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Standards, consortia, and innovation☆

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ABSTRACT

The development of formal ICT standards is a challenging form of collaborative innovation, combining consensus decision making and R&D rivalry. To supplement this formal standard setting process, it has thus become frequent that part of the involved firms creates ad hoc consortia to better align positions on a common technology roadmap. This paper aims to assess whether such consortia can effectively mitigate R&D coordination failure through enhanced cooperation. We first develop a theoretical model showing that depending on the nature of firms' incentives to contribute proprietary technology, different types of R&D coordination failure – namely a *Public Good* or *Rent Seeking* problem – may occur in equilibrium. Using a large panel of standards, we then confirm empirically the prediction that consortia have different effects on innovation under a *Public Good* or *Rent Seeking* regime. Overall, we observe an increase in innovation after a firm joined a consortium. However, this effect is significantly weakened or even reversed for standards characterized by a strong *Rent Seeking* regime.

1. Introduction

In a few decades, standardization in Information and Communication Technologies (ICT) has evolved from the definition of simple specifications to the joint development of large technology platforms including numerous patented components (Simcoe, 2007).[1] While the conditions for licensing these standard essential patents have been widely discussed (see e.g., Layne-Farrar and Lerner, 2011; Lerner and Tirole, 2004; Shapiro, 2001), the peculiar type of R&D collaboration they proceed from has received less attention so far.

Formal standards are developed and updated in standard setting organizations (SSOs) – such as the European Telecommunications Standards Institute (ETSI) and the Institute of Electrical and Electronics Engineers (IEEE) – that are open to a broad range of stakeholders. Unlike e.g. R&D joint ventures, the main originality of this process is that it does not involve any ex ante contracting between the participants. Firms develop proprietary innovations ahead of the standardization meetings, and SSO members then decide on a consensus basis which candidate technology shall be included the standard. As a result, formal standardization may entail R&D duplications and delays due to vested interests (Farrell and Simcoe, 2012; Simcoe, 2012).

Against this background, it has become frequent that part of the companies contributing to the standard forms an ad hoc consortium to supplement the formal standard setting process. Some consortia substitute for more formal SSOs and issue their own standards (Lerner and Tirole, 2006), including the Blu-Ray alliance or the W3C for web protocols. But most of them actually accompany formal standardization[2]

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[1] As an example, the number of functionalities and formats (e.g., email, video, internet) supported by the late wireless communication standards (3rd and 4th generation) considerably exceeds those of the second generation (GSM, CDMA) that are limited to voice communication.

[2] Formal SSOs indeed have policies of active cooperation with informal consortia (cf. David and Shurmer, 1996; Hawkins, 1999). The International Standards Organization (ISO) cooperates with Partner Standard Development Organizations (PSDO) through liaison agreements regarding specific standard projects. ISO also provides for a formal fast track agreement, the PAS (Publicly Available Specifications), which allows sponsoring organizations to receive formal accreditation of their specification. ISO's Joint Technical Committee 1 (JTC1) has a similar policy of featuring Approved References Specifications (ARS).

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(Cargill and Weiss, 1992). Important examples are the WiMAX Forum, providing a collaboration forum for companies contributing to wireless communication standards developed at the IEEE, and the UMTS Forum, representing the interests of its members regarding 3rd Generation mobile phone standards in SSOs such as ETSI and the 3rd Generation Partnership Project (3GPP). Such consortia are not a means for members to contractualize R&D. However, they make it easier for a smaller group of firms to align positions on a common technology roadmap (Delcamp and Leiponen, 2012), thereby enhancing R&D coordination while improving their chances to influence the standard setting process (Leiponen, 2008) and to obtain essential patents (Pohlmann and Blind, 2012).

The purpose of this paper is to assess whether such standards consortia can effectively address R&D coordination failures in formal SSOs. To do so, we develop first a theoretical framework accounting for firms' incentives to develop innovations for a standard in a context of loose R&D cooperation. We use this framework to derive predictions on the effect of enhanced cooperation between a subgroup of companies contributing to a standard, and then test our predictions empirically on a large panel of ICT standards. Our results suggest that consortia can not only unlock innovation in the standard setting process but also, in some cases, mitigate intensive patenting around the standard when it is wasteful for the firms.

The model indeed highlights two possible coordination failures depending on the share of the standard's value that accrues to owners of essential patents. A *Public Good* regime involving R&D free-riding prevails in equilibrium when firms' incentives to innovate are primarily driven by expected sales of standard-compliant products. Conversely, a wasteful *Rent Seeking* regime prevails when licensing revenues are sufficient to cover R&D costs. Against this background, we introduce consortia as a means to enhance cooperation between a subgroup of member firms. We show that consortium members then tend to increase (reduce) their R&D efforts when a strong *Public Good* (*Rent Seeking*) regime prevails in equilibrium, and can thus mitigate coordination failure at the SSO level.

We use a panel of 167 ICT standards observed over 9 years to test these predictions empirically. For this purpose, we have developed an original dataset of standard-related, citation-weighted patent applications to measure innovation at firm level, and matched these observations with information on firms' participation in 21 closely related consortia. Drawing on our theoretical framework, we use the participation of pure R&D firms in the standard setting process as a proxy to identify standards that are subject to a *Rent Seeking* regime. Our results are consistent with the prediction that joining a consortium is positively correlated with firm-level patenting under a *Public Good* regime, and negatively correlated with patenting under a *Rent Seeking regime*. Overall, we indeed observe an increase in patent output after a firm joined a consortium. However, this effect diminishes and eventually reverses as the participation of pure R&D firms in standard setting increases.

While a large strand of papers discuss optimal rules for licensing essential patents (Lerner and Tirole, 2004; Lerner et al., 2007; Shapiro, 2010; Swanson and Baumol, 2005), we take the reverse approach by highlighting how the prospect of licensing essential patents actually drives innovation in standards. In this respect, this paper is more closely related to recent empirical work on standard essential patents. Rysman and Simcoe (2008) find that SSOs not only select the most valuable patents in standards, but also enhance the value of these patents (through e.g. network effects), thereby providing incentives for firms to contribute patented inventions. Our definition of pure R&D firms also partly recoups that of Simcoe et al. (2009) who show that entrepreneurs use standards to enter an industry as stand-alone suppliers of proprietary technology.

Our theoretical framework follows the literature on R&D joint ventures (Amir et al., 2003; d'Aspremont and Jacquemin, 1988; Kamien et al., 1992) to capture firms' ability to (imperfectly) cooperate in a simple way. However, the type of interactions we aim to account for has been analyzed in more details in the literature on standard setting. Farrell and Saloner (1988), Farrell and Simcoe (2012) and Ganglmair and Tarentino (2012) model standard setting as a bargaining process entailing a discrepancy between the fully cooperative and actual outcomes. Simcoe (2012) also produces empirical evidence of a slowdown in standards production by IETF (an SSO which issues many of the Internet standards) due to distributional conflicts induced by the rapid commercialization of the Internet after 1993.

A few papers finally explore the articulation between consortia and standard setting. Lerner and Tirole (2004) and Chiao et al. (2007) respectively develop and test a model of forum shopping where firms can choose between different SSOs or consortia to develop a standard. Our approach differs in that we consider consortia as complements rather than substitutes to formal SSOs. Although more restrictive, this definition is consistent with a large subset of existing consortia that submit standard specifications to formal SSOs. Leiponen (2008) studies a number of consortia contributing to 3GPP. She shows empirically that connections with peers in related consortia enabled members to better influence the selection of standard components at 3GPP. Delcamp and Leiponen (2012) also find that joining a consortium connected with 3GPP increases cross-citations between the members' patents. These results are consistent with our approach of analyzing consortia as a means to improve R&D cooperation between members.

The remainder of this article is organized as follows. We present the theoretical model and its implications in Section 2. Section 3 discusses the empirical strategy, the database and econometric results. We conclude in Section 4.

2. Theoretical framework

We consider a standard which generates aggregate profits $v(x)$ in the industry. These profits increase with the quantity $x \geq 0$ of patented inventions embodied in the standard, but with decreasing return: $v_x \geq 0$ and $v_{xx} \geq 0$. The industry consists of n firms who can take part in the standard development and implement it in their products. Firm $i = 1$, n is defined by (c_i, s_i), denoting respectively its unit cost of invention and its market share in the market for standard-compliant products. The number of inventions originating from firm i is noted x_i, with $x = \Sigma x_i$.

We denote by $r \in [0,1]$ the share of aggregate profits accruing to essential patents owners, and posit that these aggregate licensing revenues $rv(x)$ are split between the firms according to their respective shares of essential patents (that is x_i/x). In the sequel, we will consider r as an exogenous parameter. The share of profits accruing to patent owners is partly endogenous to the strategies of the firms, but is in large parts driven by policy parameters such as the licensing policy of the standard setting organization and the courts' varying interpretations of these policies. By positing r as exogenous, our main purpose is to account for the wide variety of observed licensing practices across standard related industries ($r = 0$ denoting for instance royalty free licensing) while keeping the model tractable enough to analyze firms' innovation and cooperation strategies. This simple approach moreover allows us to capture the role of patent portfolio sizes in firms' ability to collect royalties, or to save royalty payment by striking cross-licensing agreements.[3]

The remaining part of aggregate profits – that is $(1 - r)v$ – is split between manufacturers in proportion of their weight s_i in the

[3] As far as we know, the available literature does not provide us yet with a model of price formation that would be consistent and general enough to account for the variety of actual licensing practices for standard essential patents across different industries, and for the role of patent portfolio size in this context. There are several normative discussions in the literature how to implement efficient royalty rates through public policy (e.g. Swanson and Baumol, 2005). Our contribution is to study how coordination among firms can result in more efficient innovation investment decisions even for an exogenously determined, non-optimal royalty rate.

product market. Taking into account both sources of profits, the revenue of firm $i = 1, n$ is thus:

$$b_i = v(x)\left[r\frac{x_i}{x} + (1-r)s_i\right].$$

Standard development proceeds from a particular type of R&D collaboration whereby firms have to reach consensus on the standard's specifications. Such negotiations are hampered by technology rivalry and the absence of formal contracting (e.g. on the way R&D contributions can be allocated ex ante between participants). Using bargaining models, Farrell and Simcoe (2012) and Ganglmair and Tarentino (2012) show that they fail to achieve the first best outcome.

Nevertheless, assuming fully decentralized R&D decisions by the firms would let aside their need for consensus, and their ability to punctually find and implement some mutually profitable arrangements through repeated negotiations. In order to account for this possibility while keeping the model tractable, we therefore consider an intermediate situation by giving a (small) weight $\epsilon > 0$ to the *whole* industry payoffs in *each* firm's maximization program.

$$\max_{x_i} \quad (1-\epsilon)b_i + \epsilon\sum_{j=1}^{n} b_j - x_i c_i. \tag{1}$$

Parameter ϵ is a simple way to relax the assumption of joint profit maximization usually made in the literature on R&D cooperation (Amir et al., 2003; d'Aspremont and Jacquemin, 1988; Kamien et al., 1992). It allows for the possibility that firms manage to better allocate R&D tasks in a weak cooperation environment, and thereby aims to capture in a reduced form the bargaining slack for which Farrel and Simcoe (2012) and Ganglmair and Tarentino (2012) provide microfoundations. We will however see in the sequel that our key results hold for any $\epsilon < 1$.

2.1. Public Good versus Rent Seeking

Summing the FOC of Eq. (1) for all firms $i = 1, n$ and rearranging, we obtain the following equation implicitly defining the number of inventions x^* embodied in the standard in equilibrium[4]:

$$(1-\epsilon)m(x^*) + \epsilon v_x(x^*) = \bar{c} \tag{2}$$

where $\bar{c} \equiv \sum c_i/n$ is the average cost parameter in the industry, and

$$m(x^*) \equiv \frac{1}{n}v_x(x^*) + \left[1-\frac{1}{n}\right]\frac{rv(x^*)}{x^*} \tag{3}$$

denotes the marginal profit of innovation in equilibrium.

In the absence of cooperation ($\epsilon = 0$), Eq. (2) reduces to $m(x^*) = \bar{c}$. The expression of $m(x^*)$ in Eq. (3) then highlights two kinds of private incentives to innovate for the firms. The first term on the RHS denotes the marginal benefit of enhancing the value of the standard. This incentive is lower the larger n. Accordingly, the standard has the properties of a public good investment entailing free riding among the firms. The second term on the RHS of Eq. (3) captures the firms' incentive to innovate that result from owning essential patents. This term is indeed proportional to the average licensing revenue a firm can derive from one invention, that is $rv(x^*)/x^*$. Obviously, this revenue is stronger the larger the share r of the standard's value that accrues to essential patent holders. It is also larger the more rival firms in R&D competition.

If there is full cooperation between the firms ($\epsilon = 1$), Eq. (2) reduces to $v_x(\hat{x}) = \bar{c}$, where $\hat{x}$ denotes the optimal level of innovation for the industry. With imperfect cooperation ($0 < \epsilon < 1$), Eq. (2) finally defines an intermediate solution balancing the firms' private incentives $m(x^*)$ and joint marginal benefits $v_x(x^*)$ of innovation. Note finally that only the average of the firms' unit costs matters in Eq. (2), not their distribution between firms. It is thus sufficient to compare the LHS of Eq. (2) with full versus imperfect cooperation to assess the efficiency of firms' investments. We can then derive the following result.

Proposition 1. *Two different equilibrium regimes may occur under imperfect cooperation:*

- *If $\frac{rv(x^*)}{x^*} < v_x(x^*)$, a Public Good regime prevails where $x^* < \hat{x}$. The aggregate cost of innovation then exceeds aggregate licensing revenues.*
- *If $\frac{rv(x^*)}{x^*} > v_x(x^*)$, a Rent Seeking regime prevails where $x^* > \hat{x}$. Aggregate licensing revenues then exceed the aggregate cost of innovation.*

Proof. See Appendix 1.2. ■

Whether firms tend to free ride on each other (Public Good) or compete to push inventions in the standard (Rent Seeking) ultimately depends on the profits accruing to licensors. Intuitively, a *Public Good* regime takes place when firms' incentives are primarily driven by the possibility to use the standard. This is for instance the case if patents are licensed royalty-free ($r = 0$) while the standard would benefit from further innovation ($rv(x^*) > 0$). Conversely, Rent Seeking prevails when incentives to innovate are chiefly driven by patents. This occurs for instance when patent holders can extract licensing profits ($r > 0$) although innovation does not enhance anymore the value of the standard ($rv(x^*) = 0$).

Proposition 1 establishes that licensing is a profitable activity per se in the *Rent Seeking* regime, but not in the *Public Good* regime. This in turn implies that a pure R&D firm ($s_i = 0$) with average cost $\bar{c}$ can take part in the standard setting process in the former regime only:

$$rv(x^*) \gtrless \bar{c}x^* \Leftrightarrow \frac{x_i^*}{x^*}rv(x^*) - \bar{c}x_i^* \gtrless 0. \tag{4}$$

2.2. Cooperation through a consortium

According to Proposition 1, the type of inefficiency pattern prevailing in equilibrium does not depend on ϵ. However, it is clear from Eq. (2) that a weaker ability to cooperate in the SSO increases the magnitude of the coordination failure, by reinforcing private incentives towards either free riding or rent seeking.

Consortia are a potential means to address the lack of cooperation, by allowing a subgroup of firms to work together ahead of the SSO meetings. We now consider this possibility by allowing $k < n$ firms to cooperate more closely within consortium K. Since consortia do not involve any formal contracting on joint R&D decisions, we posit a higher yet still imperfect degree of cooperation between them: $\epsilon' = \epsilon + \Delta$ with $\Delta > 0$ and small. The program of a consortium member $i \in K$ then becomes

$$\max_{x_i}(1-\epsilon-\Delta)b_i + \Delta\sum_{j \in K} b_j + \epsilon v(x) - x_i c_i$$

while the program of non-member firms remains unchanged. Summing the n FOC and comparing with Eq. (2),[5] we obtain that the consortium induces more innovation if

$$\frac{rv(x^*)}{x^*} < v_x(x^*)\left[1 + (1-r)\left(\frac{s_K}{x_K^*/x^*} - 1\right)\right] \tag{5}$$

where $s_K = \Sigma_{j \in K} s_j$ and $x_K = \Sigma_{j \in K} x_j$ denote the consortium members' aggregate market share and share of inventions in the standard. Observe first that when these two indicators of the consortium weight are aligned ($x_K^*/x^* = s_K$), condition (5) precisely defines a *Public Good* regime. Enhanced cooperation within the consortium then clearly

[4] See Appendix 1.1 for the full derivation of this equation.

[5] See Appendix 1.2 for the full demonstration.

mitigates the free riding problem at the aggregate level. Conversely, the consortium induces a fall of innovation if inequality in Eq. (5) is reversed. Since for ${x_K}^*/x^* = s_K$, reversing Eq. (5) defines a *Rent Seeking* regime, it follows that the creation of the consortium is also efficient at the industry level in this case. We summarize these findings in Proposition 2.

Proposition 2. *Effect of the creation of a consortium by a group of* $k < n$ *firms:*

- *The consortium induces more (respectively less) innovation at the aggregate level under a Public Good (Rent Seeking) regime if its market share is equal to its share of innovations contributed to the standard.*
- *The firms' reaction functions are then such that the entry of a new firm in the consortium induces more (less) innovation by the new and other members in a Public Good (Rent Seeking) equilibrium, and no direct reaction by non-members.*

Proof. See Appendix 1.3. ■

Note that when equality ${x_K}^*/x^* = s_K$ is relaxed, condition (5) may not necessarily hold if incentives towards free-riding and rent-seeking are balanced (that is, if $rv(x^*) / x^* - v_x(x^*)$ is close to zero).[6] Therefore, the consortium is more likely to mitigate coordination failures the stronger the *Public Good* or *Rent Seeking* problem prevailing in equilibrium. Observe in particular that inequality in Eq. (5) is always verified in a pure *Public Good* regime ($r = 0$). Conversely, it cannot hold in a *Rent Seeking* regime such that further innovation would not enhance anymore the value of the standard ($v_x(x^*) = 0$).

3. Empirical analysis

The theory predicts that standard setting organizations may be oriented towards two different regimes – *Public-Good* or *Rent-Seeking* – that induce opposite effects of consortium formation on firms' R&D investments. Probing this result thus requires an empirical counterpart for the distinction between both regimes.

In the model, this dichotomy primarily depends on the share of profits accruing to patent holders. However, we cannot observe this parameter empirically. As an alternative, we draw on the model's prediction that pure R&D firms should be present in *Rent Seeking* regimes only. Since such firms monetize their R&D through licensing only, they can indeed profitably take part in standard development only if licensing revenues exceed R&D costs — which is the theoretical condition for a *Rent Seeking* regime to prevail. Empirically, pure R&D firms may also have an incentive to contribute to standards in a *Public Good* regime, for instance if they have lower R&D costs than the average firm, or if they have stakes in technologies which are complementary to the standard. The incentives of pure R&D firms to contribute to a standard, relative to the incentives of firms making profits from manufacturing standard-compliant products, should nevertheless be significantly stronger in the *Rent Seeking* regime. We confirm this by testing Hypothesis 1 below, and subsequently use the firm composition (the share of pure R&D firms among the firms contributing to a standard) at the standard level to infer which regime characterizes a standard.

Hypothesis 1. The rate of participation of pure R&D firms is correlated with a higher volume of patents targeting the standard.

We then assess whether the effect of consortium membership on standard-related innovation (measured by citation-weighted patents) reverses from the *Public-Good* to the *Rent-Seeking* regime. We derive more specifically the following hypotheses from Proposition 2.

[6] The consortium may then further reduce innovation under a Public Good regime if its share of innovations strongly exceeds its market share. Conversely, it may further increase innovation under a (weak) Rent Seeking regime if its share of innovations is way below its market share.

Hypothesis 2. Entry of a new member in the consortium induces:

a) More (less) innovation by the new member when the standard is characterized by no or weak participation of pure R&D firms (a strong participation of pure R&D firms).
b) More (less) innovation by the other consortium members when the standard is characterized by no or weak participation of pure R&D firms (a strong participation of pure R&D firms).
c) No reaction by the non-members.

Proof. See Appendix 1.2. ■

Note that the decision to join a consortium is endogenous, and driven by motives that are not explicitly accounted for by the theory. We use several refinements to control for the self-selection of consortium members, and find consistent evidence confirming our hypotheses. However, in the absence of appropriate instruments, empirical results should be interpreted carefully: we do not identify the average effect of consortium membership in each regime, but a difference in this effect between *Public-Good* and *Rent-Seeking* regimes which is consistent with our theoretical model.

In Section 3.1, we present the data, describe our sample selection and discuss our measure of standard-related innovation. Section 3.2 provides descriptive statistics highlighting an increase in the rate of citation-weighted patents after a company joins a consortium. This increase is however only observable in the case of standards without participation by pure R&D firms. In Section 3.3, we find that the participation of pure R&D firms is correlated with higher volumes of citation-weighted patents, confirming Hypothesis 1. Using the participation of pure R&D firms to indicate a *Rent-Seeking* regime, we then analyze in Section 3.4 the effect of consortia on standard-related innovation in standards characterized by *Rent-Seeking* or *Public-Good* regimes. Companies increase their own output of citation-weighted patents after joining a consortium. Other consortium members also increase their innovation output as a reaction to a new firm joining the consortium. Both effects are significantly weaker or even become negative in the case of a *Rent-Seeking* regime. There is no significant reaction by non-members. These results confirm our Hypothesis 2.

3.1. Data and indicators

Our empirical analysis draws on a comprehensive dataset of ICT standard documents issued between 1992 and 2009 by one of the major formal SSOs which operate on an international level.[7] Since we aim to focus on the interaction between formal standardization and companion standards consortia, we exclude standards that are exclusively developed by informal standards consortia (e.g. BluRay).

We identify 1400 standards[8] for which companies have declared to own standard essential patents. We restrict the analysis to standards for which such declarations have been made by at least four different companies, thereby limiting the sample to 167 standards. Companies that own IPRs which they believe to be essential to a standard provide this information to the respective SSO.[9] The SSOs make the declarations publicly available, but do not assess or endorse the claim that the

[7] ISO, the International Electrotechnical Commission (IEC), JTC1, the European Committee for Standardization and the European Committee for Electrotechnical Standardization (CEN/CENELEC), the International Telecommunication Union (ITU-T and ITU-R), ETSI, and IEEE.

[8] For the purpose of the empirical analysis, we define a standard as a single standard document or technical specification. Complex technology standards, such as the 4th generation mobile telecommunication standard LTE, can consist in a large number of such specifications.

[9] For a discussion how to use this information, see Bekkers et al. (2012). Our own approach differs in several respects. First, we restrict our analysis to formal SSOs. Second, we also make use of blanket declarations, for instance to establish a connection between a firm and a standard. Third, our database relates patent declarations to single standards, using the PERINORM data to identify and aggregate different versions and technical specifications relating to the same standard.

declared patents are standard essential. We downloaded these patent declarations at the websites of the above-mentioned SSOs in March 2010.[10] Bibliometric information on standards was retrieved from the PERINORM database,[11] and includes the date of first release, releases of further versions and amendments, number of pages from the standard document, accreditations in other SSOs, references from or to other standards and the technical classification of the standard. We further collected data from the ProQuest BusinessWire search page to count how many companies mention specific standards in their product news releases. We applied this news feed count to our sample of standards to have an approximate measure of how many firms adopted the standard in their products over the last years.

We define the firms contributing to the standard as the firms declaring at least one essential patent.[12] Our sample includes 86 different companies declaring essential patents, observed over the whole period of analysis. For each firm we collect yearly information on the amount of sales, R&D expenditure, employees and market to book value ratio (Tobin's Q).[13] We distinguish between pure R&D firms, manufacturers and net providers[14] and classify our sample by the main industry in which a company is active using Standard Industrial Classification (SIC) codes.

We connect the firm level data to the specific standard information whenever a company declares essential patents for a standard and build up a panel of 577 company-standard pairs observed over a time span of 18 years (1992–2009). For each company-standard pair, we observe the patents filed by the respective company in the technological field for the respective standard and include a dummy variable indicating whether the company takes part in a consortium supporting the development of this standard.

3.1.1. Matching between informal consortia and formal standards

To identify standards consortia accompanying the formal standardization process, we use data from 15 editions of the CEN survey[15] of ICT consortia and a list of consortia provided by Andrew Updegrove.[16] We identify approximately 250 active ICT standards consortia. We categorize these consortia as to industry, function (preparation of specifications, promotion, certification etc.) and years of activity. We identify connections between these consortia and the standards in our sample by using liaison agreements, supplemented with information from consortia and SSO web pages. For instance, a connection was identified when a consortium explicitly references a formal standard or is listed as member of the SSO working group for a standard. We are conservative in establishing the connections, resulting in a narrow list of 54 consortia. We further restrict the list to 21 consortia that technologically (e.g. by drafting specifications, excluding pure promotion or certification consortia) and significantly contribute to this specific standard.[17] Using information on the websites of the consortia as well as internet archives (www.archive.org), we track consortium membership over time and connect this information with the company standard pairs of our sample.

3.1.2. Standard-related innovation

An intuitive approach to track firms' R&D contributions to a specific standard would be to count the declared standard essential patents. However, the timing of declaration is highly strategic and often disconnected from the timing of innovation (Ganglmair and Tarentino, 2012). Moreover, declared essential patents only represent a very small amount of patenting around standards (Bekkers et al., 2012). Furthermore, since the declarations of essential patents are not assessed by a third party, companies can both over- and under-declare essential patents they own. To avoid these shortcomings, we build up a new measure of standard-specific R&D innovation. In a first step we identify all patents filed from 1992 to 2009 by the companies in our sample at the three major patent offices: the US Patent and Trademark Office (USPTO), the Japanese Patent Office (JPO) and the European Patent Office (EPO). Second, for each standard, we identify International Patent Classification (IPC) classes that are technologically relevant to this particular standard. This is done by using the IPC of standard essential patents. Finally, patents are weighted by the number of forward citations received during the first four years after grant. We conduct several analyses to corroborate the reliability of our novel measure of standard-specific R&D investment (details can be consulted in Appendix 2). For instance, we verify that the variable is sensitive to the standard lifecycle, and effectively culminates in the year of standard release (Fig. 1).[18]

3.2. Descriptive statistics

3.2.1. Difference in means

In Table 2, we present differences in the volume of (citation weighted) patents, the number of employees, the value of sales and the book-to-market ratio between consortia member and other companies in the sample. Consortium membership is associated with a lower volume of standard-specific innovation, but a higher number of employees and a higher value of sales. (See Table 1.)

3.2.2. Comparison before and after consortium creation

For a first empirical analysis of the effects of consortia, we plot the aggregate innovation output (as measured by citation-weighted patents) over company-standard pairs as to the timing with respect to consortia formation. According to our theoretical implications, we expect different effects for standards subject to strong *Rent Seeking* or *Public Good* regimes, and we expect pure R&D firms to be much more likely to participate in standards characterized by the latter. We therefore split our sample according to whether or not a pure R&D firm is contributing to the standard. We normalize by the number of (citation-weighted) patents filed before consortium creation, and graph the normalized (citation weighted) patent files over the 10 years before and after consortia foundation.

Fig. 2 shows that the innovation output follows similar trends up to the date of consortium creation, but declines much stronger for

[10] A very similar dataset of patents collected more recently by Tim Simcoe is available for download at http://www.ssopatents.org.

[11] PERINORM is the world's biggest standard database with bibliographic information on formal standards and is regularly updated by the German Institute for Standardization (DIN), the British Standards Institute (BSI) and the French Association for Standardization (AFNOR).

[12] The actual membership in most of the SSOs in our sample (except the IEEE and ETSI) consists in representatives of the official national SSOs such as the American National Standards Institute (ANSI) and DIN. The technology for their standards is however dominantly contributed by private firms.

[13] We used the Thomson one Banker database to match the respective firm level data. This information is available only for companies listed on the stock market. Consistently, it appears that the firms in our sample are on average very large. While the model is very general, we can empirically validate our predictions only for the case of large firms.

[14] We used the extended business model description in the Thomson One Banker database and compared our classification to the list of companies identified by Layne-Farrar and Lerner (2011).

[15] The CEN survey lists ICT standards consortia that are active on an international level and is updated every year since 1998. For a full list of standard consortia consult: http://www.cen.eu/cen/sectors/sectors/isss/consortia/pages/default.aspx.

[16] Andrew Updegrove has been involved in the creation of 135 standards consortia since 1988. He updates the most comprehensive list of consortia, which can be consulted at http://www.consortiuminfo.org/links/#.UcJnWZSmodU and also compare Updegrove (1995).

[17] We identify consortia contributing technologically by analyzing the consortia self-description abstracts, kindly provided by A. Updegrove. We selected consortia describing their role e.g. as developing or creating standards. Details of this selection procedure can be consulted in the supplementary material, including a list of consortia and standards for which a link could be established, as well as the narrower list of consortia contributing technologically.

[18] The methodology and the various tests have been presented at the Patent Statistics for Decision Makers Conference 2011 at the USPTO and can be reviewed in Appendix 2.

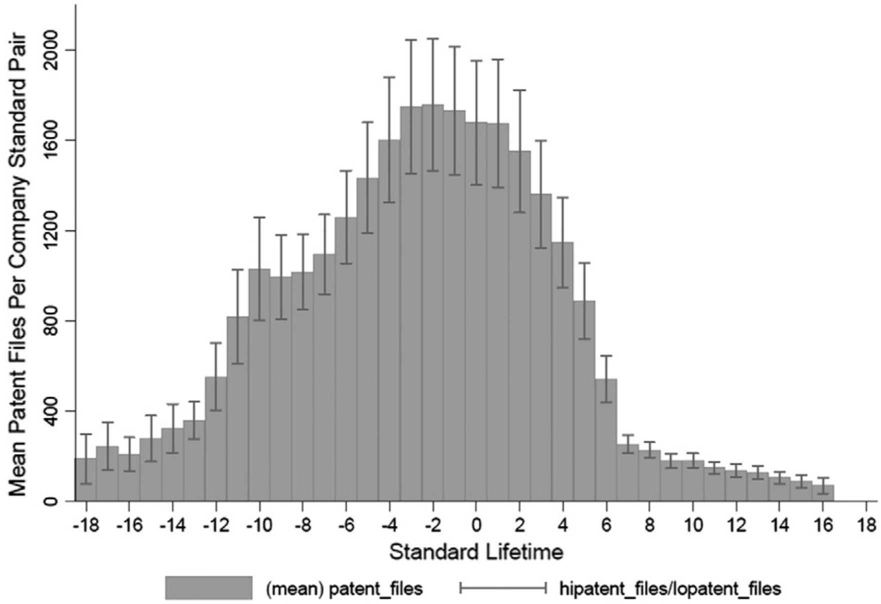

Fig. 1. Mean number of patents filed in years before and after standard release.

standards with a participation of pure R&D firms once a consortium has been created. We further differentiate these outputs for companies that become consortia member and other companies that contribute to the same standard without joining the consortium. Fig. 3 shows that the output of future members and non-members is very similar before consortium formation but then diverges. In the case of standards where pure R&D firms do not participate, consortium members increase their innovation output after consortium formation, while the output of outsiders is comparably lower. This is however not the case for standards with pure R&D firm participation. The results suggest that consortium members have a different innovation output compared to outsiders and that this effect indeed depends on the nature of firms' incentives to contribute to the standard (*Public Good* versus *Rent Seeking* regime).

3.3. Rent Seeking regimes and the participation of pure R&D firms

One contribution of our analysis is to highlight *Public Good* and *Rent Seeking* regimes in standard development. The theoretical analysis revealed that a pure R&D firm with average R&D costs finds it profitable to contribute to a standard only when the *Rent Seeking* regime prevails. We therefore expect the participation of pure R&D firms to be correlated with the occurrence of a *Rent Seeking* regime. We empirically examine this proposition by testing Hypothesis 1, which states that the participation of pure R&D firms is correlated with a higher innovation output targeting the standard. To test this prediction, we run a simple cross-section regression of innovation output (measured by citation-weighted standard related patent files) against technical characteristics

Table 1
Summary statistics of the sample variables.

Variable	Obs	Description	Data source	Mean	Std. dev.	Min	Max
Patent files	3318	Triadic patent priority filings by this firm in the standard-related IPC classes, weighted by class relevance weighted by forward citations (4 year window)	Patstat	3.110	11.435	0.000	220.000
Consortium-member	3318	Membership of this company in the consortium related to this standard consortium related to this standard	Internet search	0.156	0.363	0.000	1.000
Consortium member × overinvestment	3318	Membership of this company interacted with the share of non-producing entities for this standard	Internet search	0.022	0.056	0.000	0.400
Lag1 · Standard-event	3318	Sum of standard amendments and version releases	PERINORM	0.408	1.043	−1.000	8.000
IPC control[a]	3318	Worldwide triadic patent priority filings in either Telecom or IT	Patstat	2.725	0.197	2.225	3.019
All SEP-declarations[c]	3318	Number of patent declarations to all formal standards	Internet search	6.405	4.108	1.396	13.938
Lag1·firmsize (employees)[a]	3318	Number of employees of the company	Thomson One Banker	1.631	1.431	0.038	4.840
Lag1·Tobin'sQ	3318	Market-to-book ratio of the company	Thomson One Banker	1.540	1.315	0.110	7.422
Standard adoption	3318	Number of business news releases for this standard	Pro-Quest BusinessWire	3.271	41.750	0.000	1225.1
Accreditations cumulated	3318	Cumulative number of international SSO accreditations of this standard	PERINORM	1.038	2.161	0.000	13.000
References cumulated	3318	Cumulative number of foreword references of this standard	PERINORM	9.938	18.876	0.000	119.000
Version age	3318	Number of years since last version release	PERINORM	4.371	3.229	1.000	16.000
Pre-sample patent files[b]	4161	Mean number of standard related and citation weighted patent files in the years 1992–2001	Patstat	31.186	109.000	0.000	1420.000

Note:
[a] numbers are divided by 100,000.
[b] numbers are divided by 10,000.
[c] numbers are divided by 1000.

Table 2
Differences in variable means between consortia members and others (outsider or standard contributors without consortium).

t = 5.3553	Citation weighted patent files					
Group	Obs	Mean	Std. err.	Std. dev.	[95% conf. interval]	
Consortium members	615	42,754.2	2257.5	55,984.4	38,320.6	47,187.3
Not consortium members	2703	302,793.1	22,092.5	1,203,787.0	259,474.8	346,111.1
t = −2.2283	Employees					
Consortium members	615	170,178.9	4678.2	116,015.1	160,991.7	179,366.1
Not consortium members	2703	156,601.1	2598.3	141,576.8	151,506.5	161,695.7
t = −3.6873	Sales					
Consortium members	615	49,316.3	998.5	24,761.9	47,355.4	51,277.1
Not consortium members	2703	45,361.1	442.8	24,125.8	44,492.9	46,229.2
t = 0.2815	Book-to-market ratio					
Consortium members	615	1.5	0.1	1.4	1.4	1.6
Not consortium members	2703	1.5	0.0	1.3	1.5	1.6

of the standards and firm characteristics. We aggregate the citation-weighted patent counts of each firm-standard pair over the 8 years before and the 8 years after standard release, and restrict the sample to standards receiving declarations of essential patents from more than four companies.

$$cites_{ij} = \beta_1 rentseeking + \beta_2 X_i + \beta_3 X_j + \beta_4 + cites_{ij}^{pre-sample} + \varepsilon_{ij} \qquad (6)$$

where i is a firm and j is a standard. The key variable of interest is *rentseeking*, which is indicated by the percentage of pure R&D firms among the firms contributing to the standard. X_i is a set of firm-specific control variables, for instance the yearly average R&D expenditures by the firm and the maximum yearly sales volume reached in the period of observation, whereas X_j is a set of standard-specific control variables, including the total number of amendments received, the maximum number of pages reached, the ICS technology class and the year of first standard release. We furthermore control for the pre-sample innovation output in the technology classes relevant to the standard. We run a linear regression over the log of the explained variable in Model 1 and a negative binomial regression in Model 2. The error terms are clustered by company.

The results of the analysis are presented in Table 3. The share of pure R&D firms is very significantly positively correlated with a higher innovation output targeting the standard by all contributing firms, controlling for the characteristics of the firm and the standard. This is no evidence for a causal effect of pure R&D firm participation on patenting. This finding rather confirms that pure R&D firms are more likely to be present in standards characterized by an unusually high level of patenting. We will therefore in the following use the share of pure R&D firms as empirical indicator for the occurrence of a *Rent Seeking* regime.

Table 4 provides a descriptive overview over the distribution of the variable in the sample. The rate of pure R&D firm participation ranges from 0 to 100%. Considering our sample of firm-standard pairs for standards with more than 4 contributing firms, 51% of firm-standard-observations imply standards with a rate of pure R&D firms between 10% and 20%. This proportion is even larger if we restrict the analysis to standards related to a consortium. The full table of standards related to consortia and their share of pure R&D firms can be consulted in the supplementary material.

3.4. Effect of joining a consortium

3.4.1. Estimation methodology

To test our second set of hypotheses, we analyze the effect of joining a consortium in a panel dataset of firm-standard pairs (group) observed over the standard life (time, 0 in the year of standard release). Our dependent variable is the innovation output, as measured by the number of citation-weighted patent priority filings by firm i in the relevant IPC classes for standard j in year t. We use two different explanatory variables to test for the effect of consortium membership. Our first key explanatory variable, $member_{ijt}$, is a dummy indicating that in year t firm i participates in a consortium supporting standard j. In a second step, we test the effect of $member\_share_{ijt}$, a variable that measures the proportion of firms declaring to own essential patents for standard j who also are member of a consortium supporting this standard. Following the theoretical model, we interact the respective consortium variables

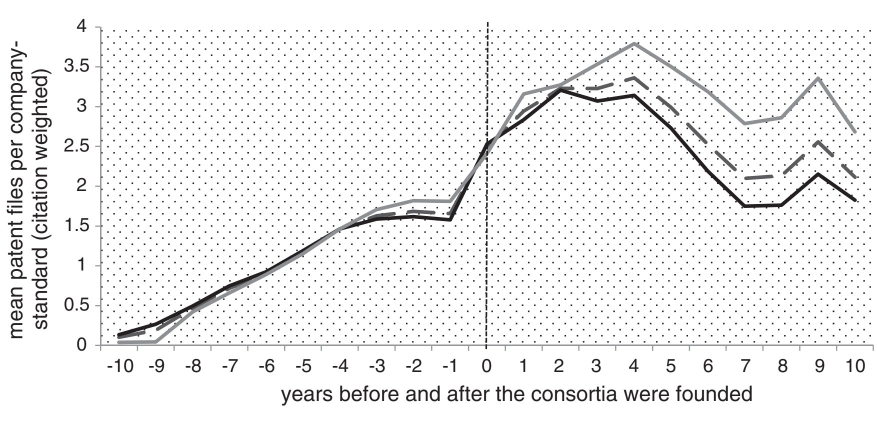

Fig. 2. Normalized patent files (citation weighted) of company-standard pairs 10 years before and after consortia foundation for standards identified with a *Rent Seeking* or *Public Good* pattern.

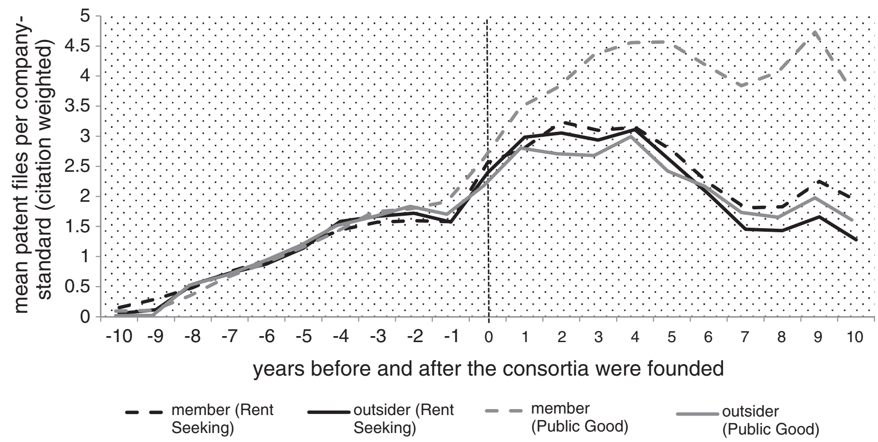

Fig. 3. Normalized patent files (citation weighted) of company-standard pairs 10 years before and after consortia foundation in a consortium member and outsider comparison.

with the *rent_seeking*$_j$ variable, denoting the share of pure R&D firms involved in the development of standard *j*.

We use two sets of control groups to identify the effect of consortium membership. Our sample includes companies staying out of an existing consortium, and companies contributing to technological standards for which no consortium has been created. While the first comparison is subject to a self-selection bias, the second analysis is prone to heterogeneity between standards. For instance, companies wishing to expand their standard-related investment are more likely to join a consortium, and consortia are more likely to be created for standards about to undergo substantial technological progress. We include fixed effects for company-standard pairs and use a wide range of control variables and sample restrictions to contain these issues. Our main identification results from the heterogeneity of the treatment effect between standards characterized by *Public Good* and *Rent Seeking* regimes. Self-selection of firms with particular interests in a standard into a consortium and the endogenous creation of consortia for dynamic standards should induce a positive correlation between consortium membership and standard-related innovation output for all standards. The expected causal effect of consortium participation however depends on the nature of the incentives that prevail for a specific standard. The distinction between *Public-Good* and *Rent-Seeking* regimes thus allows identifying a causal effect of consortia, accounting for all biases that affect innovation in *Rent-Seeking* and *Public-Good* regime standards alike.

We use the standard age dummies to control for the baseline timing of innovation with respect to standardization. We furthermore include the number of years elapsed since the issue of the current standard version. We also include the number of references that the standard receives from other standards, the number of times the standard is accredited at other SSOs, and a count of news feeds mentioning the standard to capture time-variant standard events affecting its commercial and technological importance. In order to account for immediate feedback of the dependent variable to the regressors, we lag all time-variant controls by one year.

As we include standard fixed effects and standard age, it is not possible to include year dummies as a further control because of a strict collinearity problem.[19] We therefore control for external shocks and time trends by including the overall number of triadic[20] patent priorities filed per year in the relevant technological category (respectively IPC class G for telecom and IPC class H for IT standards) and the overall number of patent declarations made to any formal ICT standard per year in order to capture policy shocks relevant to essential patents. While desirable in order to reduce within-group bias on weakly endogenous variables (Bloom et al., 2013), the long period of observation increases the likelihood of structural breaks. We therefore restrict the sample to increase the comparability of the observations, and reduce the period of observations to 2002 to 2009. For the same reason, we further restrict the sample on the firm level in case of major sudden shocks to firm size, indicating mergers, acquisitions, restructuring, etc.[21]

In addition, we control for the volume of sales and the Tobin's Q to control for a company's size and prospects. These firm-specific variables can potentially be endogenous to the firm's success in innovating for a standard. Given the large size of the firms in our sample, we don't believe this to be a significant problem. To rule out a direct effect, again, we lag the control variables by one year.

As our dependent variable is a count variable with overdispersion with respect to a poisson distribution, we will use a poisson estimator

Table 3
Results of the multivariate analysis — testing rent seeking and pure R&D firms participation.

	Model 1	Model 2
	Coeff./std. error	Coeff./std. error
NPE_share	2.408***	4.037***
	0.875	0.871
Max_Numberpages	0.001***	0.001***
	0.000	0.000
Amendments_cumulative	−0.056***	-0.075***
	0.011	0.006
Release year	0.003	0.013
	0.016	0.019
Avrg_R&D-expense	0.001***	0.000***
	0.000	0.000
Max_Sales	-0.000	−0.000
	0.000	0.000
Pre_sample_means	0.001***	0.001***
	0.000	0.000
Constant	5.781	−13.860
	32.020	37.755
Observations	973	974
F(10, 962)	39.91	
R^2	0.2932	
LR Chi2		414.98
Pseudo R^2		0.0139

Note: ***, ** and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively. The dependent variable is standard related citation weighted patent files. The unit of observation is company-standard pair. Standard errors are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firm.

19 For a discussion of this problem, see for instance Mehta et al. (2010).

20 A patent family is labeled triadic when it is represented in the three major patent jurisdictions (USA, Europe, Japan).

21 We identify positive or negative shocks to the number of employees in a one year period. If this shock takes place after 2005, all observations after the shock are dropped for this company; if the shock takes place earlier, we drop all previous observations. Major shocks are defined as the top and bottom 5% in the distribution of yearly percentual changes.

Table 4
Sample statistics: participation rate of pure R&D firms.

Strata	Share of pure R&D firms	Avge share (StdDev) of pure R&D firms	N standards	N observations sample	N observations consortium exists
1 (low)	0–10%	0.0313 (0.0365)	61 (37%)	1208 (34%)	331 (25%)
2 (mid)	10–20%	0.1401 (0.0223)	57 (35%)	1829 (51%)	903 (68%)
3 (high)	20–100%	0.2654 (0.0706)	47 (28%)	547 (15%)	102 (8%)

with robust standard errors unless explicitly stated otherwise.[22] We furthermore cluster standard errors by companies.[23]

Our baseline regression model has the following specification:

$$E\left[CITES_{ijt}\right] = exp(\alpha_1 \cdot consortium_{ijt} + \alpha_2 \cdot consortium_{ijt} * rent\_seesking_j + ST_{jt-1} \cdot \beta_1 + F_{it-1} \cdot \beta_2 + X_t \cdot \beta_3 + c_{jt} + \omega_{ij} + \varepsilon_{ijt})$$

where $CITES_{ijt}$ are the citation weighted standard related patent files, and $consortium_{ijt}$ is the key explanatory variable. In the first set of models, it takes the form of a dummy variable indicating that in year t firm i participates in a consortium supporting standard j, whereas in the second set of models it is represented by the share of consortium members among the firms contributing to standard j. Variable $rent\_seeking_j$ denotes the share of pure R&D firms and ST_{jt-1} are the variables that account for standard related activities such as standard version or amendment release, standard adoption, standard accreditations, standard references and standard version age. F_{it-1} is a vector of firm specific time-variant controls such as size changes of employees. X_t denotes other time variant control variables, such as the overall number ICT patent files and the total number of patent declarations. c_{jt} is the full vector of yearly standard age dummies. ω_{ij} is the unobserved specific effect of firm i and standard j (we control for these effects using the fixed effects model). By clustering our standard errors we allow for standard errors to have arbitrary heteroscedacity and autocorrelation. Therefore we do not report the exact functional form of our error terms.

3.4.2. Results of the models: Effect of joining a consortium on a firm's own innovation output

We first analyze the effect of joining a consortium on a firm's innovation output, in order to test the first of our hypotheses. Results are displayed in Table 5. Results based upon the whole sample are presented in model M1 (M1a is the baseline model, M1b includes a large set of control variables). The coefficients on the consortia variables are large and highly significant, but the fit of the model is low, indicating substantial unobserved heterogeneity between standards. Furthermore, we expect self-selection of firms to be significant in this specification.

In our second model (M2), we analyze the effect of consortium membership only in the sample of firms contributing to standards for which we identified a consortium. As expected, this restriction considerably reduces unobserved heterogeneity and strongly improves the fit of the model. The issue of self-selection into consortia is however particularly important in this specification, since the control group only consists of companies that were at risk of being a consortium member but have chosen not to join. Control variables like Tobin's Q can only imperfectly deal with the issue of endogeneity.

We therefore run Model 3 where consortium outsiders have been removed from the sample and the control group consists of companies contributing to different standards. As compared to self-selection of firms, the unobserved reasons for consortia existence are more likely to be orthogonal to a firm's future investment in standard-specific innovation. They include for instance strategic alignment, geographical proximity or a common experience of collaboration between firms contributing to a standard. Also the policy environment has been more or less favorable to this type of cooperation over time. Reasons that are likely to be correlated with a firm's future investment include the expected commercial value and technological complexity of the standard. The fixed effects and our large set of standard-specific time-variant control variables should partly deal with the issue of heterogeneity between standards associated to consortia and other standards. This specification however only partly accounts for the problem of self-selection into consortia, since the control group consists in companies that would and would not choose to become member if a consortium was created for this particular standard.

In our preferred model M4 we implement a propensity score matching (PSM) to identify a comparable control group of firms contributing to standards without consortia, but that have similar characteristics as firms joining consortia for other standards where we identify a consortium. We apply a logit based PSM algorithm to identify a common support region for both samples. We use variables that explain why companies join standards consortia, e.g. a company's technological closeness to a standard, a company's innovation focus on a particular standard and a company's sector relation to a standard. We apply the nearest neighbor matching method where we match partners between consortia members and companies contributing to standard without consortium. Following this approach reduces our sample to 1346 observations and 209 groups. Results in M4 are robust while the PSM match increases the fit of our model.[24]

Consortium membership has a significant positive effect on standard-specific innovation throughout the models. This result is to be interpreted with caution. Unobservable variables, such as changes in the strategic importance of the standard for the specific company, may have an impact on both standard specific patents and consortium membership. The interaction term of consortium membership with the rate of pure R&D firms, signaling a *Rent Seeking* regime, has a negative and strongly significant effect throughout the models. This effect is much less likely to be prone to endogeneity biases, and is consistent with the prediction that consortium membership induces opposite effects according to the investment regime prevailing on a standard.

In order to refine this analysis, we classify our observations into three groups according to their share of pure R&D firms. We then estimate the effect of consortium membership by group and compute incident-rate ratios (IRR, results reported in Appendix 3). According to our preferred model M4, a firm increases its level of standard-specific innovation by 30% when joining a consortium related to a standard with a low rate of pure R&D firms (less than 10%), whereas the innovation rate decreases by 68% with consortium membership for standards with a high rate of pure R&D firms (more than 20%). There is no apparent effect of consortium membership in the intermediate case. The interpretation of these numbers is subject to caution, since only the difference between the ratios, but not the level of the ratios itself, is robust to endogeneity concerns. Nevertheless, the magnitude of the reported effects suggests that the effect of consortium membership is economically highly significant.[25]

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[22] We prefer the poisson estimator with robust standard errors over a negative binomial estimator in order to fully control for the company-standard pair fixed effects.

[23] All presented results are robust to clustering standard errors by standard instead of by company.

[24] Details of the PSM matching can be consulted in the online appendix: www.inno.tu-berlin.de/fileadmin/a38335100/Aktuelles/supplementary_material_September_2013.pdf.

[25] The magnitude of the estimated effects is plausible for the observations that we analyze. Our sample consists in a relatively small number of standard-consortia pairs where the role of the consortium in the standard setting process was clearly apparent and a priori likely to be significant. Furthermore, the majority of observations in the sample are characterized by a participation rate of pure R&D firms between 10 and 20%. As compared to the overall population of technology standards, this appears to be a high value. We can therefore interpret values above this range as indicating a pronounced *rent seeking* pattern.

Table 5
Results of the multivariate analysis — testing consortia membership.

	Model 1a	Model 1b	Model 2	Model 3	Model 4
	Coeff./std.err	Coeff./std.err	Coeff./std.err	Coeff./std.err	Coeff./std.err
Consortium-member	1.009***	0.956***	0.933***	0.677***	0.616***
	(0.132)	(0.155)	(0.133)	(0.095)	(0.137)
ConsMember_overinv	−6.085***	−5.813***	−5.913***	−5.061***	−4.560***
	(0.667)	(0.349)	(0.456)	(0.721)	0.596
Lag1Standard-event	−0.125***	−0.100***	−0.076***	−0.100***	−0.097***
	(0.016)	(0.219)	(0.012)	(0.016)	(0.017)
IPC_control[a]	0.274**	0.216**	1.912***	1.598	0.103
	(0.231)	(0.237)	(0.239)	(0.229)	(0.055)
All SEP-declarations[a]	0.121***	0.121*	0.232***	0.272***	0.227***
	(0.123)	(0.111)	(0.113)	(0.135)	(0.161)
Lag1·firmsize[a] (employees)		−0.244	−0.007	−0.237	0.230
		(0.021)	(0.022)	(0.045)	(0.047)
Lag1·Tobin'sQ		−0.162***	−0.191**	−0.172	−0.159
		(0.045)	(0.055)	(0.186)	(0.131)
Standard adoption[a]		0.062**		−0.021***	−0.202***
		(0.134)		(0.126)	(0.164)
Accreditations cumulated		0.031		−0.011***	−0.131***
		(0.065)		(0.033)	(0.034)
References cumulated				0.005	0.006
				(0.007)	(0.006)
Version age				−0.140***	−0.149***
				(0.021)	(0.027)
Standard age dummies	Yes	Yes	Yes	Yes	Yes
Sample restriction	No restriction	No restriction	Consortium exist	Outsider excluded	Outsider excluded & PSM
Observations	3584	3584	1385	1715	1346
Groups	599	599	201	265	209
LogLikelihood[b]	−13,241	−13,145	−12,809	−3246	−1940
AIC[b]	2.82e[4]	2.68e[4]	3334	3492	4987
BIC[b]	2.82e[4]	2.68e[4]	3334	3492	4987

Note: ***, ** and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively. The dependent variable is standard related citation weighted patent files. The unit of observation is company-standard pair. All models are estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firm. Models 1, 2 and 4 are restricted to a limited time period 2002–2009.
[a] Coefficients inflated to make effects visible.
[b] Values divided by 1000.

3.4.3. Results of the model: Effect of joining a consortium on the patent output of other contributing firms

We now estimate the effect of the consortium member share (indicating the share of consortium members among the firms contributing to the standard) on innovation by incumbent members and outsiders. By estimating this effect on innovation output by all companies, we also obtain a measure of the overall effect of consortia on standard-related innovation.

As compared to the previous analysis, this method is less prone to endogeneity biases, as the decisions of other companies to join a consortium are probably less directly related to a firm's own current or expected future patent output. Nevertheless, the potential unobservable factors simultaneously influencing firms' incentives to file patents and to join consortia may be correlated across firms contributing to the same standard. Similar caution is therefore warranted for the interpretation of the coefficient for the consortium member share, and identification results once again from heterogeneity of treatment effects across types of standards.

We estimate the effects of consortium member share sequentially for consortium members, for non-members and for both. A company is classified as consortium outsider up to the year of entry (or after exit), and as insider only during the time when it was effectively listed as consortium member. The standard-company-year observations in which the analyzed company joins itself the consortium is removed from the sample. We control for time-variant firm characteristics, standard-company fixed effects and external shocks. Results are displayed in Table 6.

Consortium members react to increasing consortium member share by inflating their innovation output. Once again this effect strongly decreases with the participation rate of pure R&D firms, suggesting that consortia could have opposite effects in the case of marked *Patent Race* and *Public Good* regimes (Model 5). Consortium outsiders do not react in a statistically significant way to changes in consortium member share (Model 6). The overall effect (the effect indistinctly for members or outsiders) of increasing consortium member share on the volume of standard-specific innovation is positive and significant, but this effect decreases significantly with the participation rate of pure R&D firms (Model 7).

3.4.4. Robustness analysis

We check for robustness of our results to a correlation of our main explanatory variables with past outcomes of the dependent variable. We apply a methodology developed by Blundell et al. (2002) to further control for unobserved fixed effects. The authors confirm the assumption that unobserved fixed effect can be expressed as a linear function of observable pre-sample means, and suggest substituting the pre-sample averages of the dependent variable for the group fixed effect. They show that the pre-sample mean of the dependent variable is a sufficient statistic for the unobserved fixed effect. We make use of this approach as an additional regressor to control for persistent unobserved heterogeneity. Our estimations provide significant results for the consortia variables. Furthermore the coefficients of the pre-sample means are positive and significant in all specifications, which indicates that controlling for unobserved heterogeneity of the patent behavior is statistically important.[26]

[26] Results can be consulted in the supplementary material.

Table 6
Results of the multivariate analysis — effect of consortia member share on insider and outsider patent output.

	Model 5 *insiders*	Model 6 *outsiders*	Model 7 *joint*
	Coeff./(std. err.)	Coeff./(std. err.)	Coeff./(std. err.)
Relative consortia size	1.347**	0.997	1.564***
	(0.553)	(1.229)	(0.505)
Relative consortia size_overinvestment	−8.134***	5.632	−9.978***
	(2.584)	(8.770)	(3.003)
IPC-control[a]	0.201***	0.216***	0.196***
	(0.025)	(0.022)	(0.016)
All SEP declarations[a]	0.378***	0.061	0.361***
	(0.081)	(0.111)	(0.074)
References cumul	−0.005	−0.009	−0.005
	(0.004)	(0.010)	(0.004)
Accreditations cumul	0.064**	0.063*	0.058*
	(0.032)	(0.036)	(0.032)
Standard adoption[a]	−0.560	−3.218**	−0.542
	(0.412)	(1.406)	(0.485)
Standard age dummies	Yes	Yes	Yes
LogLikelihood[b]	−2258.8	−1430.5	−4027.2
AIC[b]	4517	2861	8054
BIC[b]	4517	2861	8055
Observations	812	919	1731
Groups	120	87	207

Note: ***, ** and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively. The dependent variable is standard related citation weighted patent files. The unit of observation is company-standard pair. All models are estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firm.
[a] Coefficients inflated to make effects visible.
[b] Values divided by 1000.

4. Conclusion

The question addressed in this paper is whether consortia can mitigate R&D coordination failures in the joint development of formal standards by enabling their members to better cooperate. We first developed a theoretical framework accounting for firms' incentives to develop innovations for a standard in a context of weak cooperation. This model highlights two types of coordination failure depending on the structure of the firms' incentives. When innovation is chiefly driven by expected sales of standard compliant products, a *Public Good* regime prevails in equilibrium whereby firms tend to free ride on each other's R&D. Conversely, a wasteful *Rent Seeking* prevails when incentives mainly proceed from the licensing of standard essential patents. Against this background, we show that enhanced cooperation between a subgroup of firms within a consortium can improve R&D coordination by increasing (decreasing) innovation at the formal SSO level if the *Public Good* (*Rent Seeking*) regime is strong enough.

We provide empirical support for this prediction based on a large panel of ICT standards. We use our model's prediction that a *Public Good* regime prevents pure R&D firms from taking part in the standard development to identify standards that are subject to *Rent Seeking* regime. We find that subsequent to a firm's entry into a consortium, both the firm itself and incumbent consortia members increase the level of innovation efforts. This finding is consistent with the predictions of the model, but could also be driven by self-selection into consortia and endogenous creation of consortia for particular standards. More conclusively, the positive effect of entry into consortia on patent output is significantly weakened or even reversed in the case of standards characterized by a *Rent Seeking* regime. This heterogeneity of consortium effects empirically validates the predictions of our model.

Our theoretical analysis focuses upon the case where a subset of firms contributing to a formal standard can integrate a single companion consortium in order to add an additional layer of coordination. In our empirical analysis, we have focused upon standards and consortia that fit to this story reasonably well. The universe of existing standards consortia is however more heterogeneous. In several cases, different subsets of contributing firms have created or integrated different consortia related to the same standard. In other cases, consortia that initially develop specifications for formal standards can compete with the SSO and start promoting their own standards. In these cases, consortia could potentially result in a reduced degree of R&D coordination and stronger rivalry. We do not expect our results to generally hold for the case of competing consortia, but leave a more comprehensive analysis of these issues for future research.

Appendix 1

1.1

Solving Eq. (1) gives the first order condition below:

$$(1-\epsilon)v_x(x)\left[r\frac{x_i}{x}+(1-r)s_i\right]+(1-\epsilon)\frac{rv(x)}{x}\left(1-\frac{x_i}{x}\right)+\epsilon v_x(x)=c_i. \tag{7}$$

Summing the FOC for all $i=1,n$ yields in turn

$$(1-\epsilon)v_x(x^*)+(1-\epsilon)\frac{rv(x^*)}{x^*}(n-1)+n\epsilon v_x(x^*)=\sum_{i=1}^{n}c_i.$$

Dividing by n, we obtain

$$(1-\epsilon)\frac{1}{n}\left[v_x(x^*)+(n-1)\frac{rv(x^*)}{x^*}\right]+\epsilon v_x(x^*)=\overline{c}$$

where $\overline{c}=\sum_{i=1}^{n}c_i/n$.

1.2

Comparing $v_x(x)$ with the right hand side of Eq. (2), we obtain easily that

$$\frac{1}{n}\left\{v_x(x)+(n-1)\frac{rv(x)}{x}+(n-1)\epsilon\left[v_x-\frac{rv(x)}{x}\right]\right\}>v_x(x)$$

if $rv(x)/x>v_x(x)$.

Using again Eq. (2) we can also express $v_x(x^*)$ as follows

$$v_x(x^*)=\frac{n}{1+\epsilon(n-1)}\overline{c}-\frac{(1-\epsilon)(n-1)}{1+\epsilon(n-1)}\frac{rv(x^*)}{x^*}$$

Or, after subtracting $v_x(x^*)/x^*$ on both sides and rearranging

$$v_x(x^*)-\frac{rv(x^*)}{x^*}=\frac{n}{1+\epsilon(n-1)}\left[\bar{c}-\frac{rv(x^*)}{x^*}\right].$$

It follows that

$$\frac{rv(x^*)}{x^*}\lessgtr v_x(x^*) \quad \text{if} \quad \frac{rv(x^*)}{x^*}-c\lessgtr 0.$$

1.3

Assume that $k<n$ firms form a consortium K. We posit that consortium members have a stronger ability to cooperate with each other, which we denote by $\epsilon'=\epsilon+\Delta$. The program of a consortium member is thus

$$\max_{x_i}(1-\epsilon-\Delta)v(x)\left[r\frac{x_i}{x}+(1-r)s_i\right]+\epsilon v(x) \\ +\Delta v(x)\sum_{j\in K}\left[r\frac{x_j}{x}+(1-r)s_j\right]-x_ic_i. \tag{8}$$

After rearranging, the first order condition of this program is

$$(1-\epsilon)v_x(x)\left[r\frac{x_i}{x}+(1-r)s_i\right]+(1-\epsilon)v(x)r\frac{x-x_i}{x^2}+\epsilon v_x(x) \\ +\Delta\sum_{\substack{j\in K\\ j\neq i}}\left\{v_x(x)\left[r\frac{x_j}{x}+(1-r)s_j\right]-rv(x)\frac{x_j}{x^2}\right\}=c_i. \tag{8}$$

After summing all FOCs, we thus obtain

$$v_x(x^*)+(n-1)\frac{rv(x^*)}{x^*}+(n-1)\epsilon\left[v_x-\frac{rv(x^*)}{x^*}\right] \\ +\Delta\sum_{i\in K}\sum_{\substack{j\in K\\ j\neq i}}\left\{v_x(x^*)\left[r\frac{x_j^*}{x^*}+(1-r)s_j\right]-rv(x^*)\frac{x_j^*}{(x^*)x^2}\right\}=n\bar{c}.$$

Noting $x_K^*=\sum_{i\in K}x_i^*$, this simplifies into

$$v_x(x^*)+(n-1)\frac{rv(x^*)}{x^*}+(n-1)\epsilon\left[v_x-\frac{rv(x^*)}{x^*}\right] \\ \Delta(k-1)\frac{x_K^*}{x^*}\left[v_x(x^*(1-r))\left(\frac{s_Kx^*}{x_K^*}-1\right)+v_x(x^*)-\frac{rv(x^*)}{x^*}\right]=n\bar{c}. \tag{9}$$

The only difference with Eq. (2) due to the consortium is the fourth term on the LHS. It clearly implies that the consortium induces more (respectively, less) innovation in equilibrium contribution x^* if this term is positive (negative), that is if:

$$v_x(x^*)\left[r+(1-r)\frac{s_Kx^*}{x_K^*}\right]-\frac{rv(x^*)}{x^*}>0.$$

We can finally rearrange this inequality as follows:

$$\frac{rv(x^*)}{x^*}<v_x(x^*)\left[1+(1-r)\left(\frac{s_K}{x_K^*/x^*}-1\right)\right]. \tag{10}$$

1.4. Testable predictions

Consider now again the reaction function of firm $i\in K$, as given by Eq. (8).

$$(1-\epsilon)v_x(x)\left[r\frac{x_i}{x}+(1-r)s_i\right]+(1-\epsilon)v(x)r\frac{x-x_i}{x^2}+\epsilon v_x(x) \\ +\Delta\left\{v_x(x)\left[r\frac{x_K-x_i}{x}+(1-r)(s_K-s_i)\right]-rv(x)\frac{x_K-x_i}{x^2}\right\}=c_i.$$

Let us assume first that firm i is a representative member of the consortium, so that $s_i=s_K/k=x_i/x_K$. After simplifying and rearranging, we can then rewrite this equation as:

$$(1-\epsilon)v_x(x)\left[r\frac{x_i}{x}+(1-r)s_i\right]+(1-\epsilon)v(x)r\frac{x-x_i}{x^2}+\epsilon v_x(x) \\ +\Delta\frac{k-1}{k}\left[v_x(x)(1-r)\left(s_K-\frac{x_K}{x}\right)+\frac{x_K}{x}\left(v_x(x)-r\frac{v(x)}{x}\right)\right]=c_i.$$

If the consortium induces more (less) innovation (as defined by Eq. (10)), it follows from the above expression that:

1) Starting from $\Delta=0$, a representative firm that joins the consortium (so that $d\Delta>0$) increases (decreases) its contribution x_i.
2) Following the entry of a new member ($dk=1$), a firm that was already a member increases (decreases) its contribution.
3) The entry of new firms in the consortium has no direct effect on a non-member (that is, when $\Delta=0$).

Appendix 2. Empirical methodology for measuring standard-related innovation

We propose a methodology that matches standards with IPC (International Patent Classification) patent classes for the study of innovation in ICT standards. The analysis builds upon patents that are declared essential for technological standards. However, declared essential patents only represent a very small share of all patents that are technologically related to standards. The number of declared essential patents furthermore depends upon strategic interactions and policy rules, leading to a higher or lower declaration propensity (Bekkers et al., 2012; Ganglmair and Tarentino, 2012). While the number of essential patents would thus be a poor measure of investment in standards, essential patents nevertheless indicate the IPC classes that are relevant to the standard. Therefore we identify a standard's relevant technological field by using the IPC classification of declared standard essential patents.

For our analysis we gather more than 62,000 patent declarations, yielding a list of 1.405 relevant IPC classes at the 5-digit level. We then identify patents filed by each company in the identified IPC classes. We count all patents filed from 1992 to 2009 by the companies in our sample at the three major patent offices (USPTO, JPO and EPO), using the Patstat database and company assignee merging methods of Thoma et al. (2010). This merging yields 13 million patent files. We then aggregate these patents to INPADOC patent families and inform the IPC classification and the year of priority. To create our explained variable, we compute for each company-standard pair and year the number of patents filed in the relevant IPC classes for the standard of observation.

This method is a novel way of measuring standard-specific R&D investment, and we therefore have to conduct a reliability analysis. We compute for each company-standard pair the mean number of patents filed in one year periods before and after standard release (t = 0) and report the standard derivation for high and low values (Fig. 1). The resulting regime is a convincing description of the innovation process around standardization: the number of patents filed is highest for years immediately preceding standard release, and sharply decreases after the release of the standard. The further we move away from the development phase of the standard, the lower are the calculated numbers of relevant patents. We believe that these findings are important arguments corroborating our methodology.

Appendix 3. Incident rate ratios (IRR), estimation of consortium membership by group

Table 7

Results of the multivariate analysis — incidence rate ratios (IRR) by groups.

	Model 1a	Model 1b	Model 2	Model 3	Model 4
	IRR/std.err	IRR/std.err	IRR/std.err	IRR/std.err	IRR/std.err
Consortium-member * NPE low	1.452***	1.768***	1.476***	1.345***	1.307***
	(0.205)	(0.191)	(0.153)	(0.083)	(0.060)
Consortium-member * NPE mid	1.214*	1.161	1.445	0.985	0.004
	(0.118)	(0.121)	(0.467)	(0.881)	(0.088)
Consortium-member * NPE high	0.431***	0.426***	0.442***	0.323***	0.315***
	(0.176)	(0.131)	(0.151)	(0.121)	(0.017)
Lag1Standard-event	0.886***	0.026***	0.946***	0.987***	0.912***
	(0.026)	(0.2144)	(0.222)	(0.116)	(0.016)
IPC_control[a]	0.998**	0.998**	0.999***	1.001***	1.003
	(0.241)	(0.267)	(0.289)	(0.348)	(0.015)
All SEP-declarations[a]	1.001***	1.006	1.004***	1.002***	1.008***
	(0.145)	(0.123)	(0.123)	(0.235)	(0.022)
Lag1·firmsize[a] (employees)		0.9997	1	0.999	1.001
		(0.031)	(0.122)	(0.126)	(0.922)
Lag1·Tobin'sQ		0.845***	0.882**	0.876	0.875
		(0.125)	(0.125)	(0.226)	(0.101)
Standard adoption[a]		0.998**		0.999***	0.998***
		(0.134)		(0.226)	(0.224)
Accreditations cumulated		0.931***		0.884***	0.867***
		(0.055)		(0.233)	(0.014)
References cumulated				1.007	1.026
				(0.023)	(0.007)
Version age				0.868***	0.861***
				(0.011)	(0.017)
Standard age dummies	Yes	Yes	Yes	Yes	Yes
Sample restriction	No restriction	No restriction	Consortium exist	Outsider excluded	Outsider excluded & PSM
Observations	3584	3584	1385	1715	1346
Groups	599	599	201	265	209
LogLikelihood[b]	−13,241	−13,145	−12,809	−3246	−1940
AIC[b]	2.82e4	2.68e4	3334	3492	4987
BIC[b]	2.82e4	2.68e4	3334	3492	4987

Note: ***, ** and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively. The dependent variable is standard related citation weighted patent files. The unit of observation is company-standard pair. All models are estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedasticity and allow for serial correlation through clustering by firm. IRR reports incidence rate ratios. Models 1, 2 and 4 are restricted to a limited time period 2002–2009.

[a] Coefficients inflated to make effects visible.

[b] Values divided by 1000.

Appendix 4. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ijindorg.2014.05.004.

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