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

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Abstract

This paper studies collaborative innovation in the context of developing open technology standards coordinated by standards organizations. Using consolidated longitudinal data from the world's largest R&D performing firms matched with membership information from 180 standards organizations, we analyze the firm-level determinants of the extent of participation in standards development. We identify a highly robust positive effect of a firm's R&D expenditure on its involvement in standards organizations, and find this impact being further bolstered by the firm's patenting intensity and/or product-market position. Exploiting exogenous variations induced by preferential tax treatment, we find a causal positive effect of patenting intensity on the participation of R&D-intensive firms in standards organizations. This effect is, however, only significant for membership in organizations developing standards potentially subject to Standard-Essential Patents. Our findings also underscore the significant role of the firm's product-market position in incentivizing engagement in standards development, as exemplified by trademarking intensity, brand value or number of standard-compliant end product models. Managerial and policy implications are discussed.

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Keywords: standards organizations, technology standards, intellectual property, R&D expenditures, patents, trademarks

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1 Introduction

In many technological fields, innovation activities have become increasingly complex, often requiring the collaborative efforts of a wide and diverse range of organizations. A salient example of such collaboration is the development of technology standards, which play a central role in many technologically advanced economies. Many of these standards are developed and defined in a complex ecosystem of private, voluntary, and open organizations. These include formal standards development organizations (SDOs) that develop and publish *de jure* technical standards, and also informal industry-based consortia, alongside other organizations participating in standards development in a variety of roles. The functions of standards organizations encompass the coordination of research and development (R&D) toward the definition of future standards, the resolution of commercial or policy conflicts arising in standards development, the preparation of technical specifications published as or incorporated into SDO standards, the promotion of fully developed standards, as well as the certification of compliance of products or services with existing standards.

The emergent literature on standardization has shed light on an array of motives for firms' involvement in standards development, including learning, problem-solving, appropriating value from a portfolio of proprietary technologies, influencing technology development, anticipating regulation, and networking. The existing research has particularly highlighted the role of participation in standards organizations for interorganizational learning and coordination of R&D (Leiponen, 2008; Baron et al., 2014; Delcamp and Leiponen, 2014; Vasudeva et al., 2014). Furthermore, a growing body of research investigates the interplay between participation in standards organizations and patenting (Bekkers et al., 2011; Berger et al., 2012; Fischer and Henkel, 2013). Finally, a notable effort has been devoted to explicating the role and economic effects of standard-essential patents (SEPs), i.e. patents that are necessary for any implementation of a technology standard (Rysman and Simcoe, 2008; Lerner and Tirole, 2015).

Despite this significant research interest, the role of R&D investments and intellectual property rights (IPRs) for firm involvement in standards development is poorly understood. Existing empirical studies have generally focused on smaller samples of firms and imperfect, often binary measures of participation in standards organizations. Largely owing to these limitations, empirical evidence on the role of a firm's R&D investments and patents for participation in open standards organizations remains inconclusive (Blind and Thumm, 2004; Fischer and Henkel, 2013; Blind and Mangelsdorf, 2016). In addition, the empirical literature has paid scant attention to the so-called downstream factors influencing participation in open standard development, encompassing a variety of assets (e.g., installed base of customers, brand value, or complementary product lines), which can be summarized as the firm's product-market position.

Our study contributes to the literature on standards development by providing robust empirical evidence regarding the role of R&D investments, patents, and product-market position on firms' incentives to participate in standards organizations. In contrast to earlier studies, we rely on a large longitudinal database of membership in 180 standards organizations, which allows us to quantify the intensity of participation in standards development in a sample of large and R&D intensive firms. We find highly robust evidence supporting a positive effect of R&D investments on participation in standards organizations. However, this effect is conditional on a strong patent portfolio and/or product-market position. We use favorable tax treatment of revenue from patents (the so-called patent boxes) and heterogeneity among standards organizations with respect to SEPs to corroborate a specific and causal interpretation of our results on patents. We use trademarks as a proxy of product-market position, but document that measures of brand value or counts of different standard-compliant products have a similar effect of enhancing the strategic complementarity between R&D efforts and standards organization participation.

Our results have significant implications for innovation strategies of large R&D-intensive firms, as well as policy implications for standards and IPR policy. More specifically, we identify a positive relationship between patent protection and standard development, and imply a policy change resulting in an increased profitability of patents is associated with increased participation of R&D-intensive firms in standards organizations. Furthermore, we also demonstrate that product-market factors can motivate R&D-intensive firms to participate in standards organizations which offer no specific patent-related incentives. The interaction among firms primarily driven by these two different types of incentives is an important topic for future research and ongoing policy discussions within standards organizations. Finally, our study also adds to the broader and growing literature on the subtle interplay between engagement in open innovation and exclusive appropriation mechanisms (Boudreau, 2010; Ceccagnoli et al., 2012; Huang et al., 2013; Laursen and Salter, 2014). Our setting allows us to investigate how the relative importance of different types of appropriation mechanisms varies between the heterogeneous types of organizations in which collaborative technology development takes place.

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 Collaborative innovation and complementary assets

Open and collaborative innovation processes that allow any interested firms to contribute have become a prominent feature in complex technologies where technological progress often requires collaborative efforts (Von Hippel, 1998; Chesbrough, 2006; Harhoff et al., 2003; West et al., 2014). Nevertheless, 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. They further point to a substitution effect between formal IPR and downstream capabilities.

There are important parallels between the platform participation decision of say software vendors and the decision of firms to join open standard development organizations in the Information Communication Technology (ICT) domains. Indeed, Gawer and Henderson (2007) and Boudreau (2010) refer to standards organizations as a model of fully open technology platform development.

2.2 Participation in standards development

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). Among other things, this literature emphasizes 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). A small number of studies have examined the impact of R&D expenditures, patents, and (to a much lesser extent) product-market position on this participation decision.

2.2.1 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 standard-developing activities. On one hand, standardization is often viewed as an extension of the firm's internal R&D. Joining the standardization process may help an innovating firm to be informed about new technological developments and the needs of downstream firms, thus helping the firm to ensure that there is a product-market demand for its R&D contribution. On the other hand, the firm is likely to abstain from engaging in standardization if costs stemming from knowledge leakages to competitors exceed benefits it can derive from standard-developing activities (see Blind and Thumm, 2004).

Existing empirical studies lend largely mixed support for the above hypotheses. For example, Blind and Thumm (2004) analyze 149 European firms and find that R&D intensity has no statistically significant impact on the likelihood of joining the standardization process. Similar results were obtained for German (Blind, 2004; Rauber, 2014) and Dutch (Meeus et al., 2002) firms. By contrast, 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 standard-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. Finally, Blind and Mangelsdorf (2016) study a sample of of 375 firms in the German electrical engineering and machinery industry and find that R&D intensity has a positive effect on the participation decision if the firm seeks new knowledge or attempts to facilitate market access.

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 standard-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 the problem of over- or under-compensation of patented contributions to the standard.

2.2.2 The role of patents

Existing analyses of the role of patents for participating in standardization have highlighted the importance of mechanisms that apply to collaborative technology development more generally. Blind and Thumm (2004) discuss two countervailing arguments. As noted earlier, the risk of technology leakages may deter R&D intensive firms from joining collaborative technology development processes. Formal intellectual property (IP) 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 join collaborative technology development. However, intensive patenting may indicate that a firm possesses particularly valuable technology that it is attempting to prevent from leaking to competitors; patenting may thus be negatively correlated with participation in collaborative activities posing a credible threat of information leaks.

Another argument suggesting a link between patenting and standardization activities is related to the existence of so-called standard-essential patents (SEPs). SEPs are patents that protect technologies required for the implementation of a technology standard (see Shapiro, 2001; Lerner and Tirole, 2015; Baron et al., 2016).[1] Inclusion of a 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 serve as an incentive for patent holders to actively participate in standard 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 standard-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 development organizations.[2]

At the same time, membership in standards organizations can also impose significant costs on firms with valuable IP rights. 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 faire, 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.

[1] See Baron and Pohlmann (2018) for a review of the literature and a new database with declared SEPs.

[2] Berger et al. (2012) point out that a large number of patent applications resulting in declared SEPs undergoes 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.

2.2.3 The role of the product-market position

Among other reasons for why firms might steer clear of standard-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.

Market dominance is a significant factor that may guide firms' decision not to produce a compatible product (see Farrell and Saloner, 1985; Katz and Shapiro, 1985). In industries with network externalities, the market leader may produce incompatible products to make it more difficult for consumers to switch to rival products, whereas the followers may seek compatibility to compete for the market leader's installed base of consumers.[3]

Finally, firms maintaining their product-market position by engaging in product differentiation - 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.

The arguments presented so far point to a negative effect of a firm's strong product-market position on participation in collaborative standard development. Nevertheless, in a situation of product-market rivalry, the opportunity to obtain the endorsement of a proprietary technology by a standard-developing organization can, in fact, motivate firms with a strong product-market position to join the standardization process. Such an endorsement can be perceived by the market as a positive signal about the quality of the selected technology as well as its likely future commercial success, with the latter being particularly important at an earlier stage of building the consumer network.

Several authors also 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 characterizes coordination among inventors and producers as an crucial function of these organizations. 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.[4]

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

[3]Besen and Farrell (1994) label this standard-related competitive regime as "pesky little brother".

[4]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.

relationship between R&D and participation in standard 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 fields such as genomics and open source software provides 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 standard 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 standard-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 standard-related collaborative R&D, and the interactions between these appropriability mechanisms. Using evidence collected by a survey of employees from a 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 comprehensive study has empirically addressed the role of incentives unrelated to patents in the development of open standards.[5]

3 Data and measures

3.1 An overview of data sources

3.1.1 Data on membership in standard-setting 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 approximately 180 standards organizations, including formal standards development organizations, informal consortia, and organizations that participate in other activities associated with the standardization process (e.g., coordination, certification, or advocacy). The sample focuses on organizations operating in the ICT sector, with yearly observations from 1997 to 2015, containing 299,652 membership records.

The majority of standards organizations are membership-based. Depending on the organization, membership can be open to individuals or organizations such as firms, universities, public administrations, trade associations, and other standards organizations.[6]

[5]Some notable exceptions highlight the role of downstream capabilities using trademarks in the specific context of the software industry considering both proprietary and open-source platforms (Fosfuri et al., 2008; Huang et al., 2013; Ceccagnoli et al., 2012).

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

The Searle Center Database contains membership information for standards organizations with organizational membership. The standards organizations in this sample are also *open*, meaning that any organization complying with the general criteria for membership and agreeing to abide by the standards organization's policies can become a member. Yet, the vast number of member entries in the database relate to firms.

Although membership is often not required for participation in the standardization process at a standards organization, members usually are given additional rights, including privileged voting rights on standardization decisions; the right to participate in elections of standards organization leadership; as well as the right to define 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 tiers of membership. Furthermore, standards organization members have to enter into a membership agreement: among other things, it may define obligations concerning the disclosure of potential SEPs and the requirement to make licenses for SEPs available to standard implementers. Therefore, firms have to choose carefully in which standards organizations they wish to seek membership. The firm with the largest number of membership records in the Searle Center Database – IBM Corporation – was listed as a member of 112 standards organizations.

3.1.2 Data on R&D expenditures, patents, and trademarks

The information on firms' innovation activities and other characteristics was extracted from the recent two waves of the OECD Database on the IP Bundles of the World's Top R&D Investors (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, taking into account their subsidiaries, for the period 2010-2014. The selection of firms into the OECD Database was guided by the EU Industrial R&D Investment Scoreboard (see Guevara et al., 2015), which also served as the source of economic and financial indicators. IP statistics of these 2,000 firms were derived from the five major IP offices (IP5) located in the European Union, the United States, Japan, South Korea and China. In order to avoid double counting due to patent applications being filed at different IP offices, patents were 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) and also Daiko et al. (2017). Overall, firms covered in this database own 66% of all IP5 patent families while 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 firms ranked among the top 2,000 R&D investors changed from the first wave (published in 2015) to the second (published in 2017), we kept only those firms that appeared in both waves. Having controlled for name or ownership changes over sample period and other discrepancies to ensure data consistency, we were able to identify 1,633 firms that appeared in both waves, amounting to almost 82% of all top 2,000 R&D performers originally covered in the earlier 2015 wave.

3.2 Sample construction

The OECD Database is a selected sample of firms with very large R&D spending. We use the Searle Center Database to verify that this sample provides a good coverage of the firms that most intensely participate in ICT-related standards organizations: firms included in the OECD Database are on average listed as members of 4.82 standards organizations and account for 10.2% of all membership observations. The share of these firms is much higher among the entities with a particularly large number of memberships: for example, 44 of the 50 entities with the highest numbers of standards organization memberships are included in the OECD Database (this is also the case for 82 of the top 100, 168 of the top 250, and 364 of the top 1,000 member entities).

Using a database of declared SEPs (see Baron and Pohlmann, 2018), we identify 148,236 declared SEPs; of these patents, 130,709 (88.2%) belong to the firms in the OECD Database. The database includes 36 of the top 50 entities declaring SEPs (and all of the top 10).[7] Finally, we use two different databases of certified standard implementations to count different standard-compliant products.[8] We identify 36,153 different products which comply with standards developed by ICT standards organizations; 27,005 of these products (74.7%) are sold by the firms in the OECD Database. The OECD database thus comprises a large majority of the top standards organization members, SEP owners, and implementers of ICT standards.

Next, we restrict the sample to a narrower set of industries that are similarly related to ICT standards development. We used the FTSE's Industry Classification Benchmark (ICB) to define industries, and identified industries related to ICT standards development using the same data and criteria as above (i.e., counts of memberships, declared SEPs, contributions and standard-compliant products).[9]

Firstly, we construct a narrow sample containing six industries that are most involved in developing ICT standards including Electrical and Electronic Equipment, Consumer Electronics, Broadcasting and Entertainment, Fixed Line Telecommunications, Mobile Telecommunications, as well as Technology Hardware and Equipment (*Industry sample 1*). Among these six industries, at least 15% of the firms have declared one or more SEPs. Precisely the same six industries are identified as the industries in which at least 10% of the firms are listed as selling standard-compliant products. In five out of these six industries, the average number of memberships per firm is higher than 10. Based on these observations, we conclude that membership-, patent-, and product-based criteria consistently point to these six industries as being especially relevant to ICT standardization. The OECD Database contains 509 firms operating in these six industries.

[7] Since both the membership data and the data on SEPs also contain universities, research institutions, and public administrations, the firms in the OECD Database thus account for an even larger share of the corporate entities involved in ICT standardization.

[8] In particular, we use data from *GSM Arena* (www.gsmarena.com) and the *Wi-Fi Alliance Product Finder* for standardized information on devices using standardized wireless connection technology.

[9] Throughout, 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 used ICB Subsector classifications for these sectors.

At the same time, these 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 covering 832 firms (*Industry sample 2*; see Table 1 for definitions). Among these 11 industries, firms in the OECD Database are, on average, members of at least five standards organizations: 678 of the 1,633 firms are active in these 11 industries, including 49 of the top 50 firms declaring SEPs, all of the top 50 standards organization members, and 47 of the top 50 producers of standard-compliant products. Therefore, while this sample is more heterogeneous with respect to the industry-level importance of ICT standards, these 11 industries almost fully encompass the firms that are highly active in ICT standardization.

Industry	N	SEP hold.	Prod.	Avg SO	SEP_50	SO_50	Prod_50	Ind. sam. 1
Aerospace & Defense	46	0.11	0.04	6.41	1	1	0	0
General Industrials	68	0.09	0.06	5.63	4	4	2	0
Electron. & Elec. Equip.	170	0.18	0.13	7.61	7	6	6	170
Support Services	19	0.11	0.00	6.37	0	1	0	0
Consumer Electronics	19	0.37	0.42	17.37	4	3	3	19
Broadcas. & Entertain.	6	0.33	0.33	11.67	2	0	1	6
Publishing	4	0.00	0.00	5.50	0	0	0	0
Fixed Line Telecom.	20	0.55	0.35	25.70	9	6	2	20
Mobile Telecom.	4	0.75	0.25	15.75	0	0	1	4
Software & Comp. Serv.	186	0.13	0.03	7.11	3	7	2	0
Tech. Hardw. & Equip.	290	0.29	0.22	12.96	19	22	30	290
Total: Ind. sam. 2	832	0.21	0.14	9.82	49	50	47	509

Table 1: Sample construction: An industry breakdown

3.2.1 Variable description

Dependent variables. To capture the extent of participation in standardization activities, we calculate the number of standards organizations in which a firm has a membership in a given year. We hereby distinguish between standards organizations that develop technology standards or technical specifications (*Standards developers*), organizations that promote standards developed by other organizations (*Promoters*), as well as certification bodies and other organizations (*Others*). The distinction is not always straightforward.[10] When developing our classification, we rely on each organization's self-description of its tasks and activities on the official website (consulted from February to April 2018). We refine the classification by using additional information sources. In particular, an organization is listed as a *Standard developer* if the standards developed by this organization are included in the Searle Centre Database; if it is named as an accredited developer of the American National Standards Institute; or if this organization discloses SEPs. We use the data in

[10]The case of the *Wi-Fi Alliance* provides a telling example of how the roles of standards organizations can change over time. The Wi-Fi Alliance's primary role is to certify the compliance of products with IEEE's 802.11 wireless connection standards. To this end, 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" could itself be considered as a technology standard. Nevertheless, as this role is ancillary to the Alliance's main role, we classify the Wi-Fi Alliance as a certification body and include it in the "Others" category.

Baron and Pohlmann (2018) to identify standards organizations that have received and published at least one SEP disclosure.[11]

Explanatory variables. To measure R&D investment, we use the firm's reported R&D expenditure in a given year. 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. Similarly, we identify firms with a strong product-market position by using a dummy variable that takes the value of one if the trademark-counts-to-employees ratio is greater than the sample median, and zero otherwise.[12] We draw on trademark statistics to reveal 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, we are confident that this empirical operationalization serves as a suitable proxy for product-market position of a firm.[13] Table 12 in the Appendix provides some examples of firms in our sample categorized by their IP positions based on our measures.

Control variables. We include additional firm-level characteristics to control for other factors that can potentially affect the decision to participate in developing standards. More specifically, we control for such factors as the number of employees, net sales, as well as capital intensity (measure as the firm's capital expenditures over sales). Finally, we control for year effects and regional trends.

4 Empirical analysis

4.1 Descriptive statistics

In this section, we use the matched database to provide descriptive statistics about standards organizations and their members. Descriptive statistics on membership in the different types of standards organizations are displayed in Table 2. The counts and characteristics refer to firms listed as a member of a standards organizations in at least one of the years of the OECD Database's observation period (2010-2014). For these firms, we provide information on the average values of yearly patent and trademark application counts during these years.

[11]It should be noted, however, that using the SEP disclosure data to identify organizations developing standards that contain an essential patented technology is likely to result in false negatives. Other standards organizations in our sample may also develop standards that are subject to potential SEPs, but do not require the disclosures of such SEPs or do not make such disclosure letters publicly available.

[12]To ensure that our results are not affected by the way these dummies are constructed, we have experimented with different dummy specifications. In particular, we have computed the 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.

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

	All	Standard developers	Promoters	Others	SDOs w. SEPs
Members					
mean	1,074.17	1,240.74	552.37	685.85	602.09
s.d.	1,334.81	1,490.39	432.93	622.09	338.76
Ind. sam. 2					
mean	61.69	65.06	56.12	48.38	77.21
s.d.	49.54	51.83	47.88	31.84	30.94
OECD 2000					
mean	74.64	79.69	65.46	55.62	88.17
s.d.	56.00	58.22	54.98	34.67	39.19
PT intensity					
mean	47.93	52.38	37.33	33.86	57.66
s.d.	36.23	38.30	30.91	19.54	26.16
TM intensity					
mean	33.76	37.10	28.21	20.61	39.71
s.d.	27.91	29.26	26.02	13.28	20.23
Average PT count					
mean	1,215.73	1,241.95	1,112.43	1,177.61	1,252.84
s.d.	501.84	470.71	579.49	563.27	365.05
Average TM count					
mean	44.13	46.42	39.13	36.47	41.77
s.d.	16.58	16.62	16.31	12.68	6.56
N	176	101	39	36	12

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

Each standards organization in our sample had on average 1,074 different members in the period 2010-2014.[14] Standards organizations that develop standards or technical specifications have significantly larger membership counts than other types of standards organizations, both in terms of the overall membership count, and among the firms included in the OECD Database. On average, a member of a standard-developing organization listed in the OECD Database files 1,242 patent and 46 trademark applications per year. These figures are slightly lower for standards promoters and other types of standards organizations. Standards organizations developing standards subject to SEP declarations have a lower number of members than other standards organizations in the sample, but a significantly larger share of these members is included in the OECD Database. Members of these standards organizations also have a slightly higher average patent count than members of other standards organizations.

4.2 Econometric analysis

4.2.1 Baseline models

We now turn to multivariate analyses to examine the determinants of business participation in standards development. This section presents the results of our baseline econometric model. We analyze the effect of R&D on the natural logarithm of the count of standards organization memberships in a series of OLS panel regressions, where we control for firm and year fixed effects. Throughout, for the sake of simplicity, we report results from the

[14]Since there is some entry and exit over time and we include all firms listed as a member in any of the 6 years, this number is larger than the average membership at any point in time.

narrower *Industry sample 1* in the main body of the paper. Results from estimating such baseline model for *Industry sample 2* are presented in Table 13 in the Appendix. All main results are found to be robust in this larger and more heterogeneous *Industry sample 2*.

In our preferred specification, we control for regional trends by including interaction terms between time and six regional dummies (North America, Europe, China, Japan, South Korea and other) to account for significant shifts in the pattern of patenting and standardization participation in different world regions. The increased participation of emerging market actors in international technology development may induce spurious correlations between innovation activities and standard development, which are not controlled for by fixed effects. Arguably, there is a risk of over-controlling, as the increased participation of for example Chinese firms in standards organizations could be partly explained by the increased R&D or patenting efforts of these firms. For robustness checks, we thus report results of the main specifications without regional trends in the Appendix (Table 14). All main results are robust to including or excluding regional trends.

The main explanatory variables of interest are firm R&D spending and IP positions, and we also add other firm-level controls. All continuous explanatory variables are included as natural logarithms (Model 1). Given the fixed-effects estimation we employ, the time-invariant variables such as IP dummies (indicating above-industry-median patent- and trademark-intensive positions) cannot be estimated on their own. In a second step, we interact R&D with IP dummy variables (Models 2-4), as well as a three-way interaction term between these dummies (Model 5). The results are presented in Table 3.

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5
lnRD	0.059***	0.033*	0.027	0.017	0.018
	(0.006)	(0.069)	(0.173)	(0.330)	(0.304)
PT_High#lnRD		0.134***		0.096*	0.089
		(0.006)		(0.059)	(0.215)
TM_High#lnRD			0.136***	0.095**	0.089*
			(0.002)	(0.036)	(0.081)
PT_High#TM_High#lnRD					0.014
					(0.885)
lnEmployees	0.062**	0.040	0.042*	0.032	0.033
	(0.012)	(0.113)	(0.085)	(0.201)	(0.175)
lnSales	0.036**	0.032**	0.030**	0.029**	0.029**
	(0.011)	(0.011)	(0.018)	(0.018)	(0.018)
lnCapital_Int	0.158*	0.069	0.076	0.037	0.038
	(0.084)	(0.460)	(0.417)	(0.702)	(0.682)
Constant	-39.591	-21.742	-9.661	-5.843	-6.214
	(0.106)	(0.361)	(0.680)	(0.801)	(0.790)
Year dummies	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes
R-squared	0.087	0.096	0.096	0.100	0.100
Observations	2,233	2,233	2,233	2,233	2,233
Number of companies	405	405	405	405	405

Robust pval in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3: Fixed-effects models with IP positions

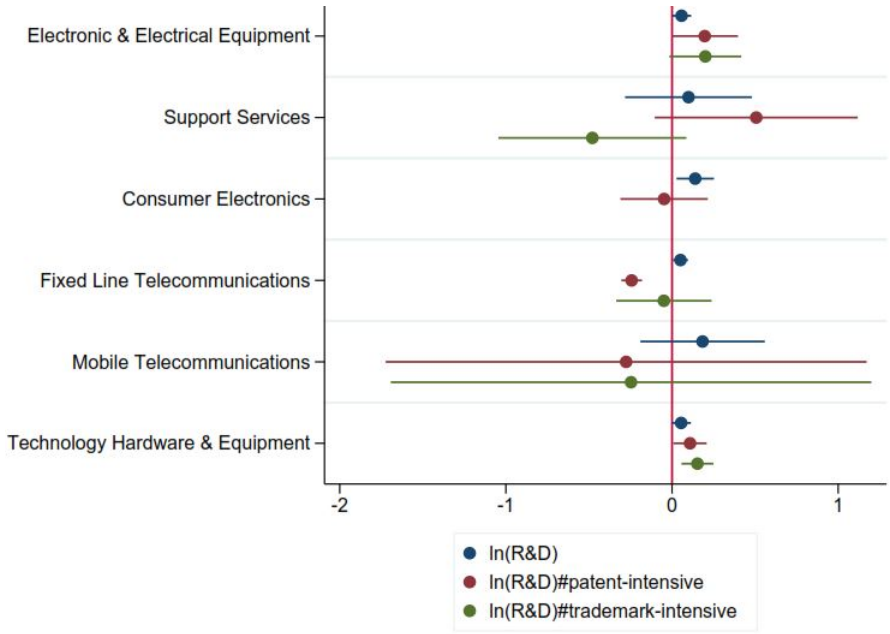
We find a strong and statistically significant positive association between R&D and counts of standards organization membership. This association however depends on the firms' IP intensity. Among firms with below-industry-median trademark-intensity, the association between R&D and participating in standards organization is insignificant. The association significantly increases in both patent- and trademark-intensity. The effect of both types of IP hereby appears to be largely independent and additive. Both IP intensity dummies significantly increase the positive association between R&D and the firm's involvement in standards organizations, even when included simultaneously (Model 4). We do not find evidence for a significant complementarity between both types of IP intensities with respect to their moderating effect on the association between R&D and membership in standards organizations (Model 5).

To assess the robustness of these results, we allow the coefficients of our main variables of interest to vary by industry. The industry-specific coefficients and 95% confidence intervals are presented in Figure 1. Overall the positive association between R&D and memberships in standards organizations is robust across industries included in our narrower *Industry sample 1*. More specifically, this positive association is individually significant in Electrical and Electronic Equipment, Consumer Electronics, Fixed Line Telecommunications, and Technology Hardware and Equipment industries. It is statistically insignificant among Support Services and Mobile Telecommunications industries, where only a small number of firms are represented among the largest 2,000 R&D performing firms. Thus given the small sample size for these two industries, the coefficients are less precisely estimated. The support for the positive interaction between R&D and IP intensity appears more heterogeneous. Setting aside the two aforementioned industries with overly small samples, the interaction between R&D and both types of IP is positive and statistically significant in the two industries with the largest samples of R&D-performing firms (i.e., Electronic and Electrical Equipment, and Technology Hardware and Equipment respectively).

An even more robust picture emerges in the larger *Industry sample 2* (Figure 2 in the Appendix) although one industry was dropped from estimation due to collinearity. The positive association between R&D and standards organization memberships receives positive support in seven out of ten industries (excluding Support Services, Publishing and Mobile Telecommunications). The interactions between R&D and IP positions are significantly positive in four industries including General Industrials as well as Software and Computer Services that are excluded from the narrower industry sample.

In the first set of models, we utilized binary measures of IP intensity as compared to the industry median. In Table 4, we present results from estimations using continuous counts of patents and trademarks. We use two different types of counts: 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; the interaction terms in the fixed effect specification can thus be interpreted as variations in the effect of the time-variant R&D measure depending on the firm's IP intensity. In Models 5-7, we include time-variant patent and trademark counts based on the flow of applications over time. These specifications are based on thicker information content because we can use up to five years' observations. The interaction terms are, however, more difficult to interpret, indicating variations in the effect of either R&D by IP intensity or variations in the effect of IP by the extent of R&D effort. The baseline effect of IP counts without interactions is included in Model 5.

Figure 1: Coefficients for R&D and R&D-IP interactions:
An industry breakdown



Notes. The ln(R&D) X trademark estimate dropped for the Consumer Electronics industry due to collinearity issues.

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	Predetermined IP counts				Time-variant IP counts		
lnRD	0.043**	0.069***	0.052***	0.049***	0.120***	0.087**	0.066*
	(0.028)	(0.001)	(0.004)	(0.009)	(0.000)	(0.012)	(0.072)
lnPT_count					-0.001	-0.048**	-0.065**
					(0.944)	(0.019)	(0.015)
lnTM_count					0.003	-0.001	-0.029
					(0.728)	(0.979)	(0.573)
lnPT_count#lnTM_count							0.003
							(0.754)
lnPT_count#lnRD	0.017***		0.014**	0.014**		0.010***	0.015***
	(0.002)		(0.024)	(0.016)		(0.007)	(0.005)
lnTM_count#lnRD		0.022***	0.013	0.011		0.001	0.010
		(0.005)	(0.116)	(0.174)		(0.940)	(0.354)
lnPT_count#lnTM_count#lnRD				0.001			-0.002
				(0.678)			(0.400)
lnEmployees	0.048**	0.058**	0.049**	0.049**	0.037	0.036	0.037
	(0.042)	(0.016)	(0.038)	(0.040)	(0.113)	(0.119)	(0.111)
lnSales	0.031**	0.034**	0.031**	0.031**	0.027**	0.026**	0.026**
	(0.014)	(0.013)	(0.015)	(0.016)	(0.018)	(0.022)	(0.022)
lnCapital_Int	0.099	0.141	0.101	0.099	0.063	0.060	0.064
	(0.272)	(0.120)	(0.261)	(0.270)	(0.450)	(0.471)	(0.440)
Constant	-17.684	-23.865	-12.785	-13.967	-48.135**	-39.596	-33.165
	(0.477)	(0.335)	(0.618)	(0.580)	(0.047)	(0.106)	(0.183)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.094	0.092	0.096	0.096	0.109	0.113	0.114
Observations	2,233	2,233	2,233	2,233	1,850	1,850	1,850
Number of companies	405	405	405	405	405	405	405

Robust pval in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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

The results are broadly in line with those obtained in previous specifications using IP dummies. The association between R&D and standards organization memberships significantly increases in the firms' number of patents (either pre-determined or varying over time). 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. As before, we find no evidence for significant complementarity between both types of IP. Similarly, the main effect of both IP counts is largely absent. This could indicate that IP counts only influence the participation decision of particularly R&D intensive firms. In addition, it is plausible that the within-variation over less than 6 years is not highly informative of the main effect of IP. This is because the flow of IP applications is often subject to significant stochastic shocks, and firms' participation decision is more likely to be driven by the overall size and value of their IP stock rather than within-variations in IP application flows over time.

4.2.2 Heterogeneity among standards organizations

We subsequently slice our sample into standards-developing, standards-promoting and other standards organizations. We also classify these organizations on the basis of whether their standards are potentially subject to standard-essential patents (SEPs). In Table 5, we provide the results from testing our baseline specification separately for membership counts within each of the five types of standards organizations. Overall, there is a broadly consistent positive effect of R&D expenditure in determining the extent of participation across all types of organizations.[15] Turning next to the conditioning role of a firm's IP positions in the R&D-participation nexus, rather heterogeneous patterns emerge among distinct types of standards organizations. Both a firm's patenting and trademarking intensities are found to significantly interact with its R&D effort in determining its membership counts in organizations developing standards (Model 2). A firm's patent position significantly increases the effect of R&D investment on participation in organizations that develop standards linked to SEPs, as well as the "Other" category. In sharp contrast, the firm's trademark position is found to exert a significantly positive moderating effect on its participation in standards-promoting organizations and standards organizations not associated with SEPs. Most notably, trademark positions thus appear to provide particularly significant incentives for R&D-intensive firms to participate in standards organizations that do not provide significant patent-based incentives.

4.2.3 Alternative measures of the product-market position

So far, we have observed that the trademark intensity enhances the willingness of an R&D intensive firm to participate in standard-developing activities. Throughout the analysis, we use trademarks as an indicator for the firm's product-market position, which is likely to be a multifaceted construct. To gain more insight into the role of the product-market position, we augment our analysis with two additional measures to capture further dimensions of this position.

[15]The coefficient is positive, albeit insignificant, for standards organizations associated with SEPs, as the small number of these organizations leads to more imprecise estimates.

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
	Standards developer		Promoter		Other		SEP		No SEP	
lnRD	0.044***	0.006	0.074***	0.044**	0.038**	0.025	0.023	0.015	0.082*	0.031
	(0.009)	(0.749)	(0.000)	(0.023)	(0.038)	(0.216)	(0.122)	(0.335)	(0.056)	(0.506)
PT_High#lnRD		0.119***		-0.016		0.068**		0.060**		0.089
		(0.000)		(0.629)		(0.041)		(0.025)		(0.257)
TM_High#lnRD		0.058*		0.135***		-0.002		-0.020		0.137*
		(0.065)		(0.000)		(0.954)		(0.467)		(0.092)
lnEmployees	0.032	0.005	0.026	0.009	0.061***	0.051**	-0.001	-0.008	0.106**	0.072
	(0.125)	(0.833)	(0.242)	(0.681)	(0.007)	(0.031)	(0.954)	(0.675)	(0.049)	(0.194)
lnSales	0.049***	0.043***	-0.004	-0.010	0.008	0.006	0.024*	0.024*	0.065*	0.056
	(0.001)	(0.003)	(0.804)	(0.518)	(0.616)	(0.703)	(0.053)	(0.062)	(0.079)	(0.133)
lnCapital_Int	0.055	-0.059	0.137	0.066	0.145	0.100	-0.013	-0.041	0.218	0.076
	(0.631)	(0.611)	(0.264)	(0.593)	(0.248)	(0.430)	(0.897)	(0.690)	(0.461)	(0.800)
Constant	-22.972	5.722	-35.517**	-7.973	-23.399	-14.769	-3.470	0.094	-88.298**	-46.319
	(0.176)	(0.751)	(0.050)	(0.679)	(0.204)	(0.454)	(0.815)	(0.995)	(0.042)	(0.319)
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	0.090	0.105	0.040	0.049	0.023	0.026	0.018	0.021	0.060	0.064
Observations	2,233	2,233	2,233	2,233	2,233	2,233	2,233	2,233	2,233	2,233
Number of companies	405	405	405	405	405	405	405	405	405	405

Robust pval 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

Our first indicator 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 Brand Finance (see www.brandfinance.com), and zero otherwise. The other measure we use is the number of ICT standards-compliant products offered by a firm. We calculate this variable by counting the number of mobile and communication devices sold by each firm. We use data obtained from the website GSM Arena for this analysis, and count different end-product models (see Section 3.2 for more details). We argue that the value of the corporate brand and the number of different standard-compliant product models are plausible indicators of the firm's general product-market position.

Similar to trademarks, the corporate brand is part of a firm's differentiation effort. Differentiation through the corporate brand can substitute for product-based differentiation reflected in trademarks. Nevertheless, valuable corporate brands can also serve as yet another, reputation-based mechanism through which the firm retains existing and attracts new customers. In this case, some degree of complementarity should be expected between brand value and the intensity of trademarking activities.

The count of standard-related product models constitutes a measure of the breadth of a firm's product offering. By contrast, the firm's trademarking intensity depends not only on the number of different products that a firm offers, but also reflects the depth of trademark protection that the firm seeks for its products, and thus serves as an indicator of product differentiation. Simultaneously testing these differing aspects of product counts and trademark intensity can thus help disentangle the effects of the breadth of the product offering and the depth of product differentiation.

Since we use annual surveys of corporate brand value, and GSM Arena provides product release dates, we can use this information to compute both time-variant and time-invariant variables. We use time-variant product counts and brand value indicators to test for the direct effects of these elements while using a pre-determined dummy indicating being a producer of such products and brand value (as of 2010) to test for interactions with time-variant R&D expenditures.

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
lnRD	0.060***	0.060***	0.056***	0.017	0.016	0.014
	(0.005)	(0.006)	(0.009)	(0.353)	(0.369)	(0.437)
Top500		0.026	-0.269*			
		(0.234)	(0.073)			
Prod_count	0.007**					
	(0.014)					
PT_High#lnRD				0.091*	0.097*	0.108*
				(0.090)	(0.078)	(0.062)
TM_High#lnRD				0.097**	0.101**	0.090*
				(0.034)	(0.034)	(0.069)
Top500#lnRD			0.046**	0.009		0.196**
			(0.050)	(0.871)		(0.015)
Prod_count#lnRD			0.001**	0.002***		
			(0.013)	(0.003)		
Producer#lnRD					0.194	
					(0.127)	
PT_High#Top500#lnRD						-0.227**
						(0.017)
TM_High#Top500#lnRD						-0.026
						(0.778)
PT_High#Producer#lnRD					-0.157	
					(0.244)	
TM_High#Producer#lnRD					-0.189**	
					(0.036)	
lnEmployees	0.061**	0.061**	0.059**	0.031	0.032	0.034
	(0.013)	(0.012)	(0.015)	(0.216)	(0.208)	(0.179)
lnSales	0.035**	0.037**	0.036**	0.028**	0.030**	0.029**
	(0.014)	(0.011)	(0.011)	(0.020)	(0.016)	(0.019)
lnCapital_Int	0.154*	0.157*	0.149	0.033	0.035	0.044
	(0.092)	(0.086)	(0.103)	(0.735)	(0.708)	(0.654)
Constant	-43.788*	-40.253*	-39.360	-5.733	-6.026	-4.661
	(0.072)	(0.099)	(0.106)	(0.805)	(0.797)	(0.843)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.088	0.087	0.089	0.100	0.100	0.101
Observations	2,233	2,223	2,223	2,233	2,233	2,233
Number of companies	405	403	403	405	405	405

Robust pval in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6: Fixed-effects models with IP positions:
Alternative measures of the product-market position

The results of this analysis are presented in Table 6. First, each of these additional measures enhances the effect of R&D on memberships in standards organizations (Models 3-4). Overall, these results corroborate the argument that the ability of a firm to appropriate its R&D investments by leveraging its product-market position can provide incentives for joining the standardization process. Notably, the positive effect of trademark intensity on the relationship between R&D expenditures and standards organization membership counts remains significant when controlling for these other dimensions of the firm's product-market position.

Second, our analysis of the time-varying product count reveals a positive relationship between product count and the membership count in standards organizations. This finding may indicate that the firm's product-market position (in particular 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. Such effects could be attributed to the firm's incentives to participate in shaping the standards developed for its products, the importance of timely information about future technology development, and the desire to benefit from knowledge spillovers from firms contributing new technologies to standard development. Nevertheless, there could also be other interpretations for this positive relationship, such as reverse causality where increased participation in standards organizations induces a greater extent of implementation of technology standards developed in these organizations.

Lastly, in terms of the interaction between IP positions and these two additional aspects of product-market position (Models 5-6), there is some evidence of potential trade-off, i.e. a substitution between trademarks and being producers of standard-compliant products, as well as between patent and corporate brand value. 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 stronger corporate brands and/or that offer directly standard-related products. These findings provide some support for the hypothesis that formal IPRs support modularity in technology development, and provide participation incentives that are particularly relevant for those R&D-intensive firms that do not have a large number of own products depending on the standards being developed.

4.2.4 Endogeneity of R&D expenditures

It is plausible that a firm that participates in standards development may increase its internal R&D expenditure due to knowledge exchange and learning taking place in open standards development and innovation collaboration. We need to address this potential endogeneity bias arising from reverse causality. Another possible source of endogeneity pertains to the 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 could range from macroeconomic environment, business growth, corporate strategies to technological evolution over time and attendant new opportunities available.

To identify the impact of R&D investment on the extent of a firm's participation in standards organizations, we adopt a two-stage instrumental variable (IV) approach in conjunction with the fixed-effects models outlined before. We use two sets of instrumental variables. The first instrument focuses on the financial resources available for R&D spending. Financing constraints have long been understood as a critical barrier for the risky and sunk investments associated with innovation (Hyytinen and Toivanen, 2005). A large empirical literature has firmly established the role of capital market imperfections in limiting long-term investments especially by smaller firms (see Carreira and Silva (2010) for a survey). Access to external finance is particularly constrained in times of macro-economic financial crises. There is robust evidence that the financial crisis 2007-2009 led to a significant decline in R&D investment, disproportionately affecting financially constrained, younger firms (Duchin et al., 2010; Paunov, 2012).[16]

Building on this body of evidence, we use the financial crisis 2007-2009 as a source of exogenous variation in R&D spending. During the crisis, firms had to rely more heavily on internal financing to fund risky long-term projects such as R&D. We thus expect financial constraints to be more binding on firms with limited current revenue during a financial crisis. On the other hand, it is less probable to expect financial constraints to directly affect membership decisions or having an effect running through omitted variables, given the relatively low financial cost and entry barriers to membership. In order to operationalize this idea, we include interaction terms between the value of firm sales and year dummies in the first stage, thus capturing the effect of the financial crisis 2008 and 2009 as excluded instrument, while sales and year dummies without interaction are included in both stages of the regression.

In addition, we draw on the country-level variation in average R&D expenditure to capture the country-specific conditions of the firm's home-country. This variable reflects the general regulatory environment, such as R&D tax support (Bloom et al., 2002), overall corporate taxation, regulation, competition policy, labor market regulation etc. Similar to Jaffe (1986), we build our instrumental variable using the average R&D investment of all other firms from the same country in our data (excluding the focal firm).

The baseline models with R&D instrumentation are reported in Table 7. Subsequently in Table 8 we also repeat previous analysis that unpacks the effect of R&D and IP positions for distinct types of standards organizations using instrumented R&D. The ideal instruments should be correlated with R&D spending but uncorrelated with the error term in the structural model of the degree of participation. This first condition of instruments relevance can be validated by the results from estimating the first-stage model of R&D expenditures shown in the Appendix (Table 15). An F statistic of 46.31 from the test of the joint significance of all instruments' coefficients indicate these being strong instruments. As expected, the value of firm sales matters significantly less in the later years of the sample (2011 to 2014) than in 2010. And the country-level variation in average R&D expenditures is highly positively associated with the focal firm's intramural R&D expenditure.

In terms of the second condition of instruments validity, the Sargan-Hansen statistics reported in both Table 7 and Table 8 suggests that the null hypothesis of over-identification restrictions may only be partially valid in modelling participation in certain types of standards organizations, viz. organizations which develop standards, those associated with declared SEPs or those not associated with SEPs. Admittedly, our instruments set may fall short of completely satisfying strong exclusion restriction. Nevertheless, we can reasonably expect the instruments to effectively address many of the sources of endogeneity in the relationships under consideration, including reverse causality and many firm- or technology-level confounding factors. For the remainder, we can not exclude that country-level or cyclical effects may have direct effects on standardization participation analogous to those on R&D, but such effects are likely to be orthogonal to the firm's IP positions. Put differently, even if financial constraints and/or country-level policy factors

[16] Archibugi et al. (2013) show that the crisis led to a concentration of R&D activities in a small number of firms that were already highly innovative before the crisis.

may have a direct effect on a firm's membership of standards organizations not transmitted via R&D, this is not expected to bias the interpretation of the interaction between R&D efforts and IP intensities.

Independent variables	Model 1	Model 2	Model 3	Model 4
lnRD	0.166**	0.129**	0.042	0.048
	(0.016)	(0.030)	(0.459)	(0.367)
PT_High#lnRD		0.158***		0.121***
		(0.000)		(0.010)
TM_High#lnRD			0.147***	0.107**
			(0.002)	(0.034)
lnEmployees	0.018	-0.006	0.033	0.011
	(0.628)	(0.861)	(0.299)	(0.742)
lnSales	0.019	0.015	0.026	0.021
	(0.322)	(0.406)	(0.154)	(0.243)
lnCapital_Int	-0.007	-0.104	0.041	-0.048
	(0.966)	(0.512)	(0.786)	(0.754)
Constant	-84.539**	-60.988*	-13.391	-15.157
	(0.015)	(0.051)	(0.673)	(0.619)
Year dummies	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes
F-test of joint sig of all IVs	46.31	46.31	46.31	46.31
(P-value)	(0.000)			
Sargan/Hansen test [chi-sq]	18.89			
(P-value)	(0.002)			
Observations	2,227	2,227	2,227	2,227
Number of companies	404	404	404	404

Robust pval in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notes. The following variables are used as IVs: (1) the effect of the financial crisis captured by Time trend X lnSales; and (2) the country-level variation in the average level of R&D expenditures.

Table 7: 2SLS fixed-effects models with IP positions: The 2nd stage

Table 7 presents the results from estimating the second stage structural model of the extent of participation utilizing both IVs outlined above. Taking into account the potential endogenous link between R&D spending and memberships, Model 1 reveals a highly significantly positive effect of R&D while Model 4 showing the effect of R&D effort being significantly enhanced by both the firm's patent and trademark intensities. Our analysis exploring the heterogeneous patterns across various types of standards organizations (Table 8) suggest a largely robust effect of R&D across different standards organizations (except for those that develop standards, Model 1). Furthermore, a firm's patent intensity is found to significantly amplify the effect of R&D investment on participation in organizations that develop standards as well as those subject to declared SEPs. By contrast, a firm's trademark position is found to positively moderate the effect of R&D on participation in organizations that promote standards fully developed elsewhere. Finally, to ensure our results are not driven by specification errors in using IVs, we have also experimented with alternative two stage least squares models using one instrument at a time and found these results to be robust to the use of alternative IVs.[17]

[17]Results not reported here but available upon request.

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
	Standards developer		Promoter		Other		SEP		No SEP	
lnRD	0.043	-0.022	0.128*	0.069	0.341***	0.198***	0.097*	0.037	0.289*	0.073
	(0.484)	(0.652)	(0.052)	(0.180)	(0.000)	(0.000)	(0.075)	(0.388)	(0.067)	(0.554)
PT_High#lnRD		0.202***		-0.020		0.035		0.088**		0.079
		(0.000)		(0.659)		(0.460)		(0.018)		(0.463)
TM_High#lnRD		0.040		0.088*		0.022		-0.002		0.185
		(0.382)		(0.070)		(0.667)		(0.956)		(0.109)
lnEmployees	0.033	0.000	0.004	0.012	-0.064*	-0.019	-0.032	-0.028	0.021	0.046
	(0.311)	(0.991)	(0.918)	(0.707)	(0.088)	(0.563)	(0.265)	(0.274)	(0.798)	(0.531)
lnSales	0.048***	0.043***	-0.012	-0.010	-0.039**	-0.021	0.013	0.017	0.030	0.043
	(0.005)	(0.008)	(0.500)	(0.578)	(0.049)	(0.242)	(0.396)	(0.227)	(0.494)	(0.296)
lnCapital_Int	0.055	-0.080	0.053	0.078	-0.322*	-0.157	-0.127	-0.118	-0.104	-0.029
	(0.706)	(0.558)	(0.736)	(0.596)	(0.060)	(0.308)	(0.326)	(0.329)	(0.782)	(0.935)
Constant	-20.943	21.257	-59.366*	-24.274	-156.265***	-89.290***	-35.924	-5.799	-172.874**	-53.282
	(0.499)	(0.436)	(0.074)	(0.407)	(0.000)	(0.004)	(0.189)	(0.810)	(0.029)	(0.446)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F-test of joint sig of all IVs	46.31		46.31		46.31		46.31		46.31	
(P-value)	(0.000)		(0.000)		(0.000)		(0.000)		(0.000)	
Sargan/Hansen test [chi-sq]	9.11		40.49		32.98		6.61		8.14	
(P-value)	(0.105)		(0.000)		(0.000)		(0.251)		(0.149)	
Observations	2,227	2,227	2,227	2,227	2,227	2,227	2,227	2,227	2,227	2,227
Number of companies	404	404	404	404	404	404	404	404	404	404

Robust pval in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notes. The following variables are used as IVs: (1) the effect of the financial crisis captured by Time trend X lnSales; and (2) the country-level variation in the average level of R&D expenditures.

Table 8: 2SLS fixed-effects models with IP positions: The 2nd stage; by the type of standards organizations

4.2.5 Policy change: An analysis of patent boxes

The instrumental variable models presented above elucidate that the effect of R&D on standards organization memberships is particularly strong for firms with larger patent portfolios. Nevertheless, 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 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 in order to protect the firm's knowledge assets against unintentional spillovers.

In order to further assess the mechanisms underlying 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. First, a patent box regime makes patent ownership more attractive, and thus induces firms to file an increased number of patent applications, or acquire patents from other firms not benefiting from the patent box. Second, 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 affected firms. Naturally, this effect should increase in the extent to which a 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. Nevertheless, 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, nevertheless, acknowledge that other firms may also be impacted, either because they already hold patents in this country, or because they may relocate patents from other jurisdictions (Ciaramella, 2017). For greater robustness, we thus 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 having introduced patent box regimes between 1973 and 2015. We first 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, as we wish to reliably attribute the empirical results to patents.[18] We are left with eight patent box regimes introduced between 2000 and 2014, which affect 92 firms in *Industry sample 1.* Just under half of these firms (41) are from China, with the remainder from Europe (Table 9).

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 9: Patent box regimes in different countries

We estimate the effect of patent box introduction in a fixed-effects setting over a panel spanning cross a longer period of time than our 5 years sample period. We subsequently interact the dummy variable indicating a patent box being introduced with time-invariant firm-level variables (namely average R&D expenditures and patent/trademark counts averaged over 5 years or IP dummies). We continue to control for year dummies and regional trends. The results are displayed in Table 10. We find a statistically significantly

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

positive effect of patent box introduction on standards organization membership counts. This effect increases in the number of patents owned by the firm, but decreases in the number of trademarks (Model 5). Using IP dummies rather than counts, we find that the effect of patent box introduction is stronger for patent-intensive firms (Models 6 and 8). In terms of 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	Model 6	Model 7	Model 8
box_active	0.228***	0.186**	0.232***	0.186**	0.259***	-0.152*	0.109	-0.126
	(0.003)	(0.024)	(0.006)	(0.024)	(0.002)	(0.097)	(0.256)	(0.209)
box#av_RD		0.000	-0.000*	0.000	-0.000	-0.000	0.000	-0.000
		(0.140)	(0.057)	(0.320)	(0.108)	(0.962)	(0.188)	(0.990)
box#av_PT			0.001***		0.001***			
			(0.001)		(0.000)			
box#av_TM				0.000	-0.009**			
				(0.983)	(0.030)			
box#PT_High						1.002***		1.023***
						(0.000)		(0.000)
box#TM_High							0.181	-0.079
							(0.123)	(0.516)
Constant	-33.318**	-31.459*	-38.583**	-31.460*	-41.631**	-9.348	-25.527	-11.466
	(0.044)	(0.058)	(0.021)	(0.058)	(0.013)	(0.577)	(0.134)	(0.502)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.459	0.459	0.460	0.459	0.460	0.464	0.459	0.464
Observations	8,483	8,483	8,483	8,483	8,483	8,483	8,483	8,483
Number of companies	499	499	499	499	499	499	499	499

Robust pval in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 10: Fixed-effects models with average IP counts/IP positions: Patent box

As in the previous section, we distinguish between the effect of a patent box on membership counts in the 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 most robust estimation of the effect of the patent box. The results are displayed in Table 11. The introduction of a patent box has a positive effect on memberships of affected firms with a sufficiently large number of patents in standards developing organizations (Model 1), as well as organizations with standards subject to declared SEPs (Model 7). There is no significant effect on memberships in the much larger sample of standards organizations without standards subject to SEPs (Model 9), organizations promoting but not developing standards (Model 3), or organizations participating in standard developing in an otherwise ancillary role (Model 5). The differentiation by type of standards organization thus further corroborates the patent box analysis. As expected, the effect of the patent box is most pronounced for firms with larger numbers of patents, but only with respect to standards organizations developing standards potentially subject to declared SEPs. In line with the results of our baseline model, the effect of patents also seems to be to increase the effect of R&D on memberships in standards organizations. Again it is worth noting that such amplification effect of patents on the R&D-participation relationship seems to be only salient in the case of those organizations developing standards (Model 2) and/or those associated with SEPs (Model 8).

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
	Standards developer		Promoter		Other		SEP		No SEP	
box_active	-0.221***	-0.082	0.054	-0.017	0.226***	0.217	-0.026	0.243**	0.052	-0.172
	(0.006)	(0.545)	(0.501)	(0.900)	(0.007)	(0.125)	(0.701)	(0.031)	(0.793)	(0.611)
box#av_RD	-0.001**	-0.002*	-0.000	0.000	-0.000	0.000	-0.001***	-0.003***	-0.000	0.002
	(0.011)	(0.051)	(0.113)	(0.855)	(0.213)	(0.990)	(0.002)	(0.001)	(0.408)	(0.504)
box#av_PT	0.002**	0.000	0.000	0.001	-0.001	-0.000	0.002***	-0.001	-0.000	0.002
	(0.048)	(0.976)	(0.931)	(0.618)	(0.609)	(0.861)	(0.005)	(0.472)	(0.899)	(0.555)
box#av_TM	0.009**	0.014**	0.010***	0.016**	-0.006	-0.009	-0.006*	-0.010**	0.002	0.005
	(0.017)	(0.026)	(0.009)	(0.010)	(0.159)	(0.147)	(0.093)	(0.046)	(0.824)	(0.722)
box#av_RD#av_PT		0.000*		-0.000		-0.000		0.000***		-0.000
		(0.090)		(0.742)		(0.743)		(0.005)		(0.419)
box#av_RD#av_TM		-0.000		-0.000		0.000		0.000		-0.000
		(0.385)		(0.253)		(0.482)		(0.213)		(0.770)
Constant	28.043*	27.364*	16.786	16.974	18.925	19.038	11.871	10.827	21.782	22.669
	(0.066)	(0.072)	(0.271)	(0.266)	(0.233)	(0.231)	(0.351)	(0.394)	(0.568)	(0.552)
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	0.095	0.097	0.030	0.031	0.023	0.023	0.037	0.041	0.052	0.052
Observations	2,436	2,436	2,436	2,436	2,436	2,436	2,436	2,436	2,436	2,436
Number of companies	406	406	406	406	406	406	406	406	406	406

Robust pval in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 11: Fixed-effects models with average IP counts/IP positions: Patent box; by the type of standards organizations

5 Discussion

In this paper, we advance the understanding of the motivations for partaking in open standards development by focusing on the role of R&D expenditures, patents and product-market position. We document a remarkably significant and positive impact of firms' investment in R&D on membership in various types of standards organizations. This finding has implications for the economic analysis of technological innovation. Acemoglu et al. (2012) discuss a theoretical model in which standardization competes with the development of new technologies for scarce R&D resources. In light of our findings, we believe that it would be important to explore models of innovation in which the development of new technologies and standardization are strategic complements rather than substitutes.

Our results contrast with earlier studies, which find either little empirical support for a firm-level correlation between R&D and participation in standards organizations (Meeus et al., 2002; Blind, 2004; Blind and Thumm, 2004; Rauber, 2014), or a positive correlation only at lower levels of R&D expenditures (Blind, 2006). This discrepancy may be attributed to sample construction, empirical methodologies used as well as the heterogeneity of standards organizations. In particular, our larger sample of standards organizations allows us to, for the first time, quantify the extent of standardization participation among large players which are mostly involved in developing standards. Furthermore, our sample consists in international standards organizations in the ICT context. These organizations are more likely to draw the participation of large R&D-intensive corporations than for instance National Standards Bodies (NSB).[19]

Within our sample, the positive association between R&D and standards organization membership counts is highly robust across industries and types of standards organizations. Furthermore, our instrumental variable estimations suggest that membership in standards organizations is caused by R&D expenditures, or by exogenous factors that also lead to increases in R&D. This positive effect is, however, contingent upon the existence of appropriation mechanisms, which allow the firm to reap a return to their participation in collaborative standard development. Consistent with qualitative research (Baron et al., 2018) and practitioner characterizations of the relevant stakeholder constituencies in standard development, we document *patent*- and *product*-centric appropriation strategies.

The most robustly significant R&D appropriation mechanism in our analysis is patent protection. This finding contrasts with policy discussions that emphasize conflicts and tensions at the interface between patent and standardization systems. The relevance of patent protection for firm participation in standards organizations concentrates in the organizations that set and develop their own standards, as opposed to promotion, certification, or other ancillary groups. More specifically, the positive effect of patents can be attributed to a relatively small number of organizations that develop standards subject to declared SEPs, whereas patents do not play a role for participation in organizations not associated with SEPs. This finding suggests that the additional incentives provided by patent protection to participate in standards organization can primarily be attributed to the value that patent holders derive from having their patented technologies included into technology standards (Rysman and Simcoe, 2008; Hussinger and Schwiebacher, 2015; Pohlmann et al., 2016). The results of our analyses using exogenous changes in the tax treatment of patent revenue suggest that our findings have a causal interpretation. This implies that policies with the effect of strengthening (weakening) patent protection would result in increased (reduced) participation of R&D-intensive firms in collaborative standard development, at least within the sample of standards organizations with SEPs. Despite the small number of standards organizations with declared SEPs, these organizations account for a very significant share of the commercial and technological relevance of ICT standards development.

Moreover, our findings underscore that the firm's R&D effort is reinforced not only by patented technologies, but also by complementary downstream capabilities. Our results do not corroborate the hypothesis that technology firms with a leading product-market position prefer to market their products without the reliance on formal standardization. The product-market position provides incentives for R&D-intensive firms to participate in standards organizations where patents do not provide strong incentives - organizations *promoting* standards developed elsewhere, as well as standards organizations not related to SEPs. Empirically, we use trademark intensity, as well as measures of brand value and counts of standard-compliant product models to capture a firm's product-market position. Our analysis suggests that brand value and product counts provide additional channels whereby firms can appropriate value of their R&D investments in collaboratively

[19] The difference between these standardization environments has sometimes been characterized as a difference between R&D-intensive standard *development*, and traditional standard *setting*.

developing standards. There is also some evidence of potential substitution between a strong trademark position and offering standards-compliant products, and between a strong patent position and brand value, in determining standards organization membership of R&D-intensive firms. A finding worth further investigation.

Our findings hence 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 an additional appropriation mechanism, alongside patent protection, that allows firms to profit from their R&D efforts and appropriate the value of innovation (Teece, 1986; Pisano, 2006).

Finally, despite our sample consisting in large firms, our results suggest disparate patterns of participation contingent on the size of firms. That is, firm size (in terms of net sales) positively correlates with the extent of participating in organizations that develop standards instead of those promoting standards or other ancillary organizations. This observation adds to earlier findings regarding the nexus between size and collaborative innovation (e.g., in joining strategic alliances or standards organizations) - see Leiponen (2008) and Audretsch and Feldman (2004). For instance, Leiponen (2008) points to more limited benefits enjoyed by small firms from cooperation networks. Our results suggest that the size effect may depend on the type of standards organizations.

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 180 ICT-related standards organizations.

We find robust evidence for a strategic complementarity between R&D and standards organization membership. The effect of R&D on standards organization membership counts increases in the size of the firm's patent and trademark portfolios. While we corroborate a causal interpretation of the effect of patents using preferential tax treatment of patent revenue as exogenous source of variation, we argue that trademarks capture a salient dimension of a firm's product-market position. Similar to patents, a strong product-market position (as measured, for instance, by the firm's brand value or number of end product models) provides incentives for R&D-intensive firms to join standards organizations. Nevertheless, patents and product-market position are observed to provide differing incentives to join distinct types of standards organizations.

Our results have important implications for business strategy, innovation research, and standardization policy. Most notably, our findings highlight the role of the patent system for the functioning of standard 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 have a positive effect on firm participation in standards organizations.

Our analysis of distinct types of standards organizations allows a finer-grained understanding of the diverse roles of patents. We find that patents induce participation in standards organizations mainly because participation in standards development may allow the firm to increase the returns to its patents, and not so much because patents protect against the risk of unintended spillover of technology to other participants of the standardization processes.

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 standard 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 expect interactions 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 only exist 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 treated as time-invariant in our empirical analysis, which does not consider the dynamic effects of IP on developing standards. Lastly, future research could consider more detailed contribution from firms to standards development or identify the performance or innovation outcome of participation in collaborative standards development, all of which are still not well understood.

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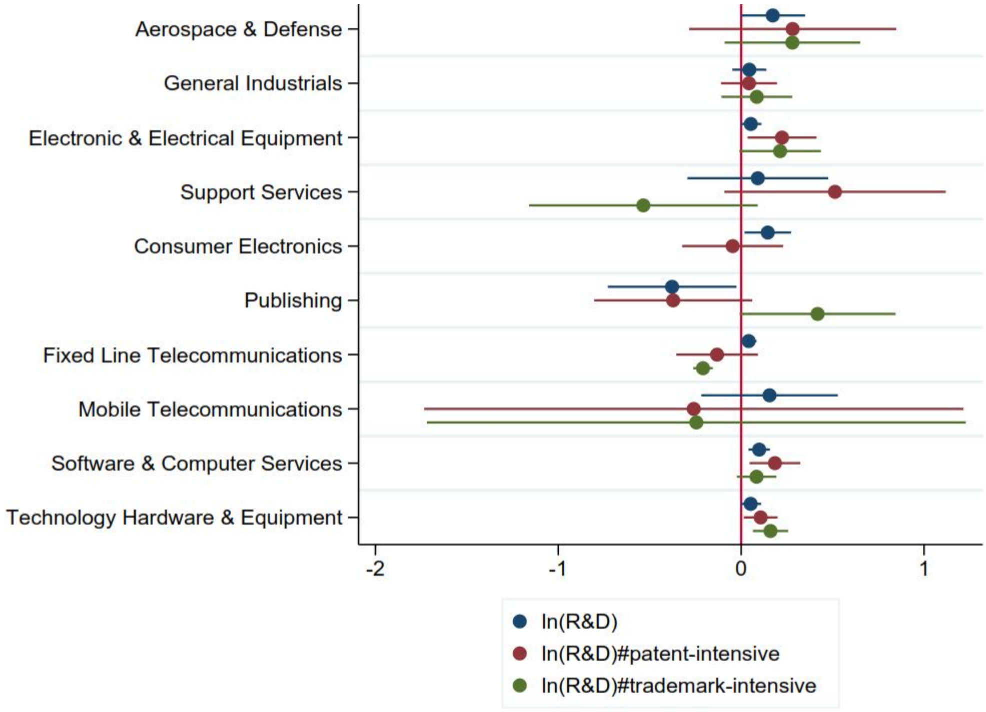
Appendix

	Trademark low	Trademark high
Patent low	AT&T Inc.; Siemens AG; Vodafone Group plc	Cisco Systems, Inc.; Deutsche Telekom AG; The Emerson Electric Company; VTech
Patent high	Canon Inc.; Ericsson; Lenovo Group Ltd.; ZTE Corporation; Seiko Holdings Corporation; Intel Corporation; Foxconn Technology Group; Hitachi, Ltd.; The Hewlett-Packard Company; Mitsubishi Motors Corporation	Apple Inc.; Fujifilm Holdings Corporation; HTC Corporation; Qualcomm Incorporated; Nikon Corporation; LG Electronics Inc.; Samsung Group; Sony Corporation; Huawei Technologies Co., Ltd.

Table 12: Examples of sample firms based on their patent and trademark intensities

Figure 2: Coefficients for R&D and R&D-IP interactions:
An industry breakdown (*Industry sample 2*)



Notes. The Broadcasting & Entertainment industry dropped from the estimation, as well as the ln(R&D) X trademark estimate dropped for the Consumer Electronics industry due to collinearity issues.

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5
lnRD	0.072***	0.050***	0.041***	0.029**	0.031**
	(0.000)	(0.002)	(0.006)	(0.041)	(0.023)
PT_High#lnRD		0.136***		0.113***	0.091*
		(0.000)		(0.004)	(0.064)
TM_High#lnRD			0.119***	0.094**	0.083*
			(0.002)	(0.011)	(0.060)
PT_High#TM_High#lnRD					0.038
					(0.614)
lnEmployees	0.048**	0.035	0.024	0.018	0.020
	(0.037)	(0.128)	(0.256)	(0.407)	(0.339)
lnSales	0.042**	0.037*	0.033*	0.031*	0.031*
	(0.041)	(0.054)	(0.081)	(0.095)	(0.091)
lnCapital_Int	0.121	0.053	0.023	-0.013	-0.008
	(0.176)	(0.549)	(0.788)	(0.882)	(0.929)
Constant	-16.706	-5.100	6.441	11.204	10.586
	(0.409)	(0.796)	(0.743)	(0.555)	(0.576)
Year dummies	Yes	Yes	Yes	Yes	Yes
Regional trends	Yes	Yes	Yes	Yes	Yes
R-squared	0.075	0.085	0.084	0.090	0.091
Observations	3,622	3,622	3,622	3,622	3,622
Number of companies	655	655	655	655	655

Robust pval in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 13: Fixed-effects models with IP positions
(*Industry sample 2*)

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5
lnRD	0.041**	0.020	0.021	0.013	0.014
	(0.020)	(0.199)	(0.211)	(0.413)	(0.369)
PT_High#lnRD		0.128***		0.089*	0.079
		(0.007)		(0.080)	(0.266)
TM_High#lnRD			0.122***	0.080*	0.072
			(0.004)	(0.079)	(0.157)
PT_High#TM_High#lnRD					0.022
					(0.829)
lnEmployees	0.064**	0.045*	0.047*	0.040	0.040
	(0.015)	(0.089)	(0.064)	(0.129)	(0.111)
lnSales	0.034**	0.028**	0.026**	0.025**	0.025**
	(0.014)	(0.019)	(0.030)	(0.033)	(0.033)
lnCapital_Int	0.174*	0.088	0.097	0.063	0.065
	(0.069)	(0.361)	(0.321)	(0.521)	(0.500)
Constant	0.428*	0.419*	0.440**	0.429**	0.434**
	(0.060)	(0.057)	(0.041)	(0.046)	(0.049)
Year dummies	Yes	Yes	Yes	Yes	Yes
Regional trends	No	No	No	No	No
R-squared	0.083	0.092	0.091	0.095	0.095
Observations	2,233	2,233	2,233	2,233	2,233
Number of companies	405	405	405	405	405

Robust pval in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 14: Fixed-effects models with IP positions and no regional trends (*Industry sample 1*)

Independent variables	DV: ln(R&D) expenditures
y2010#lnSales	-0.016
	(0.135)
y2011#lnSales	-0.030***
	(0.009)
y2012#lnSales	-0.029**
	(0.013)
y2013#lnSales	-0.056***
	(0.000)
y2014#lnSales	-0.052***
	(0.000)
Avg_lnRD_ctry	0.548***
	(0.000)
lnEmployees	0.387***
	(0.000)
lnSales	0.180***
	(0.000)
lnCapital_Int	1.415***
	(0.000)
Constant	157.595***
	(0.000)
Year dummies	Yes
Regional trends	Yes
R-squared	0.583
F-test of joint sig of all IVs	46.31
Observations	2,227
Number of companies	404

Robust pval in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes. The following variables are used as IVs: (1) the effect of the financial crisis captured by Time trend X lnSales; and (2) the country-level variation in the average level of R&D expenditures.

Table 15: 2SLS fixed-effects model: The 1st stage; determinants of R&D expenditures