider the dynamic effects of IP on developing standards. Lastly, future research could examine more detailed contribution from firms to standards development or identify the performance and innovation outcome of participation in collaborative standards development, all of which are still not well understood.

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Appendix A. Additional tables

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5
lnRD	0.039**	0.019	0.003	-0.007	-0.004
	(0.027)	(0.239)	(0.864)	(0.667)	(0.807)
lnRD#PT_High		0.155***		0.134***	0.104*
		(0.000)		(0.001)	(0.050)
lnRD#TM_High			0.123***	0.100***	0.087**
			(0.002)	(0.006)	(0.032)
lnRD#PT_High#TM_High					0.052
					(0.510)
lnEmployees	0.033	0.017	0.015	0.004	0.006
	(0.377)	(0.638)	(0.690)	(0.904)	(0.873)
lnSales	0.052***	0.043***	0.043***	0.037**	0.038**
	(0.001)	(0.004)	(0.005)	(0.017)	(0.016)
lnCapital_Int	-0.027	-0.108	-0.106	-0.160	-0.158
	(0.839)	(0.406)	(0.419)	(0.211)	(0.219)
Constant	-0.240	12.212	29.587	34.595	33.965
	(0.992)	(0.597)	(0.208)	(0.140)	(0.147)
Year dummies	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes
R-squared	0.075	0.088	0.085	0.094	0.094
Observations	3,130	3,130	3,130	3,130	3,130
Number of companies	670	670	670	670	670

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 12: Fixed-effects models with IP positions; Industry Sample 2

Independent variables	Model 1	Model 2	Model 3	Model 4	
	DV: LnRD	DV: LnRD#PT_High	DV: LnRD#TM_High	DV: LnRD#PT_High	DV: LnRD#TM_High
RDTaxGDP	3.770***	-2.590**	-0.432	-2.727**	-1.851**
	(0.003)	(0.027)	(0.532)	(0.034)	(0.033)
RDTaxGDP#PT_High		9.690***		9.559***	2.794**
		(0.000)		(0.000)	(0.041)
RDTaxGDP#TM_High			6.708***	0.657	6.158***
			(0.000)	(0.660)	(0.000)
lnEmployees	0.329***	0.253***	0.193***	0.251***	0.192***
	(0.000)	(0.000)	(0.002)	(0.000)	(0.002)
lnSales	0.099	0.051	0.076	0.051	0.077
	(0.203)	(0.251)	(0.209)	(0.250)	(0.205)
lnCapital_Int	1.173***	0.921***	0.738***	0.916***	0.732***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Constant	307.557***	60.918	-51.035	62.519	-48.408
	(0.000)	(0.251)	(0.320)	(0.237)	(0.346)
Year dummies	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes
R-squared	0.544	0.397	0.397	0.397	0.400
Observations	1,128	1,128	1,128	1,128	1,128
Number of companies	289	289	289	289	289

Robust p-value in parentheses: *** p < 0.01, ** p < 0.05, * p < 0.1.
Note. Each dependent variable (DV) is considered at time T. The instrumental variable is the amount of indirect government support via R&D tax incentives (as % of GDP) at time T-1.

Table 13: 2SLS fixed-effects model: The 1st stage

Appendix B. The validity of instrumental variables

To assess the validity of our instrumental variable, we perform a variety of tests and checks. First, we make sure that R&D tax support (as percentage of GDP, lagged by one year) is a good predictor of corporate R&D expenses, and that this relationship is broadly supported across the sample. We start with analyzing the relationship between *L.rd_tax_support_pctgdp* and business R&D expenditures on the country level. In a sample of 29 countries, we confirm that *L.rd_tax_support_pctgdp* is a strongly significant predictor of business R&D expenditures when controlling for country fixed effects (Model 1). This relationship remains statistically significant at 5% when controlling for year fixed effects and regional trends (Model 2), GDP in constant US dollars (Model 3), as well as significant at 10% when controlling for an additional set of control variables, such as the unemployment rate, government expenses in R&D, and higher education expenses in R&D (Model 4). The loss in significance between Models 3 and 4 is attributable to the fact that the additional control variables are only available for a shorter time span (the significance level of the instrument also drops to 10% when running Model 3 on the smaller sample of Model 4). We thus conclude that there is a stable relationship between *L.rd_tax_support_pctgdp* and business R&D expenditures, which is independent of cyclical effects, regional trends, GDP growth, and non-business R&D.

We also confirm that this relationship is broadly supported across World regions. The coefficient for *L.rd_tax_support_pctgdp* receives positive support from five out of six World regions (Model 5), the exception being Europe. Nevertheless, in the smaller sample and with additional control variables, also Europe provides positive support for the coefficient. The coefficient is individually strongly significant for North America and Japan.

As a next step, we wish to ensure that this relationship carries over to the firm level, and in particular to the large firms in our sample, which often conduct R&D in multiple countries. We thus use the country of residence of the inventors of patents included in the OECD database to observe where these firms conduct R&D. The measure is a matrix, where if 70% of the inventors of firm A are residents of country 1, and 30% are residents of country 2, the level of R&D tax support of country 1 is weighted by 0.7, and the level of tax support of country 2 is weighted by 0.3, and we sum these weighted R&D tax support figures to build a firm-specific measure of weighted-average R&D tax support in the countries in which the firm's R&D takes place. We then use this measure to predict *lnRD*.

Controlling for firm and year fixed effects and regional trends, in addition to the usual firm level control variables *lnEmployees*, *lnSales* and *lnCapital_Int*, we find that *L.rd_tax_support_pctgdp* strongly predicts *lnRD* in the OECD sample of top R&D performing firms (Model 1). This holds true when controlling for weighted average GDP, in constant USD (Model 2). As adding the control variable GDP has little effect on the relationship between *L.rd_tax_support_pctgdp* and even increases the significance of this relationship in all models, we use the more conservative version of the model without GDP control throughout the remainder of the analysis. The relationship is similarly significant in the 11-industries Sample 2 (Model 3), and the 6-industries Sample 1 (Model 4). In fact, the coefficient receives positive support form 35 out of 43 industries represented in the OECD sample, and is thus highly robust to between-industry variation (Figure

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
L.rd_tax_support_pctgdp	3,426***	2,257**	909**	951*		
	(0.001)	(0.015)	(0.047)	(0.062)		
L.rd_tax_support_pctgdp#...						
...N.America					26,292***	8,361
					(0.000)	(0.157)
...Europe					-192	430
					(0.635)	(0.347)
...Japan					16,956***	20,567***
					(0.000)	(0.000)
...S.Korea					5,226	5,545
					(0.467)	(0.330)
...China					12,352	
					(0.582)	
...Other					391	-120
					(0.771)	(0.956)
L.gdp_constantUSD			2.809***	3.003***	2.635***	2.683***
			(0.000)	(0.000)	(0.000)	(0.000)
L.gerd_constantUSD				0.076		0.034
				(0.542)		(0.760)
L.herd_constantUSD				0.000		0.000
				(0.176)		(0.140)
L.unemploymentrate				-3.605		-5.784
				(0.640)		(0.389)
Constant	2,560***	2,637,898***	-339,250	369,371***	-184,802	261,665
	(0.000)	(0.000)	(0.139)	(0.000)	(0.359)	(0.110)
	M2-M6: Year fixed effects and region trends included					
Observations	318	318	318	181	318	181
R-squared	0.039	0.502	0.881	0.775	0.920	0.835
Number of country_idn	29	29	29	27	29	27

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 14: IV validity analysis: country-level regressions;
DV: Business R&D expenditures in constant USD

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
L.rd_tax_support_pctgdp	4.123***	3.969***	3.169***	3.028***	9.210**	6.410**	2.968***	2.060*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.017)	(0.017)	(0.000)	(0.083)
L.gdp_constantUSD		0.000***						
		(0.005)						
lnEmployees	0.387***	0.388***	0.411***	0.399***	0.445***	0.400***	0.410***	0.399***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnSales	0.042	0.040	0.183*	0.134	0.135	0.159	0.134	0.135
	(0.322)	(0.351)	(0.062)	(0.158)	(0.156)	(0.119)	(0.156)	(0.158)
lnCapital_Int	0.634***	0.635***	1.447***	1.395***	1.063***	1.403***	0.371	1.392***
	(0.004)	(0.004)	(0.000)	(0.000)	(0.003)	(0.000)	(0.658)	(0.000)
L.rd_tax_support_pctgdp#...								
...lnEmployees					-0.656*			
					(0.093)			
...lnSales						-0.438		
						(0.178)		
...lnCapital_Int							5.000	
							(0.199)	
...PT_High								1.573
								(0.172)
...TM_High								-0.274
								(0.776)
Constant	347.359***	267.000***	284.842***	256.276***	256.385***	256.311***	253.119***	258.146***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	5,661	5,661	2,282	1,501	1,501	1,501	1,501	1,501
R-squared	0.379	0.381	0.609	0.564	0.568	0.565	0.567	0.565
Number of company_idn	1,187	1,187	485	320	320	320	320	320

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 15: IV validity analysis: Firm-level regressions;
DV: lnRD

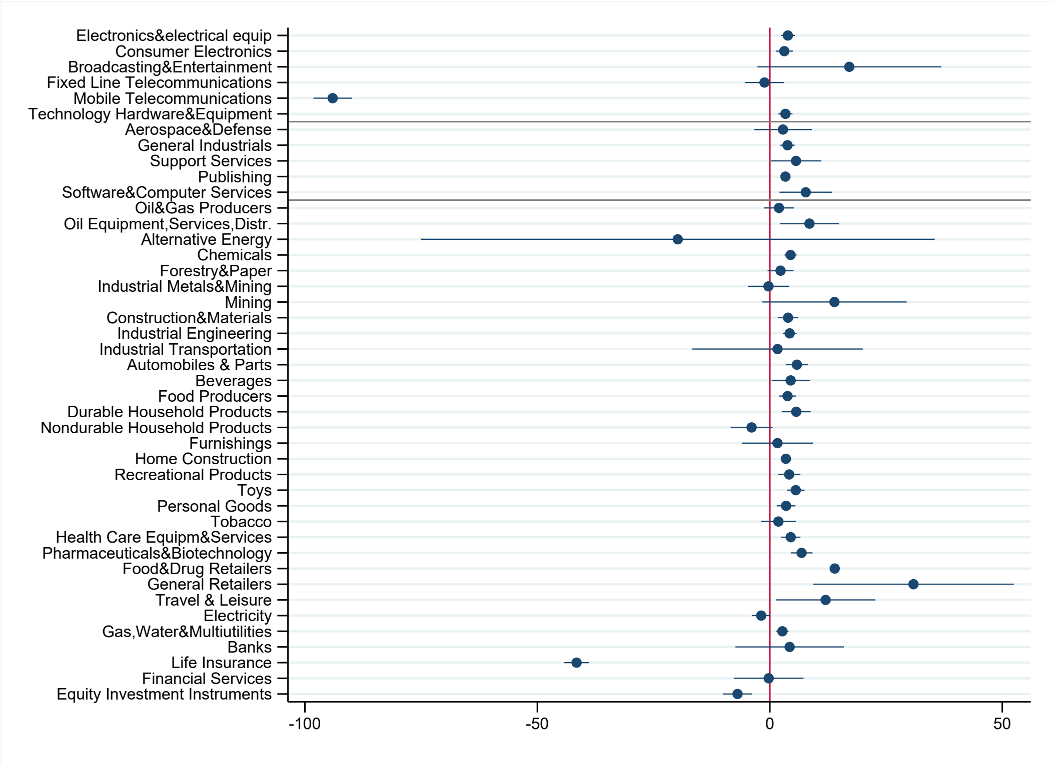
3). Among the industries included in our analysis sample, the only exception to this is Mobile Telecommunications, where there is a strongly significant negative relationship. Nevertheless, given that this industry only accounts for four of the OECD top R&D performing firms, this is unlikely to affect any of our results.

While we find evidence that the significance of the effect of *L.rd_tax_support_pctgdp* on *lnRD* decreases in firm size, this is only true when measuring firm size by number of employees, and in any case, the heterogeneity of effects is only mildly significant (Models 5-7). More importantly, there is no evidence that the effect of *L.rd_tax_support_pctgdp* on *lnRD* depends on the patent- or trademark-intensity of firms. *L.rd_tax_support_pctgdp* is thus likely to be an equally strong instrument for *lnRD* of firms that are relatively more patent- or trademark-intensive.

Finally, we want to assess whether the IV is likely to violate the exclusion restriction. Despite rules for the R&D tax support eligibility of expenses varying from one country to another, support is generally limited to activities directed at scientific or technological discoveries.[24] Membership fees in standards organizations, travel expenditures for meeting attendance, and other non-R&D-related expenditures arising from participation in standards organizations should thus generally not be eligible. If the R&D tax support has the

[24]The Internal Revenue Service in the US limits R&D tax credits to the expenses "undertaken for the purpose of discovering information which is technological in nature" (see https://www.irs.gov/businesses/audit-techniques-guide-credit-for-increasing-research-activities-i-e-research-tax-credit-irc-41-qualified-research-activities).

Figure 2: Coefficients for R&D tax support (as percentage of GDP, lagged by one year) for explaining lnRD - An industry breakdown



Note. Coefficients and 95% confidence intervals. All estimates are based on Model 1 in Table 16

effect of subsidizing participation in standards organizations, this effect is transmitted via a reduction of the firm's cost of conducting R&D.

While there is thus no significant risk that R&D tax support may directly subsidize non-R&D expenses for participation in standards organizations, there may still be an indirect effect not transmitted via increased R&D expenses, but through reduced tax payments, resulting in increased profits. To rule out this alternative channel, we run Models 1-8 from the previous analysis with *lnOperatingProfit* instead of *lnRD* as dependent variable. There is no evidence for a significant effect of R&D tax support on operating profits, thus attenuating concerns regarding the validity of the exclusion restriction.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
L.rd_tax_support_pctgdp	-1.099	-1.045	1.163	1.170	-3.922	-9.974	1.224	2.597
	(0.325)	(0.343)	(0.434)	(0.478)	(0.608)	(0.146)	(0.455)	(0.215)
L.gdp_constantUSD		-0.000						
		(0.575)						
lnEmployees	-0.106	-0.107	-0.103	-0.073	-0.109	-0.073	-0.082	-0.062
	(0.227)	(0.227)	(0.273)	(0.554)	(0.419)	(0.552)	(0.517)	(0.613)
lnSales	1.107***	1.108***	0.975***	0.963***	0.963***	0.882***	0.964***	0.961***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
lnCapital_Int	0.363	0.362	-0.115	0.087	0.363	0.060	1.058	0.120
	(0.107)	(0.111)	(0.745)	(0.848)	(0.561)	(0.894)	(0.482)	(0.793)
L.rd_tax_support_pctgdp#...								
...lnEmployees					0.538			
					(0.469)			
...lnSales						1.438*		
						(0.091)		
...lnCapital_Int							-4.703	
							(0.480)	
...PT_High								-0.480
								(0.843)
...TM_High								-3.379
								(0.183)
Constant	-136.973*	-106.760	-10.378	36.914	37.407	38.154	39.806	27.657
	(0.056)	(0.176)	(0.904)	(0.702)	(0.700)	(0.691)	(0.682)	(0.773)
Observations	5,090	5,090	2,035	1,311	1,311	1,311	1,311	1,311
R-squared	0.221	0.221	0.246	0.252	0.252	0.254	0.252	0.253
Number of company_idn	1,146	1,146	476	314	314	314	314	314

Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 16: IV validity analysis: Firm-level regressions; DV: lnOperatingProfit