Standards, consortia, and innovation

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Abstract

The development of formal ICT standards is a challenging form of collaborative innovation, as it combining consensus decision and R&D rivalry. To supplement this formal standard setting process, it has thus become frequent that a sub-group of involved firms create ad hoc consortia to try and better align positions on a common technology roadmap. This paper aims to assess whether such consortia can 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* pattern. 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* pattern.

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1 Introduction

Over the past thirty years, standardization in ICT has evolved from the definition of simple specifications to the joint development of large technology platforms including increasingly complex technologies[1]. Consequently, standards tend to embody a growing number of patented components (Bekkers et al, 2012).

While the conditions for licensing these standard essential patents have been widely discussed (see e.g., Shapiro, 2001; Lerner & Tirole, 2004; Layne-Farrar & Lerner, 2011), the peculiar type of R&D collaboration they proceed from has received less attention so far. Formal ICT standards are developed in standard setting organizations (SSOs)–such as ETSI (telecommunications) or IEEE (electronics)–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 become the standard. As a result, formal standardization may entail R&D duplications and delays due to vested interests (Farrell & Simcoe, 2012; Simcoe, 2012).

Against this background, it has become common that a sub-group of the companies contributing to the standard form an ad hoc consortium to supplement the formal standard setting process. Some consortia substitute for more formal SSOs and issue their own standards (Lerner & Tirole, 2006), including the Blu-Ray alliance or the W3C for web protocols. But most of them actually accompany formal standardization[2] (Cargill & Weiss, 1992). Important examples are the WiMAX Forum, providing a collaboration forum for companies contributing to wireless communication standards developed at the IEEE, or the UMTS Forum, representing the interests of its members regarding 3G mobile phone standards in SSOs such as ETSI and the 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 & 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

[1] As an example, the number of functionalities and formats (e.g., email, video, internet) supported by the late wireless communication standards (3G and 4G) considerably exceed 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). 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. JTC1 has a similar policy of featuring Approved References Specifications (ARS).

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 unlock innovation in the standard setting process but also, in some cases, mitigate excessive patenting around standards.

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* pattern 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* pattern 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*) pattern 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, citations-weighted patent applications to measure innovation at firm level, and matched these observations with information on firms' participation in 21 closely related consortia. The main source of identification is hereby the opposite effect of consortia participation on standards characterized by Public Good and Rent Seeking patterns. 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* pattern. Our results are consistent with the predictions. Overall, we observe an increase in patent output after a firm joined a consortium. The effect of joining a consortium however significantly and negatively depends upon participation of pure R&D firms. This finding is consistent with a weaker positive or even negative effect of consortia in the case of strong *Rent Seeking* patterns.

While a large strand of papers discuss optimal rules for licensing essential patents (Lerner & Tirole, 2004; Swanson & Baumol, 2005; Lerner et al., 2007; Shapiro, 2010), we take the reverse approach by highligting 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 (d'Aspremont & Jacquemin, 1988; Kamien et al. 1992; Amir et al., 2003) to capture firms' ability to (imperfectly) cooperate in a simple way. However, the type of interactions we aim to account for have been analyzed in more details in the literature on standard setting. Farrell and Saloner (1988), Farrell and

Simcoe (2012) and Ganglmair and Tarantino (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, Lerner and Tirole (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 the 3rd Generation Partnership Project (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 $v(x, r)$ 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 $v_{xx} < 0$. Parameter $r \in [0, 1]$ denotes the share of aggregate profits accruing to essential patents owners through royalties, and can by thought of as reflecting the IP policy of the standard setting organization[3]. Since royalties tend to raise the marginal costs of product manufacturers, thereby hampering demand for standard compliant product, r has a negative effect on aggregate profits: $v_r < 0$, $v_{xr} < 0$. In the sequel, we will however consider r as exogenous, and focus the analysis on the number of inventions contributed by firms under different appropriation regimes. For simplicity of notation we will therefore write $v(x)$ from now on.

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 $x = \sum x_i$. In line with actual industry practices, we posit that aggregate licensing revenues $rv(x)$ are split according to the firms' shares of essential patents, that is

[3] Setting $r = 0$ would for instance denote a royalty free licensing policy.

x_i/x. The remaining part of aggregate profits–that is $(1-r)\,v$–is split between manufacturers in proportion of their weight s_i in the product market. Taking into account both sources of profits, the revenue of firm $i = 1, n$ is thus:

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

Cooperation at the SSO level 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, Farrel and Simcoe (2012) and Ganglmair & Tarantino (2012) show that they fail to achieve the first best outcome.

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

$$\max_{x_i} \; (1-\varrho)\, b_i + \varrho \sum_{j=1}^{n} b_j - x_i c_i \tag{1}$$

Parameter ϱ is a simple way to relax the assumption of joint profit maximization usually made in the literature on R&D cooperation (d'Aspremont & Jacquemin, 1988; Kamien et al, 1992; Amir et al., 2003). 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 & Tarantino (2012) provide microfundations. We will however see in the sequel that our key results hold for any $\varrho < 1$.

Public Good versus Rent Seeking Summing the FOC of (1) for all firms $i = 1, n$ and rearranging, we derive the number of inventions x^* embodied in the standard in equilibrium[4].

$$\frac{1}{n}\left[v_x(x^*) + (n-1)\frac{rv(x^*)}{x^*}\right] + \varrho\frac{n-1}{n}\left[v_x - \frac{rv(x^*)}{x^*}\right] = \bar{c} \tag{2}$$

where $\bar{c} = \sum c_i/n$. The first term on the LHS captures the aggregate marginal profits in absence of cooperation ($\varrho = 0$). It displays the properties of public good investment (marginal benefits are diluted when n increases), but also royalty driven incentives for $r > 0$ which are larger the number of rival firms. Note that the latter might in particular induce firms to continue developing inventions even though they have no incremental value for the standard anymore (that

[4] See Appendix 1.a for the full derivation of this equation.

is, when $v_x(x^*) = 0$). The second term on the LHS captures the marginal aggregate cost or benefit of invention by firm i when there is some cooperation between the firms ($\varrho > 0$) and will be discussed in the sequel.

On the RHS of (2), x^* depends on the average of the firms' unit costs, but not on their distribution between firms. Accordingly, we can use the outcome $\hat{x}$ of a fully cooperative scenario ($\varrho = 1$) with average cost $\bar{c}$ as a benchmark to assess the firms' incentives to innovate in a co-opetitive equilibrium ($\varrho < 1$). By simply comparing the LHS of (2) with $v_x(x^*)$, we derive the following result.

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

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

Proof. See Appendix 1.b ■

Whether firms tend to free ride on each other (*Public Good*) or compete aggressively to push inventions in the standard (*Rent Seeking*) ultimately depends on the profits made by licensors. Intuitively, a *Public Good* equilibrium takes place when firms' incentives are primarily driven by the possibility to use the standard. Conversely, *Rent Seeking* prevails when licensing is profitable per se. Formally, this translates into a condition on the average profitability of licensing. Observe in particular that the participation of a pure R&D firm ($s_i = 0$) with average cost $\bar{c}$ is profitable only in a *Rent Seeking* equilibrium:

$$rv(x^*) \gtrless \bar{c}x^* \quad \Leftrightarrow \quad \frac{x_i^*}{x^*} rv(x^*) - c_i x^* \gtrless 0 \tag{3}$$

Since pure R&D firms monetize their innovations through licensing only, their business model is indeed hardly compatible with *Public Good* standards. One can therefore expect their involvement to be selective, which provides us with a first testable hypothesis for empirical analysis.

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

Cooperation through a consortium According to Proposition 1, the type of inefficiency pattern prevailing in equilibrium does not depend on ϱ. However, it is clear from (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 SSP meetings. We now consider this possibility by allowing $k < n$ firms to cooperate more closely a 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: $\varrho' = \varrho + \Delta$ with $\Delta > 0$ and small. The program of a consortium member $i \in K$ then becomes

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

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

$$\frac{rv(x^*)}{x^*} - v_x(x^*) < (1-r) v_x(x^*) \left[\frac{s_K x^*}{x_K^*} - 1 \right] \tag{4}$$

where $x_K = \sum_{j \in K} x_j$ and $s_K = \sum_{j \in K} s_j$. Conversely, the consortium induces a fall of innovation if inequality (4) is reversed. Observe first that the term on the LHS is positive (negative) in a *Rent Seeking* (*Public Good*) equilibrium. When the joint contributions of consortium members reflect their market shares ($x_K^* / x^* = s_K$), it is thus clear that enhanced cooperation within the consortium helps to mitigate free-riding or rent seeking strategies at the aggregate level. However, relaxing this assumption may generate a bias of the consortium towards either free-riding ($s_K x^* < x_K^*$) or rent seeking ($s_K x^* > x_K^*$)[6] if the LHS of (4)) is small (denoting a small coordination failure). Accordingly, a sufficient condition for the consortium to be pro-efficient is that the *Rent Seeking* or *Public Good* pattern be strong in equilibrium. Observe in particular that inequailty (4) is always true in a pure *Public Good* ($r = 0$), while it never holders in a pure *Rent Seeking* pattern ($r = 1$).

Proposition 2 *Effect of a consortium:*

- *The creation of a consortium by a group of $k < n$ firms induces more (respectively less) innovation at the aggregate level if a strong enough Public Good (Rent Seeking) pattern prevails in equilibrium.*
- *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.c ■

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[5] See Appendix 1.c for the full demonstration.

[6] The bias towards free-riding occurs if (i) for $s_K = k/n$, the members' average cost of innovation is relatively low (that is, if $c_K = \sum_{j \in K} c_j < k\bar{c}$) or, assuming that $c_K = k\bar{c}$ if (ii) members have relatively low market shares ($s_K < k/n$) in a Rent Seeking equilibrium, or iii) they have relatively high market shares ($s_K > k/n$) in a Public Good equilibrium. Symmetrically, a bias towards free riding occurs in the reverse conditions.

Proposition 2 provides us with a set of predictions contrasting the impact of a consortium in the Public Good or Rent Seeking patterns. Drawing on Proposition 1, we can test these results empirically, by using the rate of participation of pure R&D firms to track standards with Rent Seeking patterns. In order to account for standards with *strong* coordination failures, we will focus especially on cases where the participation of pure R&D firms is important or inexistent. We derive our predictions from the firms' reaction to the entry of a new member in the consortium.

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 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 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.b ■

3 Empirical analysis

We test our hypotheses empirically on a panel of 167 standards and 21 consortia from 2002 to 2009, using citations-weighted patents as a measure of standard-related innovation. Our main objective is to assess whether the effect of consortium membership on innovation reverses as predicted with the pattern of coordination failure at the standard level. Therefore, we focus the analysis on heterogeneity across different categories of standards, more than the main effect of consortium membership.

3.1 Data and indicators

Our empirical analysis draws on a comprehensive dataset of technological standards including standard essential patents. Our sample includes all ICT standards 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 1,400 standards for which essential patents have been declared and restrict the analysis to standards including standard essential patents of at least four different companies, thereby limiting the sample to 167 standards.

[7] ISO, IEC, JTC1 - a joint committee of ISO and IEC -, CEN/CENELEC, ITU-T, ITU-R, ETSI, and IEEE.

Companies that own IPRs which are essential to a standard provide this information to the respective SSO[8]. We downloaded these patent declarations from the websites of the above-mentioned SSOs in March 2010. Bibliometric information on standards was retrieved from the PERINORM database[9], 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[10]. 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)[11]. We distinguish between pure R&D firms, manufacturers and net providers[12] and classify our sample by the main industry in which a company is active using 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.

INSERT TABLE 1 HERE

Matching between informal consortia and formal standards To identify standards consortia accompanying the formal standardization process, we

[8] 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.

[9] PERINORM is the world's biggest standard database with bibliographic information on formal standards and is regularly updated by the SSOs DIN, BSI and AFNOR.

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

[11] 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.

[12] 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).

use data from 15 editions of the CEN survey[13] of ICT consortia and a list of consortia provided by Andrew Updegrove[14]. 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[15]. 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.

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 Tarantino, 2012). Moreover, declared essential patents only represent a very small amount of patenting around standards (Bekkers et al., 2012). To avoid these shortcomings, we build up a new measure of standard-specific 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 (USPTO, JPO and EPO). Second, for each standard, we identify 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 innovation (details can be consulted in Appendix 2). For instance, we verify that the variable is sensitive to the standard life-cycle (Figure 1). Over the standard lifetime, our measure effectively culminates in the year of standard release[16].

[13] 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.

[14] 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).

[15] 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.

[16] 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.

INSERT FIGURE 1 HERE

3.2 Descriptive Statistics

Difference in means In the following 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. Membership observation is associated with a lower volume of standard-specific innovation, but a higher number of employees and a higher value of sales.

INSERT TABLE 2 HERE

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*** patterns, 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.

Figure 1 shows that the innovation output follows similar trends up to the date of consortium creation, but declines much stronger for 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. Figure 2 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*** pattern).

INSERT FIGURE 2 AND FIGURE 3 HERE

3.3 Rent seeking patterns and the participation of pure R&D ftrms

One contribution of our analysis is to highlight ***Public Good*** and ***Rent Seeking*** patterns in standard development. As shown in the theoretical model, a pure

R&D firm with average R&D costs finds it profitable to contribute to a standard only when the *Rent Seeking* pattern prevails. We therefore expect the participation of pure R&D firms to be correlated with the occurrence of a *Rent Seeking* pattern. To test this prediction, we run a simple cross-section regression of standard related innovation against technical characteristics of the standards[17].

$$st\_patents_j = \beta X_j + \varepsilon_j \quad (5)$$

where j is a standard. The errors are not i.i.d. over the sample of standards. A *Rent Seeking* pattern results in a larger innovation output than for standards in a *Public Good* pattern at given technological characteristics: $\varepsilon_{RS} > \varepsilon_{PG}$, where the subscript RS and PG respectively stand for the standard being subject to a *Rent Seeking* or *Public Good* pattern.

By Hypothesis 1, we then also expect the residuals of our estimations (5) to be higher for standards with participation of pure R&D firms. A t-test analysis shows that the residual values are on average positive for standards where pure R&D firms participate and negative for those where pure R&D firms are not involved. The difference is highly significant. In the remainder of the analysis, we will use the participation of pure R&D firms as indication for a *Rent Seeking* pattern; a higher share of pure R&D firms indicating a more pronounced *Rent Seeking* pattern.

INSERT TABLE 3 HERE

3.4 Effect of joining a consortium

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 member share of the firms contributing to the standard. Following the theoretical model, we interact the respective consortium variables with the $rent\_seesking_j$ 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

[17] Details are provided in the supplementary material.

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 patterns. While the expected effect of consortium membership is opposite in the two patterns, we expect that the endogeneity of consortia creation and participation induce the same upward bias for both types of standards.

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[18]. We therefore control for external shocks and time trends by including the overall number of triadic 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-groups bias on weakly endogenous variables (Nickell, 1981; Bloom et al., 2005), 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[19].

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 with robust standard errors unless explicitly stated otherwise[20]. We furthermore cluster

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

[19] 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.

[20] We prefer the poisson estimator with robust standard errors over a negative binomial

standard errors by companies[21] .

Our baseline regression model has the following specification:

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

where $CITES_{ijt}$ are 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 $rent\_seesking_j$ denotes the share of pure R&D firms, ST_{jt-1} are variables that account for standard related activities such as standard version or amendment release, standard adoption, standard accreditations, standard references or 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.

Results of the models: Effect of joining a consortium on a ftrm'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 empirical implication of hypothesis 2. 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 that firms self-select into consortia due to factors that are correlated with their future innovation output related to the particular standard. This problem is not adequately addressed 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. The reasons for this choice are

estimator in order to fully control for the company-standard pair fixed effects.

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

likely to be highly correlated with the company's incentives to invest in standard-related innovation. Our firm-level control variables can only imperfectly deal with this issue of endogeneity.

We therefore run Models 3 and 4 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 firms' 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. The group of firms contributing to different standards however includes firms that would and firms that would not join a consortium if such a consortium existed.

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 in 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 standard consortia e.g. a company's technology 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 identify matching partners of treated and untreated standards. Following this approach reduces our sample to 1,346 observations and 209 groups. Results in M4 are robuts while the PSM match increases the fit of our model[22].

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 pattern, 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 pattern prevailing on a standard. The coefficient is consistently 6 to 7 times larger in magnitude than the coefficient for consortium membership. Even though subject to caution, these results indicate that the net effect of consortium membership is negative for standards with a pure R&D firms participation rate of above approx. 15%, which is the case for almost 25%

[22] Details of the PSM matching are provided in the supplementary material.

of the standards in this sample.

Insert Table 4 here

Results of the model: Effect of joining a consortium on the patent output of other contributing ftrms 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 5.

INSERT TABLE 5 HERE

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* patterns (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).

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. The authors 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[23].

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*** pattern 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***) pattern 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*** pattern prevents pure R&D firms from taking part in the standard development to identify standards that are subject to ***Rent Seeking*** pattern. 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*** pattern. 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

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

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.

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Appendix 1.a

Solving (1) gives the first order condition below:

$$(1-\varrho)v_x(x)\left[r\frac{x_i}{x}+(1-r)s_i\right]+(1-\varrho)\frac{rv(x)}{x}\left[1-\frac{x_i}{x}\right]+\varrho v_x(x)=c_i \quad (6)$$

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

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

Isolating the terms in ϱ and dividing by n, we obtain

$$\frac{1}{n}\left[v_x(x)+(n-1)\frac{rv(x)}{x}\right]+\frac{n-1}{n}\varrho\left[v_x(x)-\frac{rv(x)}{x}\right]=\frac{\sum_{i=1}^{n}c_i}{n}$$

Appendix 1.b

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

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

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

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

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

Or, after substracting $rv(x^*)/x^*$ on both sides and rearraging

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

It follows that

$$\frac{rv(x^*)}{x^*}\lesseqgtr v_x(x^*) \text{ if } \frac{rv(x^*)}{x^*}-\bar{c}\lesseqgtr 0$$

Appendix 1.c

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 $\varrho'=\varrho+\Delta$. The program of a consortium member is thus

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

After rearranging, the first order condition of this program is

$$
\begin{aligned}
&(1-\varrho)v_x(x)\left[r\frac{x_i}{x}+(1-r)s_i\right] \\
&+(1-\varrho)v(x)r\frac{x-x_i}{x^2} \\
&+\varrho v_x(x) \\
&+\Delta\sum_{\substack{j\in K\\ j\neq i}}\left(v_x(x)\left[r\frac{x_j}{x}+(1-r)s_j\right]-rv(x)\frac{x_j}{x^2}\right) \\
=\;& c_i
\end{aligned}
\tag{7}
$$

After summing all FOCs, we thus obtain

$$
\begin{aligned}
&v_x(x^*)+(n-1)\frac{rv(x^*)}{x^*}+(n-1)\varrho\left[v_x-\frac{rv(x^*)}{x^*}\right] \\
&+\Delta\sum_{i\in K}\sum_{\substack{j\in K\\ j\neq i}}\left(v_x(x^*)\left[r\frac{x_j^*}{x^*}+(1-r)s_j\right]-rv(x^*)\frac{x_j^*}{(x^*)^2}\right) \\
=\;& nc
\end{aligned}
$$

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

$$
\begin{aligned}
&v_x(x^*)+(n-1)\frac{rv(x^*)}{x^*}+(n-1)\varrho\left[v_x-\frac{rv(x^*)}{x^*}\right] \\
&+\Delta(k-1)\frac{x_K^*}{x^*}\left[v_x(x^*)(1-r)\left[\frac{s_K x^*}{x_K^*}-1\right]+v_x(x^*)-\frac{rv(x^*)}{x^*}\right] \\
=\;& nc
\end{aligned}
\tag{8}
$$

The only difference with (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:

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

We can rearrange this inequality as follows:

$$
\left[\frac{s_K x^*}{x_K^*}-1\right](1-r)v_x(x^*)>\frac{rv(x^*)}{x^*}-v_x(x^*)
\tag{9}
$$

where the term on the RHS of (9) is positive (negative) if a Rent Seeking (Public Good) pattern prevails in equilibrium.

Testable predictions Consider now again the reaction function of firm $i \in K$, as given by (7).

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

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:

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

If the coordination failure is strong enough in equilibrium (as defined by (9)), 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 in a Public Good (Rent Seeking) equilibrium.

2) Following the entry of a new member ($dk = 1$), a firm that was already a member increases (decreases) its contribution in a Public Good (Rent Seeking) equilibrium.

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 (Ganglmair and Tarantino, 2012; Bekkers et al., 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 (figure 1). The resulting pattern 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.

Variable	Obs	Description	Data Source	Mean	Std. Dev.	Min	Max
Patent files	3,318	Triadic patent priority filings by this firm in the standard-related IPC classes, weighted by class relevance weighted by forward citations (4 years window)	Patstat	3.110	11.435	0.000	220.000
Consortium-member	3,318	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 X Rent Seeking	3,318	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	3,318	Sum of standard amendments and version releases	PERINORM	0.408	1.043	-1.000	8.000
IPC control[1]	3,318	Worldwide triadic patent priority filings in either Telecom or IT	Patstat	2.725	0.197	2.225	3.019
All SEP-declarations[3]	3,318	Number of patent declarations to all formal standards	Internet search	6.405	4.108	1.396	13.938
Lag1 Firmsize (employees)[1]	3,318	Number of employees of the company	Thomson One Banker	1.631	1.431	0.038	4.840
Lag1.Tobin'sQ	3,318	Market-to-book ratio of the company	Thomson One Banker	1.540	1.315	0.110	7.422
Standard adoption	3,318	Number of business news releases for this standard	Pro-Quest BusinessWire	3.271	41.750	0.000	1,225.1
Accreditations cumulated	3,318	Cumulative number of international SSO accreditations of this standard	PERINORM	1.038	2.161	0.000	13.000
References cumulated	3,318	Cumulative number of foreword references of this standard	PERINORM	9.938	18.876	0.000	119.000
Version age	3,318	Number of years since last version release	PERINORM	4.371	3.229	1.000	16.000
Pre-sample patent files[2]	4,161	Mean number of standard related and citation weighted patent files in the years 1992-2001	Patstat	31.186	109.000	0.000	1,420.000

Note: [1]numbers are divided by 100,000; [2]numbers are divided by 10,000, [3]numbers are divided by 1,000

Table 1:*Summary statistics of the sample variables*

t = 5.3553	Citation weighted Patent Files					
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	615	42,754.2	2,257.5	55,984.4	38,320.6	47,187.3
not consortium members	2,703	302,793.1	22,092.5	1,203,787.0	259,474.8	346,111.1
t = -2.2283	Employees					
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	615	170,178.9	4,678.2	116,015.1	160,991.7	179,366.1
not consortium members	2,703	156,601.1	2,598.3	141,576.8	151,506.5	161,695.7
t = -3.6873	Sales					
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	615	49,316.3	998.5	24,761.9	47,355.4	51,277.1
not consortium members	2,703	45,361.1	442.8	24,125.8	44,492.9	46,229.2
t = 0.2815	Book-To-Market Ratio					
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	615	1.5	0.1	1.4	1.4	1.6
not consortium members	2,703	1.5	0.0	1.3	1.5	1.6

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

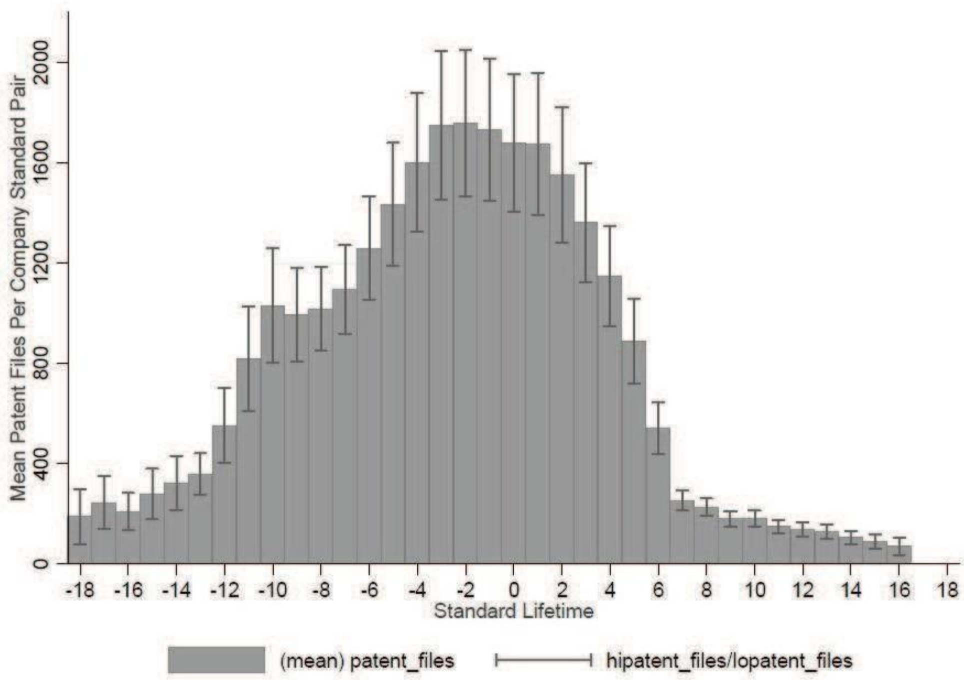

Figure 1: *Mean number of patents filed in years before and after standard release*

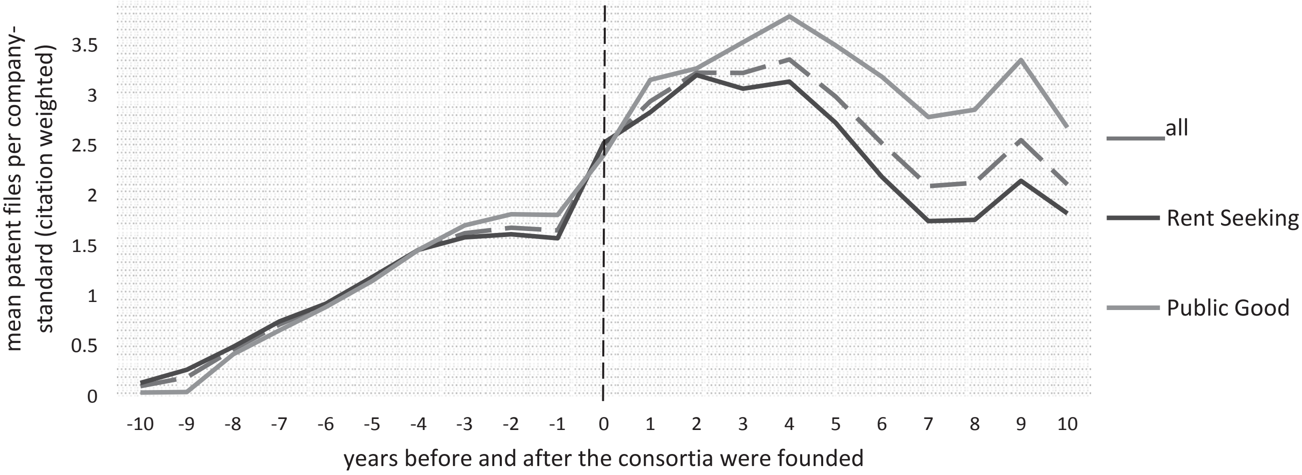

Figure 2: *Normalized patent files (citation weighted) of company-standard pairs 10 years before and after consortia foundation for standards identified with a Rent Seeking or Public Good pattern*

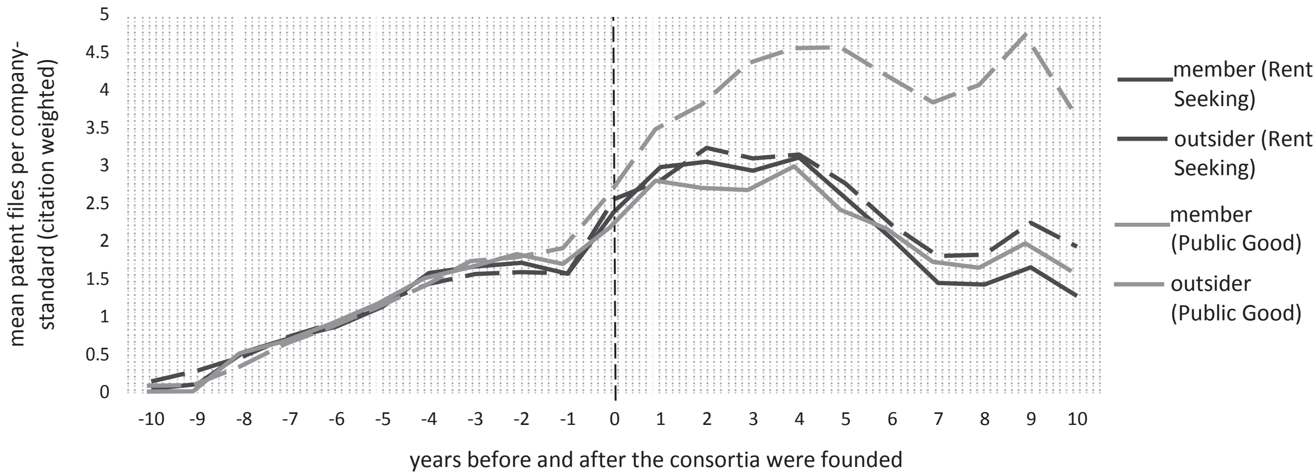

Figure 3: *Normalized patent files (citation weighted) of company-standard pairs 10 years before and after consortia foundation in a consortium member and outsider comparison*

T-test of linear residual values by pure R&D firms contribution						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
pure R&D firms do not contribute	1,669	-0.0721	0.0842	3.4412	-0.2374	0.0931
pure R&D firms contribute	1,649	0.0672	0.0798	3.3751	-0.0892	0.2236
combined	3,318	0.0000	0.0579	3.4074	-0.1136	0.1136
diff		-0.1394	0.1159		-0.3666	0.0879
t = -8.6356						
degrees of freedom = 3,316						
Ha: diff != 0 Pr(|T| > |t|) = 0.028						

Table 3: *T-test of residual values from a fixed effect regression on patent files controlled for standard dynamics and year trends*

	Model 1a		Model 1b		Model 2		Model 3		Model 4	
	Coef. / IRR / (SE)		Coef. / IRR / (SE)		Coef. / IRR / (SE)		Coef. / IRR / (SE)		Coef. / IRR / (SE)	
Consortium-member	0.538*** (0.132)	2.744*** (0.479)	0.542*** (0.135)	2.602*** (0.439)	0.431*** (0.124)	2.541*** (0.404)	0.461*** (0.095)	1.968*** (0.283)	0.616*** (0.137)	1.852*** (0.254)
ConsMember X Rent Seeking	-3.658*** (0.783)	0.002*** (0.002)	-3.666*** (0.859)	0.003*** (0.002)	-2.961*** (0.434)	0.003*** (0.002)	-3.274*** (0.721)	0.007*** (0.004)	-4.560*** 0.596	0.010*** (0.006)
Lag1Standard-event	-0.086*** (0.015)	0.883*** (0.025)	-0.086*** (0.019)	0.905*** (0.026)	-0.064*** (0.010)	0.926*** (0.024)	-0.039*** 0.013	0.905*** (0.015)	-0.098*** (0.018)	0.907*** (0.016)
IPC_control[1]	-0.850** (0.349)	0.999** (0.002)	-0.862** (0.347)	0.999** (0.002)	-1.548*** (0.167)	0.999*** (0.002)	1.466 (0.219)	1.001 (0.001)	0.103 (0.025)	1.001 (0.002)
All SEP-declarations[1]	0.189*** (0.063)	1.001*** (0.005)	0.173* (0.100)	1.006* (0.004)	0.347*** (0.061)	1.002*** (0.007)	0.309*** (0.075)	1.002*** (0.006)	0.227*** (0.081)	1.002*** (0.008)
Lag1.Firmsize[1] (employees)			-0.005 (0.020)	0.999 (0.003)	-0.025 (0.030)	1.001 (0.004)	-0.275 (0.290)	0.999 (0.003)	0.230 (0.047)	1.002 (0.008)
Lag1.Tobin'sQ			-0.025 (0.060)	0.850 (0.037)	-0.128** (0.050)	0.826*** (0.074)	-0.088 (0.086)	0.843 (0.095)	-0.159 (0.131)	0.853 (0.012)
Standard adoption[1]			-0.051** (0.024)	0.999** (0.004)			-0.042*** (0.026)	0.999*** (0.001)	-0.202*** (0.164)	0.999*** (0.001)
Accreditations cumulated			0.031 (0.033)	0.915 (0.029)			-0.011*** (0.031)	0.894*** (0.038)	-0.131*** (0.034)	0.877*** (0.029)
References cumulated							0.005 (0.004)	1.004 (0.003)	0.006 (0.006)	1.006 (0.005)
Version age							-0.019*** (0.011)	0.869*** (0.019)	-0.149*** (0.027)	0.862*** (0.023)
Standard age dummies	Yes		Yes		Yes		Yes		Yes	
Sample restriction	No restriction		No restriction		Consortium exist		Outsider excluded		Outsider excluded & PSM	
Observations	3,318		3,318		1,361		1,715		1,346	
Groups	577		577		201		265		209	
LogLikelihood[2]	-14,041		-13,946		-1,699		-3,246		-1,940	
AIC[2]	$2.81e^4$		$2.79e^4$		3,399		6,492		4,987	
BIC[2]	$2.81e^4$		$2.79e^4$		3,399		6,492		4,987	

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. Coef. reports coefficients, IRR reports incidence rate ratios. All models are estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (SE reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. Models 1, 2 and 4 are restricted to a limited time period 2002-2009.. [1]Coefficients inflated to make effects visible. [2] Values divided by 1,000.

Table 4: *Results of the multivariate analysis – testing consortia membership*

	Model 5 (*Insiders)*		Model 6 (*Outsiders)*		Model 7 (*Joint)*	
	Coef. / IRR / (SE)		Coef. / IRR / (SE)		Coef. / IRR / (SE)	
Relative consortia size	1.347**	3.846**	0.997	2.711	1.564***	2.019***
	(0.553)	(2.125)	(1.229)	(3.331)	(0.505)	(0.747)
Relative consortia	-8.134***	0.002***	5.632	279.186	-9.978***	0.049***
size X Rent Seeking	(2.584)	(0.007)	(8.770)	(2448.456)	(3.003)	(0.077)
IPC-control[1]	0.201***	1.002***	0.216***	1.002***	0.196***	1.002***
	(0.025)	(0.002)	(0.022)	(0.002)	(0.016)	(0.001)
All SEP declarations[1]	0.378***	1.003***	0.061	1.006	0.361***	1.003***
	(0.081)	(0.008)	(0.111)	(0.001)	(0.074)	(0.009)
References cumul	-0.005	0.995	-0.009	0.991	-0.005	0.995
	(0.004)	(0.003)	(0.010)	(0.009)	(0.004)	(0.004)
Accreditations cumul	0.064**	1.066**	0.063*	1.065*	0.058*	1.062
	(0.032)	(0.034)	(0.036)	(0.038)	(0.032)	(0.029)
Standard adoption[1]	-0.560	0.999	-3.218**	0.999**	-0.542	0.999
	(0.412)	(0.004)	(1.406)	(0.001)	(0.485)	(0.004)
Standard Age Dummies	Yes		Yes		Yes	
Log likelihood[2]	-2,258.8		-1,430.5		-4,027.2	
AIC[2]	4,517		2,861		8,054	
BIC[2]	4,517		2,861		8,055	
Observations	812		919		1,731	
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. Coef. reports coefficients, IRR reports incidence rate ratios. All models are estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (SE reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. [1]Coefficients inflated to make effects visible. [2] Values divided by 1,000

Table 5: *Results of the multivariate analysis – effect of consortia member share on insider and outsider patent output*

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 (Ganglmair and Tarantino, 2012; Bekkers et al., 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 (figure 1). The resulting pattern 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.

Supplementary material can be consulted under:

http://www.inno.tu-berlin.de/fileadmin/a38335100/Bilder-Mitarbeiter/Data_Files/supplementary_material_Baron_et_al__2013_.pdf