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Why Do R&D-Intensive Firms Participate in Standards Organizations? The Role of Patents and Product-Market Position

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Abstract

This paper examines the determinants of participation of R&D-intensive firms in standards development. Using data on R&D spending, patent, and trademark activities of the world's largest corporate R&D investors and their membership of standards organizations, we find a highly robust positive association between a firm's R&D spending and its participation in standards development. However, the causal effect of R&D spending on membership of standards organizations is conditional upon the firm's patent and/or product-market position, and varies across different types of standards organizations. More specifically, a strong patent position amplifies the effect of R&D spending on participation in standards-developing organizations, while a strong product-market position strengthens the impact of R&D spending on participation in the organizations that promote established standards. Finally, we also show that policy changes that increase the value of patents, such as variations in the preferential tax treatment of patent-related revenue, induce R&D-intensive firms to intensify their participation in standards organizations.

JEL classification: L24, O34
Keywords: standards organizations, R&D expenditure, patents, trademarks

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1 Introduction

Open technology standards play an increasingly important role in the information and communication technology (ICT) industry. Many promising technologies currently under development, including the 5^{th} generation of wireless communication technologies, the internet of things, and artificial intelligence, require a high degree of interoperability to fulfill their inherent potential, thereby necessitating open and high-quality technology standards. Designing these open standards is a formidable task for the industry, and demands participants to devote a significant amount of R&D resources to the development of the technical contributions on which those standards will be based.

To appropriate a return on their R&D investment, firms contributing to the development of open standards often rely on formal intellectual property rights (IPR). However, this appropriation regime may create a significant tension between the goal of standards organizations to develop open standards available for general use, and the inclusion of proprietary technologies subject to exclusive rights such as patents (Farrell et al., 2007; Lerner and Tirole, 2015). Given this tension, it might be preferable to develop open technology standards in a different appropriation regime, where firms are motivated to contribute the outcome of their R&D effort by the prospect of using those standards in new products. In fact, several important technology standards were developed under a royalty-free licensing regime, with standardization relying entirely on the incentives of users of standardized technologies to provide the required R&D effort.[1]

This strategic choice raises an important question: what are the (distinct) roles of patent-based and product-based appropriation strategies in motivating innovating firms to contribute their R&D resources to standards development? Despite the significance of this issue to policy making and business strategy, there is a surprising dearth of reliable evidence about how a firm's patent and product-market positions influence its participation in the development of open standards.

Firms may simultaneously decide on the levels of R&D spending, participation in standards development, and investment in patents or product-market position. It is thus crucial to understand the interdependencies and strategic interplay among these decisions. For instance, does a firm's participation in standards development increase in its R&D effort; or does participation in open standardization (and the appurtenant access to other firms' R&D contributions) become less valuable to a firm heavily investing in internal R&D capacity?[2] The role of patents as a means of appropriation is also theoretically ambiguous. On the one hand, R&D activities and participation in standards development may be more

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

[2] Acemoglu et al. (2012) develop a model in which R&D efforts and standardization compete for scarce resources in the firm.

complementary for firms relying mainly on patents to secure their investment because patents reduce the risk that participation in an open process would result in unintended technology spillovers. On the other hand, recognizing the restrictions that standardization places on the licensing and enforcement of patents, firms that depend on patents may be less inclined to participate in standards development when their R&D efforts increase.

If the reliance on patents reduces the complementarity between R&D activities and participation in standards development, R&D-intensive firms may choose either to shift to a different appropriation regime while still continuing to participate in standards development, or to limit their participation in order to retain a greater degree of control over the development and commercialization of their technologies. The existing literature on platforms and innovation networks points to an array of strategies that allow a firm to elicit contributions from other firms to further the development of its technology while retaining exclusive control over key proprietary assets (Boudreau, 2010; Laursen and Salter, 2014; Wen et al., 2015; Alexy et al., 2018).[3] If, to the contrary, patents increase the complementarity between R&D activities and participation in the development of open standards, R&D-intensive firms may have to decide between the business models characterized by high levels of patenting and participation in open standards development (e.g., Ericsson or Qualcomm), and the models of collaborative technology development that draw less extensively on either of these strategies (e.g., Google and its Android OS).

It is equally important to consider the product-based incentives and how these condition the interplay between R&D activities and participation in standards development. For example, a negative effect of the product-market position on this interplay could rationalize the decisions of firms that heavily invest in R&D and contribute to open standards development, to reduce or even divest their product-market activities (e.g., Nokia and Philips). Such an effect would also be in line with the strategies of some R&D-intensive firms who, while being leaders in product markets, choose to limit their participation in the development of open standards (e.g., Apple). Nevertheless, there are also firms that make a significant investment in R&D directed at the development of open standards, albeit their own R&D activities seem to be primarily motivated by product-market considerations (e.g., Cisco, Huawei, and Samsung). Even among patent-intensive firms whose main comparative advantage consists in their ability to provide technological solutions for open technology standards, the product-market position can be used as an important means of appropriating a return on the firms' R&D contribution to open standards development.[4]

[3]IBM and Intel are examples of this type of platform leadership; see Wen et al. (2015) for the former, and Gawer and Henderson (2007) for the latter.

[4]A recent illustration of this important role is the settlement between Apple and Qualcomm, involving an agreement on chip supply as well as patent licenses. Qualcomm's product market position in the chip business was thus a strategic factor allowing Qualcomm to monetize its contributions to the development of 5G wireless communication standards.

Unpacking these strategic interdependencies is, therefore, important for informing managerial decisions pertaining to business models. It can additionally help us move beyond those anecdotal comparisons, and meaningfully inform important policy debates. In particular, depending on the respective roles of patent and product-market incentives, policy choices that strengthen or weaken patents in comparison with other appropriation strategies may increase or decrease R&D-intensive firms' incentives to participate in the development of open standards.

In this study, we empirically investigate how the interrelation between a firm's R&D spending and its participation in standards development depends on the strengths of the firm's patent and product-market positions. To do so, we utilize a longitudinal database on the membership of 191 standards organizations (Baron and Spulber, 2018). The great number of standards organizations covered by our data allows us to identify meaningful variations in the degree of participation even among large and R&D-intensive firms, most of which participate in standards development to some extent. Furthermore, the rich set of standards organizations allows us to identify the distinct motives for participation in different types of standards organizations. The functions of standards organizations vary and encompass such areas as the preparation of technical standards or technical specifications (published as or incorporated into other organizations' standards); the coordination of R&D activities towards the definition of future standards; the resolution of commercial or policy conflicts arising in standards development; the promotion of fully developed standards; as well as the certification of compliance of products or services with established standards. Therefore, we distinguish between organizations that develop and publish technical standards, and organizations that promote technology standards or act in a variety of other ways (such as certification). Our distinction is akin to that between technically oriented and marketing-oriented consortia used by Delcamp and Leiponen (2014). Previous research has largely been concerned with standards-developing (*upstream*) organizations, whereas little attention has been paid to the role of (*downstream*) organizations that certify newly developed standards and promote their implementation. We argue that downstream standards organizations serve as a necessary bridge between the development of technical standard specifications and the effective standardization through industry coordination on a single standard.

We reveal a highly robust association between a firm's R&D spending and its participation in standards development, which increases in both the firm's patent intensity and the strength of its product-market position.[5] However, we find that only patent intensity increases the positive causal effect of the firm's R&D spending on its membership counts.

[5]We initially use trademarks as an indicator of the firm's product-market position, but also find that alternative measures (such as brand value and the number of products that comply with a standard) similarly strengthen the association between R&D spending and participation in standards development.

In the absence of a strong patent position, the intensity of the firm's R&D expenditure exhibits a negative effect on its participation in standards organizations. Finally, we also show that product- and patent-based appropriation strategies have an association with membership of different types of standards organizations: firms with higher R&D spending expand their membership of standards-developing organizations if their patent position is stronger, whereas a stronger product-market position motivates those firms to expand their membership of standards-promoting organizations.

The positive effect of patent protection on the strategic complementarity between a firm's R&D spending and its participation in the development of open standards has important policy implications. We particularly predict that a policy change resulting in an increased profitability of patents would be associated with increased participation of R&D-intensive firms in standards development. We confirm this prediction by studying the effect of preferential tax treatment of patent revenue (commonly known as "patent boxes"). In turn, product-market factors can motivate R&D-intensive firms to participate in standards organizations that offer no patent-related incentives, although this effect is limited to standards-promoting organizations. Therefore, our findings also shed light on the modularity of standards development – that is, different firms participate in different parts of the standards ecosystem, depending on the strengths of their patent and product-market positions (see Simcoe, 2015).

The remainder of the paper is organized as follows. Section 2 provides an overview of the related literature. Section 3 describes the data sources and the firm sample utilized in the empirical analysis. Section 4 presents our econometric strategies and results, alongside a set of robustness checks. Section 5 concludes with study implications and limitations.

2 Related literature

Research on the decision of a firm to participate in a standards organization often looks at this decision as a choice between different organizations providing alternative venues for standardization (Lerner and Tirole, 2006; Chiao et al., 2007; Lerner and Tirole, 2015). This so-called *forum shopping* literature emphasizes the role that the patent policy adopted in standards organizations plays in the venue choice of patent-intensive firms. While some studies analyze the interplay between memberships of different standards organizations (Leiponen, 2008; Bar and Leiponen, 2014; Baron et al., 2014), there is a lack of causal evidence regarding the firm-level determinants of the *extent* of such participation.

A smaller number of studies focus particularly on firm-level determinants of participation in standards development. Although these studies have looked at such factors as R&D spending and patenting, they offer no causal evidence drawing on exogenous variation; they also tend to use binary measures of participation derived from surveys or the membership data of a single organization. These measures are informative about the participation decisions of smaller or peripheral firms, but are of more limited use for analyzing the participation decision of large R&D-intensive firms.

2.1 The role of R&D expenditure

There are two competing hypotheses regarding the impact of R&D expenditure on a firm's decision to participate in the development of standards. On the one hand, participation in standards development offers a variety of benefits to firms investing heavily in R&D. In particular, participation in standards development may help firms to coordinate their R&D efforts with other participants (Baron et al., 2014; Delcamp and Leiponen, 2014), and may also reduce the risk that is inherent to R&D (Aggarwal et al., 2011). For instance, Fleming and Waguespack (2009)'s work suggests that small firms and start-ups especially benefit from participation in standards development primarily by learning about other firms' technological advances.[6] On the other hand, participation in standards development may entail a risk of knowledge leakage to competitors (Blind and Thumm, 2004).

Empirical studies – limited by the absence of causal identification – have produced mixed evidence regarding the role of R&D in firm participation in standards development. Blind and Thumm (2004) analyze 149 European firms and find no statistically significant relationship between R&D intensity and the likelihood of participation. Similar results were obtained for German (Blind, 2004; Rauber, 2014) and Dutch (Meeus et al., 2002) firms. Blind (2006) finds an inverted-U shaped relationship between R&D intensity and the firm's decision to participate in standards development, arguing that meaningful participation requires the firm to have enough capacity to process and internalize the discussed knowledge, while leading R&D performers may limit their involvement in standards development because of the risk of knowledge leakage.

2.2 The role of patents

As noted earlier, the risk of technology leakages may deter R&D-intensive firms from participating in the development of open standards. Patents tend to reduce this risk: so, when firms have a strong patent position, it should be less likely that an increase in their R&D effort reduces the extent of such participation (Blind and Thumm, 2004).

In addition to the role of patents in protecting against unintended knowledge spillovers, participation in standards development may be an opportunity for firms to lobby for their

[6] Blind and Mangelsdorf (2016) find that a firm's R&D intensity is positively associated with seeking new knowledge or attempting to facilitate market access as motives for participation in standards development.

patents to be included in a standard as SEP (Prufer and Larrain, 2018).[7] The value of participation in standards development is thus more likely to increase in R&D efforts for firms relying on patents. Inclusion of a patented technology into a standard may significantly increase its value (Rysman and Simcoe, 2008) and thereby 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 firms relying on patents to reap a return on R&D efforts to actively participate in standards development in order to increase the chances that their patented technology is included in the standard. Bekkers et al. (2011) show that the extent to which a firm participates in the development of standards is an important predictor of the likelihood of its patents being declared essential for a technology standard.[8]

At the same time, membership of standards organizations can impose significant costs on firms with valuable patents. More specifically, standards organizations can oblige their members to make SEPs available to standards users on specified licensing terms. In most cases, they require the owners of potential SEPs to commit to making licenses available on fair, reasonable and non-discriminatory (FRAND) terms. Layne-Farrar et al. (2014) argue that a firm owning a potentially standard-essential technology may choose to stay out of standards organizations that stipulate strict licensing requirements, just so that it is free to offer licenses to standards implementers on unconstrained terms.

Empirical evidence on the firm-level correlation between patenting and participation in standards development is inconclusive. Blind and Thumm (2004) find that firms strongly relying on patents to protect the outcomes of their R&D activities are less inclined to participate in standards development. In contrast, Gandal et al. (2004) reveal a positive correlation between patenting and participation in standards committees (as measured by meeting attendance) in the modem industry, but find that it is committee participation that precedes increases in patenting, while patenting is not a significant predictor of committee participation.

Survey-based evidence indicates that there is a complementarity between patenting and contributing to open standards. Fischer and Henkel (2013) survey low- to high-level managers of a communications equipment firm to investigate the interactions between different strategies to appropriate benefits from technological innovation. The survey

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

[8]Kang and Motohashi (2015) observe a similar pattern at the inventor level: there are more chances of a patent being declared standard-essential if the technology inventor regularly attends meetings of standards organizations. Berger et al. (2012) note that a large number of patent applications resulting in declared SEPs undergo amendments that seem to be specifically designed to ensure that these patents' claims correspond with the standard specification. Firms participating in standards development may thus obtain information on the progress of the standard to tailor their strategies for acquiring IPR.

respondents identify patenting and contribution to open standards as mostly complementary strategies. While the benefits of patent protection initially increase as the firm contributes to open standards, the effect becomes insignificant or even negative at higher levels of patenting and contribution.

2.3 The role of the product-market position

While there is some research on firm-level determinants of participation in standards development, there is a scarcity of evidence regarding the role of product-market incentives. Nevertheless, product-market incentives seem to play an important role for the participation decision of a large number of firms. 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 standards development. Similarly, Spulber (2013) emphasizes the existence of both product- and patent-related incentives for participation in standards development, and argues that coordination between inventors and producers is a crucial function of standards organizations.[9] A firm's product-market position is likely to have a significant direct effect on the firm's decision to participate in standards development: for example, participation allows the firm to learn about new technologies, as well as advocate standardization decisions benefiting its products and production processes. Prufer and Larrain (2018) develop a theoretical model, in which patent-owning contributors join standards organizations to increase the chance of their technology being selected for a standard, whereas implementers join standards organizations to benefit from knowledge spillovers arising in standards development.

Along with directly influencing the incentives to participate in standards organizations, a firm's product-market position is likely to have a conditioning effect on the relationship between R&D expenditure and participation in standards development. Internet standards published by the World Wide Web Consortium (W3C), the Bluetooth Wireless communication standard, or the USB standard for connections between computers and peripheral devices are just some prominent examples of standards developed under policies requiring that all essential IPR are licensed royalty-free to standards implementers. While firms contributing costly R&D to the development of these standards must recoup their investment entirely in the market for standards-related products or services, product-market incentives in most standards organizations coexist with the incentives provided by patents. There is little empirical evidence on the relative importance of product- and patent-based

[9] Teece and Sherry (2003) point to the important implications of the interplay between these different types of firms for the governance of standards organizations and the antitrust approach to standardization. Contreras (2013) presents a case study highlighting the opposing interests of *product*- and *patent*-centric firms regarding a patent policy change in a standards organization.

incentives for standards-related collaborative R&D, and the interactions between these appropriability mechanisms.[10]

Nevertheless, outside the field of standards development, there are salient examples of collaborative technology development processes in which the decision to participate in collaborative forms of R&D is primarily driven by product-market incentives (Fosfuri et al., 2008; Ceccagnoli et al., 2012; Huang et al., 2013). Most comparable to our study, 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 by independent software vendors. Studying the role of product-market incentives for participation decisions in fields such as genomics and open source software, Pisano (2006) refer to an ”IP Revolution” and a change in the prevailing R&D *appropriation regime* (de-emphasizing the role of patents).

3 Data and measures

3.1 An overview of the main data sources

3.1.1 The data on membership of standards organizations

We obtain information about membership of standards organizations from the Searle Center Database on Technology Standards and Standard Setting Organizations (see Baron and Spulber, 2018). This database contains membership data for 191 standards organizations, including formal standards-developing organizations, informal consortia, and organizations that participate in standards development in a variety of ancillary roles (e.g., coordination, certification, or advocacy).[11] It particularly focuses on the organizations that operate in the ICT sector, with yearly observations covering the period 1997-2015.

The standards organizations in the Searle Center database are membership-based. Depending on the organization, membership can be open to individuals or other organizations – firms, universities, public administrations, trade associations, and standards bodies.[12] The Searle Center database contains membership of standards organizations with organizational membership. The majority of member entries in the database are commercial firms. The standards organizations in this database are also *open*, meaning

[10]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.

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

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

that any organization complying with the general criteria for membership and agreeing to abide by the organization's policies can become a member.

Although membership is often not required for participation in standards development, members are often given additional rights, such as the right to participate in elections of the organization's leadership, and the right to participate in defining the rules and policies of the organization. Most standards organizations charge a membership fee, which can vary with the size of the participating organization and the tier of membership.[13] Furthermore, there is usually a membership agreement that may define, *inter alia*, obligations concerning the disclosure of potential SEPs and the requirement to make licenses for SEPs available to standards implementers. Firms thus have to choose carefully which standards organizations they join. The firm with the largest number of membership records in the Searle Center database is IBM Corporation – it is listed as a member of 112 standards organizations.

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

The information on firms' innovation outcomes and other characteristics is extracted from two waves of the OECD Database on the IP Bundles of the World's Top R&D Investors (see Dernis et al., 2015; Daiko et al., 2017). This database contains annual statistics on the patent and trademark activities of the world's top 2,000 corporate R&D performers, including their subsidiaries, for the period between 2010 and 2014. The selection of firms to add to the OECD database is guided by the EU Industrial R&D Investment Scoreboard (see Guevara et al., 2015), which also serves as the source of economic and financial data. The intellectual property (IP) statistics is derived from the five major IP offices (IP5), located in Europe, the United States, Japan, South Korea, and China. To avoid double counting of patent applications filed at different IP offices, the patent data in each of the waves is further consolidated in "[families] of patent applications with members filed at least in one of the IP5, excluding single filings" (Dernis et al., 2015, p.20). Overall, the firms included in the OECD database own 66% of all IP5 patent families; trademark ownership is more dispersed, with about 8% of all applications being filed in the European Union, the United States, Japan, and Australia (Dernis et al., 2015).

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

[13] Many standards organizations offer different *tiers* of membership, where higher tiers are associated with higher fees and additional rights. The database does not include information on the membership tier, but excludes entities that are merely listed as observers.

3.2 Sample construction

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

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

Using the Database of Declared SEPs (see Baron and Pohlmann, 2018), we find that out of 144,521 declared SEPs, 124,846 patents (86.4%) belong to the firms included in both waves of the OECD database. In particular, this database contains 36 of the 50 entities with the highest number of declared SEPs.[14] We further draw on two databases of certified standard implementations to calculate the number of standards-compliant products each firm offers.[15] We identify 36,831 unique products that comply with standards developed by ICT standards organizations, of which 26,257 products (72.2%) are offered by the firms included in both waves of the OECD database. Overall, this analysis suggests that the OECD database contains a large majority of the top standards organization members, SEP owners, and implementers of ICT standards.

The second stage of sample construction is to limit the matched sample to the firms in the industries most relevant to ICT standards development. We adopt the FTSE's Industry Classification Benchmark (ICB) to define industries, and then select the industries of

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

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

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

Note. SO_50 denotes the 50 entities with the highest number of memberships of standards organizations. SEP_50 denotes the 50 entities with the highest number of declared SEPs. Prod_50 denotes the 50 producers with the highest number of products that comply with the standards developed by ICT standards organizations. The statistics for these indicators is based on the firms in the OECD database, not the Searle Center Database: for example, all the 50 firms in the OECD database with the highest number of memberships of standards organizations in the Searle Center Database are included in *Industry Sample 2*, but only 42 of these 50 entities – in both waves of the OECD database.

Table 1: The construction of the sample: An industry breakdown

interest using the same data and criteria as above (i.e., membership counts, declared SEPs, and standards-compliant products; see Table 1 for further details).[16] We create two samples. There is a narrower sample covering six industries that are most involved in developing ICT standards, namely: Broadcasting and Entertainment, Consumer Electronics, Electronic and Electrical Equipment, Fixed Line Telecommunications, Mobile Telecommunications, and Technology Hardware and Equipment (*Industry Sample 1*). In each of these six industries, the average number of membership counts per firm is higher than 10, apart from in the Electronic and Electrical Equipment sector; at least 20% of the firms have declared one or more SEPs; and at least 15% of the firms sell standards-compliant products. From the intersection of the two waves of the OECD database, 417 firms are included in this industry sample. Recognizing that the above six industries do not encompass all of the most significant corporate entities participating in standards development, we also construct a larger sample of 11 industries, which covers 694 firms (*Industry Sample 2*). This sample is selected to account for all the most relevant stakeholders in ICT standards development among the firms in the OECD database, but it includes industries that are more heterogeneous with respect to the relevance of ICT standards development.[17]

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

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

3.3 The description of variables

Dependent variables. To capture the extent of a firm's participation in various types of standardization activities, we calculate the number of standards organizations of which the firm was a member in a given year (we use its log-transformed form).[18] Moreover, we differentiate standards organizations with respect to their prevailing role in standards development. We design and adopt the following classification:

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

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

In applying the above classification, we rely on each organization's self-description on its official website (websites were consulted from February to April 2018). Since the distinction is not always straightforward,[19] we refine the classification by using additional sources of information. For example, an organization is classified as a standards developer if the Searle Center database includes standards that it developed; if it is listed among the developers accredited by the American National Standards Institute; or if it publishes information on disclosed SEPs. In order to identify standards organizations that have received and published at least one SEP disclosure, we use the data from Baron and Pohlmann (2018).[20]

[18]For a small number of standards organizations, the membership data in the Searle Center database has gaps (i.e., missing years). In these cases, we introduce *interpolated* membership counts. According to this method, a firm is classified as a member of a standards organization in a given year if there is no information on membership in that standards organization for that year, but the firm was the organization's member in the year before and the year after the year with the missing information.

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

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

Overall, among the 177 standards organizations included in our analysis, 58% are classified as standards developers, 23% as standards promoters, and 19% as "other" organizations. Of the sampled firms, 41% were a member of a standards organization in the developers group, 17% in the promoters group, and 15% in the "other" group (all numbers are averaged across the 5 years of the sample period).

Explanatory variables. To measure the level of R&D investment, we take the natural logarithm of the firm's reported R&D expenditure in a given year (*lnRD*). Patent-intensive firms are captured by a dummy variable that takes the value of one if the firm's ratio of patent counts to the number of employees is above the sample median, and zero otherwise (*PT_High*). Similarly, we identify firms with a strong product-market position by introducing a dummy variable that takes the value of one if the firm's ratio of trademark counts to the number of employees is greater than the sample median (*TM_High*).[21] We use trademark statistics to capture the firm's product-market position, largely owing to the variety of functions trademarks can perform: along with differentiating the product offering of one producer from that of another, trademarks are also shown to be a reliable proxy for innovation and, more generally, new product development activities, especially at the commercialization stage (see Mendonça et al., 2004; Helmers and Rogers, 2010; Sandner and Block, 2011; Crass et al., 2016). Given the diversity of market-related information trademark statistics tend to incorporate, we are confident that this approach provides us with a suitable proxy for the product-market position of a firm.[22]

Control variables. We include several firm-level characteristics to control for the factors that can potentially affect the firm's decision to participate in standards development: the total number of employees (*lnEmployees*), net sales (*lnSales*), and the firm's capital intensity (measured as capital expenditure over net sales; *lnCapital_Int*). Each of these variables is log-transformed. We also control for year fixed effects and regional trends. The latter are controlled for by adding interaction terms between year (as a continuous variable) and regional dummies (i.e., North America, Europe, China, Japan, South Korea, and other).[23] We thus attempt to capture any notable shifts in the patterns of patenting and participation in standards development in different regions of the world. For example, the increased participation of firms from emerging markets in global technological development may induce spurious correlations between patent counts and membership of standards organizations, which are not controlled for if only year and firm fixed effects are used.

[21] Our results are robust to alternative dummy specifications, such as computing dummies based on each industry's median, as well as using the total amount of sales instead of number of employees for scaling.

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

[23] To assign firms to regions, we largely rely on the country of incorporation provided in the OECD database. If firms are incorporated in tax havens, where they are unlikely to have significant business activities, we search for additional information in publicly available sources to assign those firms to the region where they conduct most of their business.

4 Empirical analysis

4.1 Descriptive statistics

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

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

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

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

In the 2010-2014 period, standards organization listed in the Searle Center database had 239 members on average, with about 10% of this number being firms from one of our industry samples. Standards-developing organizations had significantly larger membership counts than other types of standards organizations, both in terms of the overall membership counts as well as among the firms included in the OECD database. The average member of a standards-developing organization filed 1,430 patent and 48 trademark applications per year. Although the trademark figures were lower for standards promoters and "other" standards organizations, the latter type had higher average patent counts than standards-developing and standards-promoting organizations. Finally, standards organizations with SEP disclosures had the highest number of members from the OECD database. Members of these standards organizations also had a higher average patent count than members of all other types of standards organizations.

4.2 Econometric analysis

4.2.1 Baseline models

In this section, we present the estimates of our baseline model of firm participation in standards organizations. More specifically, we adopt the following model specification:

$$y_{i,t} = \alpha_1 rd_{i,t-1} + \alpha_2 rd_{i,t-1} pt_i + \alpha_3 rd_{i,t-1} tm_i + \beta X_{i,t-1} + \gamma Y_t + \delta reg\_trend_{i,t} + \epsilon_{i,t}, \quad (1)$$

where $y_{i,t}$ is the count of firm i's memberships of standards organizations in year t; $rd_{i,t}$ is the firm's R&D spending; pt_i and tm_i are time-invariant dummy variables measuring firm i's patent and trademark intensity; $X_{i,t}$ is a vector of firm-level control variables, including number of employees, sales, and capital intensity; Y_t is a vector of year dummies; $reg\_trend_{i,t}$ is a vector of regional trends; and $\epsilon_{i,t}$ is a normally distributed error term (all variables are log-transformed). To attenuate concerns of reverse causality, we use one year lags of all firm level independent variables (results are robust to using simultaneous values instead).

We estimate Equation 1 using a fixed-effects OLS regression. Throughout the analysis, we report the results from the narrower and more homogeneous *Industry Sample 1*. However, we observe very similar results from the larger and more heterogeneous *Industry Sample 2* (see Table 12 in Appendix A). The results of this analysis are reported in Table 3.

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

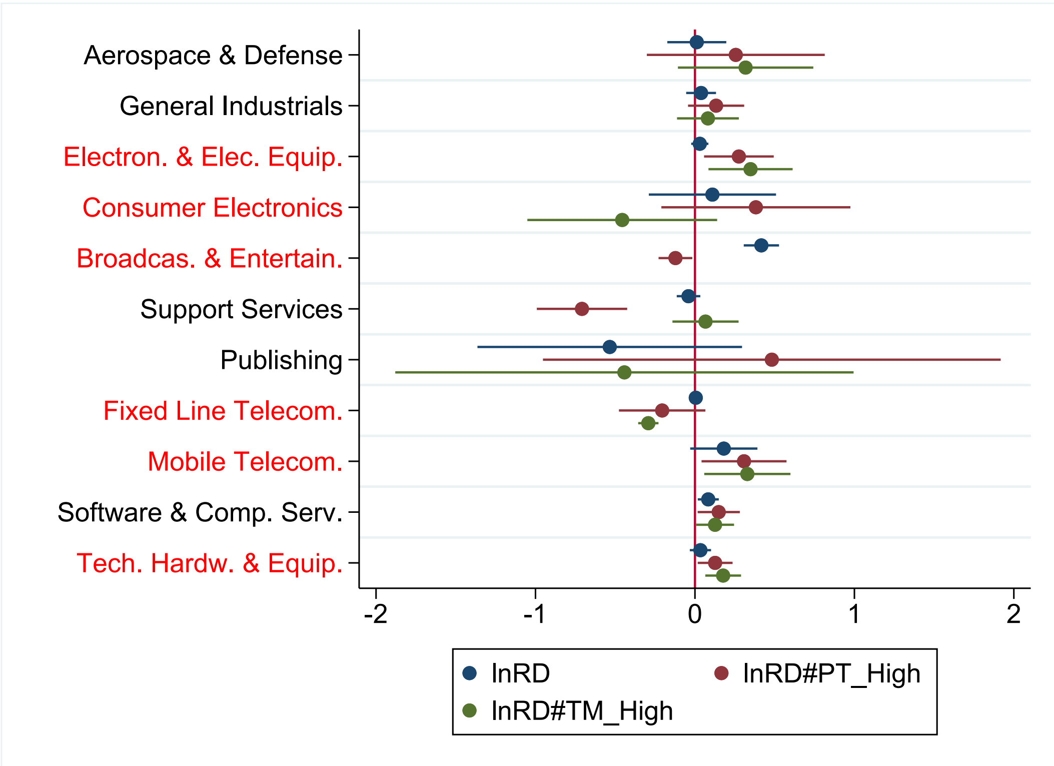
Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 3: Fixed-effects models with IP positions

The main explanatory variable of interest is the firm's R&D expenditure (Model 1), depending on its IP positions. Given that we utilize the fixed-effects estimation technique, the time-invariant variables, such as IP dummies, cannot be estimated on their own. We first interact R&D spending with each IP dummy variable separately (Models 2-4), and then include a three-way interaction term incorporating all three variables (Model 5).

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

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



Note. Coefficients and 95% confidence intervals. The RD#TM_High coefficient for the Broadcasting and Entertainment industry is dropped due to collinearity. Industries constituting *Industry Sample 1* are in red.

To gain further insight into the results, we allow the coefficients of interest to vary by industry. Figure 1 presents industry-specific coefficients and their 95% confidence intervals. This analysis suggests that the association between the firm's R&D expenditure and the count of its standards organization memberships is positive in all 6 industries included in

Industry Sample 1, and in 9 out of 11 industries included in *Industry Sample 2*. However, it is individually significant only in Broadcasting and Entertainment, and Software and Computer Services. The effect of the interaction between the firm's R&D spending and IP positions is, in turn, positive in 8 (for patents) and 7 (for trademarks) industries. Each interaction is significant in Electronic and Electrical Equipment, Technology Hardware and Equipment, Mobile Telecommunications, and Software and Computer Service industries.

Overall, the above findings suggest that the associations of interest are very robust. It should be noted that in some industries, there are negative coefficients for the interaction terms. We attribute such results to the fact that only small samples of firms from those industries are included in the OECD database, thereby leading to less precise estimates. This reasoning is supported by the fact that our findings for the industries with the largest number of firms (i.e., Electronic and Electrical Equipment, Technology Hardware and Equipment, and Software and Computer Services) are similar (in terms of both the sign of the coefficient and the level of significance) to the averages across all industries.

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

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

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

While the results presented so far are based on binary measures of IP intensity, in Table 4, we present the results from estimating models with continuous counts of patents and trademarks. In Models 1-4, we include *pre-determined* counts based on the number of IP applications in 2010, the first year of our sample period. Similar to the previously used IP dummies, these pre-determined counts are time-invariant; thus, the interaction terms in the fixed-effect specification can be regarded as variations in the effect of the time-variant R&D measure depending on the firm's IP intensity. In Models 5-7, we use time-variant patent and trademark counts based on the flow of applications over time. These specifications draw on richer information because we also take into account variations in IP intensity over time. However, the interaction terms are more difficult to interpret in this case: they can indicate variations in the effect of either the extent of R&D spending by IP intensity or IP intensity by the extent of R&D spending. The baseline effect of IP counts without interactions is included in Model 5.

The results are broadly in line with those obtained from the baseline specifications with IP dummies. More specifically, the association between the firm's R&D expenditure and its membership of standards organization significantly increases in the firm's number of patents (pre-determined). The number of trademarks also has an amplification effect on this association, even though the effect vanishes when patent counts are included in the model as well (but not for time-invariant trademark counts). As before, there is no evidence for significant interactions between the two types of IP counts.

While using time-variant IP counts allows us to test for direct effects of IP positions, we find these to be insignificant. This can suggest that IP counts influence the participation decision of only particular R&D-intensive firms. It is also plausible that the within-variation over 5 years is not highly informative of the main effect of IP counts because the flow of IP applications is often subject to significant stochastic shocks. We hypothesize that the firm's participation decision is more likely to be driven by the overall size and value of its IP stock rather than within-variations in IP applications over short time horizons.

4.2.2 The heterogeneity among standards organizations

Next, we divide our sample into standards-developing, standards-promoting, and "other" standards organizations. Among standards developers, we further distinguish between the organizations with standards potentially subject to SEPs and those without such patents. In Table 5, we present the results from testing our baseline specification for membership counts within each of the five types of standards organizations. We find that there is a positive effect of R&D spending on the firm's membership count of standards-promoting organizations (Models 3 and 4), whereas the effect is insignificant for other types.[24] Regarding the conditioning effect of the firm's IP positions on the association between R&D expenditure and membership counts, rather heterogeneous patterns emerge among different types of standards organizations: both patent and trademark intensities significantly interact with the firm's R&D expenditure in determining its membership count of standards-developing organisations (Model 2). Moreover, the patent position

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

substantially enhances the effect of the firm's R&D expenditure on its membership of the organizations that develop standards linked to SEPs (Model 8). In contrast, the firm's trademark intensity is found to have a positive moderating effect on its membership of standards-promoting organizations (Model 4). We can thus conclude that a strong product-market position appears to provide an incentive to R&D-intensive firms to be a member of standards organizations that do not offer explicit patent-based rewards.

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

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

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

4.2.3 The endogeneity of R&D expenditure

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 thus need to address this potential endogeneity bias arising from reverse causality. Another likely source of endogeneity pertains to various confounding factors (i.e., omitted variables) that may simultaneously lead to higher levels of business innovation and greater participation in the development of technology standards. Such unobserved factors can range from the macroeconomic environment, business growth, and corporate strategies to technological evolution over time and the corresponding new opportunities.

To identify the causal effect of R&D investment on the extent of a firm's membership of standards organizations, we adopt an instrumental variable (IV) approach in conjunction with the fixed-effects models specified before. Following Bloom et al. (2013), we utilize firm-specific R&D tax support to instrument for firms' R&D expenditure. A large body of literature provides strong evidence that national and/or state-level R&D tax support has a positive effect on firms' R&D spending (Bloom et al., 2002; Hall and Van Reenen, 2000; Rao, 2016). We draw on an OECD database on implied tax support for R&D.[25] From the database, we select the levels of implied tax support for R&D expenditures by large firms in a profit-making scenario. In line with the literature (Griffith et al., 2006; Bloom et al., 2013), we use the listed country of residence of inventors from the firms' patents (obtained from the OECD database) to build a firm-specific measure of the total weighted tax support, which sums over the tax support in each country where the firm operates, weighted by the share of the firm's R&D activities conducted in that country.

While we rely on the literature in using R&D tax support as an IV for firm-level R&D expenditure, there are some caveats. First of all, R&D tax support may be endogenous to the factors that also influence the firm's functioning, such as macroeconomic conditions or the political environment. Nevertheless, some recent evidence suggests that the endogeneity of R&D tax support leads to a downward bias, thereby underestimating its causal effect on R&D spending (Chang, 2018). We are therefore confident that, if relevant, potential confounding factors should bias us against finding a significant first-stage effect. Second, there is evidence for variations in the effect of R&D tax credits by industry and firm size (Castellacci and Lie, 2015), leading to bias in the estimation of instrumented interaction terms. While R&D tax credits are often found to be more significant in affecting R&D spending by smaller firms, this effect should once again bias us against finding a significant first stage effect in our sample of large firms. We undertake a thorough analysis of the validity of our IV (see Appendix B), and conclude that the firm-specific total weighted R&D tax support significantly predicts R&D spending by the firms included in our sample, and there is no evidence that this effect varies in the firm's IP intensity.

Table 6 reports the results from estimating the second-stage structural model of the extent of participation in standards development using the IV outlined above. Accounting for the potentially endogenous link between the firm's R&D spending and its membership of standards organizations, there is no statistically significant effect of R&D expenditure (Model 1) on avarage. Instead, this effect is conditional upon the firm's patent position (Models 2 and 4). In Table 7, we present the analysis examining the heterogeneous patterns across different types of standards organizations. It suggests that the patent intensity is a conditioning factor for the effect of the firm's R&D spending on its membership of standards-developing organizations (Model 2). At the same time, the trademark intensity has a positive effect on the link between the firm's R&D expenditure and its membership of standards-promoting organizations (Model 4).

[25]https://www.oecd.org/sti/rd-tax-stats.htm

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

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

Table 6: 2SLS fixed-effects models with IP positions: The 2nd stage

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

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

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

4.2.4 Alternative measures of product-market position

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

We argue that both measures may reflect the firm's product-market position as well. For example, differentiation by means of the corporate brand can substitute for product-related differentiation captured by trademarks (Agostini et al., 2015). Valuable corporate brands can serve as a reputation-based mechanism via which the firm retains its existing customers and attracts new ones. In this case, some degree of complementarity is expected between the value of the corporate brand and the intensity of product-related differentiation. In turn, the number of ICT standards-compliant products capture the breadth of the firm's product offering. Since trademark intensity corresponds with the number of differentiated products, using product counts and trademark intensity at the same time should help us distinguish between the effects of the breadth of product offering and the depth of product differentiation.

The results of this analysis suggest (see Table 8) that each of the additional measures enhances the effect of the firm's R&D spending on its membership of standards organizations (Models 3 and 4). This finding supports the argument that the firm's ability to appropriate its R&D investment by leveraging a strong product-market position can provide an incentive for participation in standards development. The positive effect of trademark intensity on the association between R&D spending and standards organization membership remains significant even after controlling for other dimensions of the firm's product-market position.

Next, our analysis of time-varying product counts identifies a positive relationship between the firm's product counts and its counts of standards organization memberships. This finding may indicate that a firm's strong product-market position (particularly in the relevant end-product markets directly implementing the standards under development) provides incentives for it to participate in standards organizations that are independent of its

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

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

Table 8: Fixed-effects models with IP positions:
Alternative measures of the product-market position

R&D effort. This observed effect may be attributed to the firm's willingness 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 other firms contributing new technologies to standards development. Nevertheless, there can also be other interpretations for this positive relationship, such as reverse causality, whereby increased participation in standards development induces greater implementation of new technology standards.

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

4.2.5 The policy change: An analysis of patent boxes

Our analysis has so far revealed that a strong patent position increases the strategic complementarity between a firm's R&D investment and its participation in standards development. Therefore, we expect that a policy change that increases the value of patent protection will induce R&D-intensive firms to expand their membership of standards organizations. To test this prediction, we analyze the effect of the introduction of *patent boxes*, or fiscal regimes that grant favorable tax rates to revenue derived from patents. The introduction of patent boxes increases the value of patent protection relative to other mechanisms facilitating the appropriation of returns on R&D investment.

Specifically, we hypothesize that the introduction of a patent box has a twofold impact on affected firms. First, the patent box regime makes patent ownership more attractive and thus induces firms to file more patent applications or acquire patents from other firms not benefiting from the patent box. Second, a lower tax rate on patent-related revenue increases the value of both existing and new patents, rendering firms more responsive to the strategic incentives provided by patents. We thus expect that the introduction of a patent box increases the extent to which the R&D-intensive firms benefiting from the box participate in standards. Moreover, we expect that this effect increases in the extent to which the firm relies on patents to protect its new technologies. A firm with a higher patent intensity (prior to introduction of the box) has a greater revenue share benefiting from the favorable tax treatment.

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

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

Using information from PwC (2013) and Ciaramella (2017), we first identify 16 countries that introduced patent box regimes in the period 1973-2015 (see Table 9). We then exclude Ireland and Italy, where the introduction of a patent box regime occurred outside of the observation period for our data on membership of standards organizations. We also exclude patent box regimes that apply to both patents and trademarks because we seek to reliably attribute the empirical results to patents.[26] So, we are left with eight patent box regimes introduced in the period 2000-2014. They have an effect on 92 firms in *Industry Sample 1*: under a half of them (41 firms) are from China, while the remainder are from Europe.

We estimate the effect of patent box introductions in a fixed-effects setting over a panel spanning a longer period than our 5-year sample period. We further interact the dummy variable indicating the patent box being introduced with time-invariant firm-level variables (i.e., average R&D expenditure and IP dummies); we also continue to control for year fixed effects and regional trends. As the results suggest (see Table 10), there is a statistically significant positive effect of patent box introduction on standards organization membership counts (Model 1), and this effect is stronger for patent-intensive firms (Models 3 and 5). More specifically, the introduction of a patent box regime increases a patent-intensive firm's number of memberships of standards organizations by approximately one organization.

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

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

Table 10: Fixed-effects models with IP positions: The Patent box analysis

We next distinguish between the effect of a patent box regime on membership counts across different types of standards organizations. We focus on the difference-in-difference-in-difference comparison between patent-intensive firms in patent box countries and other firms in the sample as the most robust estimation of the effect of the patent box regime. The results indicate (see Table 11) that the introduction of a patent box has a positive effect on membership counts of the affected firms with a higher intensity of patent applications across all but "other" standards organizations.

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

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

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

Table 11: Fixed-effects models with IP positions:
The Patent box analysis; by the type of standards organizations

5 Discussion and conclusions

In this paper, we have advanced our understanding of why large R&D investors participate in standards organizations. We have revealed a positive and statistically significant association between a firm's R&D expenditure and its membership of standards organizations, which is robust across various ICT industries included in our sample. Nevertheless, our IV estimations fail to corraborate a positive causal effect of R&D spending on participation in standards organizations *on average*. Instead, we have found robust evidence indicating that a positive effect of R&D on standards organizations memberships is contingent upon the existence of appropriation mechanisms that enable firms to secure a return on their investment in R&D contributions to open standards development.

The most prominent appropriation mechanism identified by our analysis is patent protection. As our IV estimations suggest, the interaction between a firm's R&D spending and its patent position positively determines membership counts, but its effect is confined to the organizations that develop and set their own standards (vis-a-vis those tasked with promotion, certification, or other ancillary functions). This finding underscores a significant strategic complementarity between patenting and participating in standards development. Both strategies are characteristic of a highly modular form of innovation, where diverse actors create individual pieces of a complex technology, and then use licensing to generate a return on their investment (Arora and Fosfuri, 2003). Our findings suggest that compared with other commonly used means of appropriation, such as secrecy, complexity, and lead time (Cohen et al., 2000), patents offer a higher level of compatibility with the processes adopted by open standards organizations.

We have further shown that the association between a firm's R&D spending and its membership of standards organizations is reinforced not only by the firm's patent protection, but also by its product-market position. In our empirical analysis, we have used such measures as trademark intensity, brand value, and counts of standards-compliant products to capture various dimensions of a firm's product-market position. Our findings thus attest to the significance of downstream assets underlying these dimensions (e.g., capabilities in manufacturing, distribution, or marketing) for standards development. Such assets can serve as yet another appropriation mechanism that allows the firm to profit from its R&D contribution to those standards organizations in which patent-based incentives are absent (Teece, 1986; Arora et al., 2001; Pisano, 2006).

Our findings identify the distinct causal effects of R&D expenditure on membership of standards-developing organizations and standards-promoting organizations, with the former effect being enhanced by a strong patent protection, and the latter effect by a strong product-market position. This finding suggests that a firm's decision to participate in upstream and downstream standards organizations is associated with different appropriation mechanisms. Such finding resonates with the increasingly modular organization of standards-based technology development: the development of standardized interfaces and the existence of technology markets relying on IPR allow each firm to contribute to those tasks in standards development that are best aligned with its assets and capabilities. Moreover, our results draw attention to standards-promoting (downstream) organizations that have been understudied, despite being instrumental in the development and implementation of standards specifications, as well as in the commercialization of products incorporating standardized technologies.

It should be noted that the development of a high-quality technical specification *per se* does not guarantee the effective standardization and subsequent adoption of technologies that rely on it. As a result, various standards-related industry associations and consortia exist to facilitate industry coordination on a single set of standards, support certification of standards compliance, and administer the licensing of standards certification marks. Due to their contribution to the diffusion of standardized technologies and the facilitation of *effective* standardization in the marketplace, these organizations are an integral part of the technology standardization ecosystem. For example, despite having developed the early IEEE 802.11 standard (now known as Wi-Fi technology), the Institute of Electrical and Electronics Engineers (IEEE) had no provision for testing equipment for compliance with this standard. In 1999, the Wireless Ethernet Compatibility Alliance (WECA, the predecessor of the Wi-Fi Alliance) was formed to solve these problems by promoting the adoption, performing testing, and certifying product compatibility with the Wi-Fi technology. Another telling example is the MPEG Industry Forum responsible for promoting MPEG standards, developing MPEG certifications for products, and collaborating on designing new *de facto* MPEG standards. In doing so, it coordinates an extensive network of content creators, developers, manufacturers, service providers, and end users.

The findings presented in our study have important implications for business strategy and policy making concerning standardization in the ICT sector. Above all, they emphasize the role of patent-based incentives for business participation in standards development, which is in line with previous research that links patenting to engagement in collaborative technology development (e.g., the participation of independent software vendors in software platforms; see Huang et al., 2013). The fact that the effect of patent protection is not exclusive to standards organizations with standards subject to declared SEPs suggests that patents induce participation in standards organizations not only through increasing a return on innovation (the appropriation mechanism), and providing legal protection against the risk of unintended spillover of technology to other firms participating in the standardization process.

These findings add to the ongoing debate on appropriate policies for the inclusion of patented technologies into standards and the enforceability of those patents (see Lerner and Tirole, 2015). It is well understood that the decision of an individual standards organization to tighten its patent policies may induce firms relying on patents to opt for a different venue to pursue standards development (Lerner and Tirole, 2006; Chiao et al., 2007).[27] Our results highlight that overall participation of R&D-intensive firms in standards development may be affected by the pronouncements of courts and/or policy makers that impact the value and enforceability of patents more generally. The results of our patent box analysis corroborate our interpretation of the baseline results, confirming that policies that strengthen the value of patents may motivate R&D-intensive firms to participate in a larger number of standards organizations, especially those organizations that develop standards. This effect is highly relevant, as governments and regulatory authorities around the world seek to formulate principles for patents used in the standardization process.[28]

There are several limitations to this study, which present opportunities for future research. First, since our sample only consists of large R&D investors, some of our findings may have limited application to small firms. For example, Simcoe et al. (2009) point to a disparity between incumbents and entrepreneurial start-ups in standards development. Second, our measures of product-market position may not fully encompass all its dimensions given the complexity associated with this construct. Third, in our empirical analysis, IP positions are largely treated as time-invariant, thus rendering it difficult to consider the dynamic effects of patents and trademarks on participation in standards development. Fourth, we have identified the coexistence of different appropriation mechanisms that

[27]The IEEE is among prominent standards organizations that amended its patent policy in 2015 to tighten restrictions on the licensing and enforcement of patents used in standardization.

[28]The European Commission in its 2017 Communication on the EU approach to Standard Essential Patents states two main objectives for the policy framework for SEPs: "incentivising the development and inclusion of top technologies in standards, by preserving fair and adequate return for these contributions, and ensuring smooth and wide dissemination of standardised technologies based on fair access conditions".

motivate R&D-intensive firm to participate in standards organizations. Future research could study the interactions between firms driven by patent- and product-based incentives in the course of standards development. In particular, a debate is gaining traction among practitioners and policy makers in ICT standards development about the nature, extent and implications of the interplay between *contributors* and *implementers*. Our distinction between patent- and product-based incentives offers a more nuanced approach to these important issues. Moreover, our membership data may not present a full picture of activities pertaining to ICT standardization, and thus another promising future avenue is to offer finer-grained insight by incorporating data on detailed contributions, meeting attendance, votes and so forth. Finally, while our study has focused on the determinants of participation in standards organizations, the effect of participation in collaborative standards development on business performance and innovation is still not well understood.

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Appendix A. Additional results

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

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

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

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

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

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

Appendix B. The validity of instrumental variables

To assess the validity of our instrumental variable, we perform a variety of tests and checks. First, we make sure that R&D tax support (as percentage of GDP, lagged by one year) is a good predictor of corporate R&D expenses, and that this relationship is broadly supported across the sample. We start with analyzing the relationship between *L.rd_tax_support_pctgdp* and business R&D expenditure at the country level (Table 14). In a sample of 29 countries, we confirm that *L.rd_tax_support_pctgdp* is a strongly significant predictor of business R&D expenditure when controlling for country fixed effects (Model 1). This relationship remains statistically significant at 5% when controlling for year fixed effects and regional trends (Model 2), GDP in constant US dollars (Model 3), as well as significant at 10% when controlling for an additional set of control variables, such as the unemployment rate, government expenses in R&D, and higher education expenses in R&D (Model 4). The loss in significance between Models 3 and 4 is attributable to the fact that the additional control variables are only available for a shorter time span (the significance level of the instrument also drops to 10% when running Model 3 on the smaller sample of Model 4). We thus conclude that there is a stable relationship between *L.rd_tax_support_pctgdp* and business R&D expenditure, which is independent of cyclical effects, regional trends, GDP growth, and non-business R&D.

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

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

Controlling for firm and year fixed effects, regional trends, and other firm level characteristics, results in Table 15 show that *L.rd_tax_support_pctgdp* strongly predicts *lnRD* in the OECD sample of top R&D performing firms (Model 1). This holds true when controlling for weighted average GDP, in constant USD (Model 2). As adding the control variable GDP has little effect on the relationship between *L.rd_tax_support_pctgdp* and even

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

Dependent variable: business R&D expenditures in constant USD; Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 14: IV validity analysis: country-level regressions of business R&D expenditures

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

Dependent variable: lnRD; Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

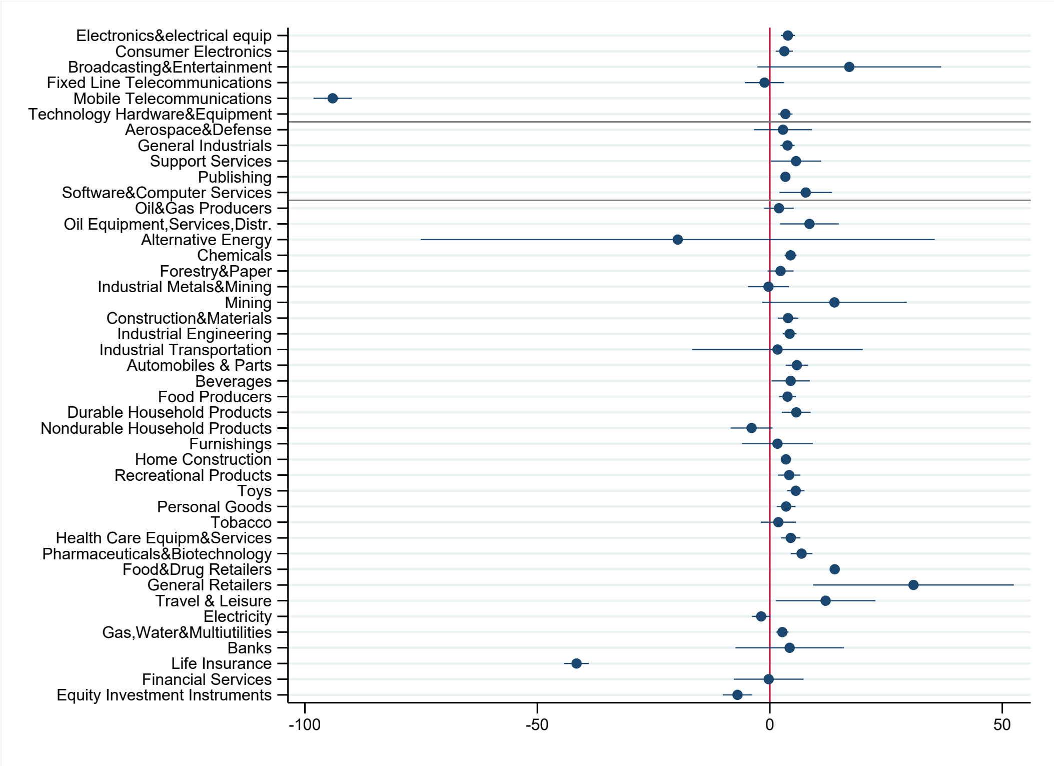
Table 15: IV validity analysis: Firm-level regressions of R&D expenditures

increases the significance of this relationship in all models, we use the more conservative version of the model without GDP control throughout the analysis. The relationship is similarly significant in the 11-industries Sample 2 (Model 3), and the 6-industries Sample 1 (Model 4). In fact, the coefficient receives positive support in 35 out of 43 industries represented in the OECD sample, and is thus highly robust to between-industry variation (Figure 3). Among the industries included in our analysis sample, the only exception to this is Mobile Telecommunications, where there is a strongly significant negative relationship. Nevertheless, given that only four of the OECD top R&D performing firms belong to this industry, this is unlikely to affect our results.

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

Finally, we want to assess whether the IV is likely to violate the exclusion restriction. Despite rules for the R&D tax support eligibility of expenses varying from one country to another, support is generally limited to activities directed at scientific or technological

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



Note. Coefficients and 95% confidence intervals. All estimates are based on Model 1 in Table 15

discoveries.[29] Membership fees in standards organizations, travel expenditure for meeting attendance, and other non-R&D-related expenditure arising from participation in standards development should thus generally not be eligible. If the R&D tax support has the effect of subsidizing participation in standards development, this effect is transmitted via a reduction of the firm's cost of conducting R&D.

While there is thus no significant risk that R&D tax support may directly subsidize non-R&D expenses for participation in standards development, there may still be an indirect effect not transmitted via increased R&D expenses, but through reduced tax payments, resulting in increased profits. To rule out this alternative channel, we run Models 1-8 from the previous analysis with *operating profits* instead of *R&D expenditure* as dependent variable. As shown in Table 16, there is no evidence for a significant effect of R&D tax support on operating profits, thus attenuating concerns regarding the validity of the exclusion restriction.

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

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

Dependent variable: lnOperatingProfit; Robust p-value in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 16: IV validity analysis: Firm-level regressions of operating profits