Innovation in standards

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Abstract

The development of formal ICT standards is a loose form of collaborative innovation whereby firms develop rival technologies, of which some only are eventually selected in the standard on a consensus basis. Against this background, firms often use informal consortia to define a clearer technology roadmap ahead of the formal standard setting process. The paper aims to assess whether such consortia can enhance R&D cooperation between the firms that develop a standard. We develop a theoretical model showing that firms' R&D investments may be subject to a Public Good or Rent Seeking pattern depending on their expected rewards for essential patents. Against this background, enhanced cooperation may result in either more or less innovation depending on the type of coordination failure prevailing in equilibrium. Using a large panel of standards, we confirm this result empirically, by showing that consortia induce more (less) patent files when the standard is subject to a Public Good (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 critical technologies[1]. Consequently, standards tend to embody a growing number of patented components.

While the conditions for licensing these *essential* patents have been widely discussed (see e.g., Shapiro, 2001; Lerner & Tirole, 2004; Layne-Farrar & Lerner, 2011), the peculiar type of R&D cooperation they proceed from has received little 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 before the standardization meetings, of which only a fraction are eventually selected in the standard on a consensus basis (Rysman & Simcoe, 2008). As a result, formal standardization may entail R&D duplications and delays due to vested interests (Farrell & Simcoe, 2012; Simcoe, 2012).

Againt this background, firms increasingly use parallel consortia in order to agree on a standard blueprint that they can jointly push in the formal SSO[2] (Cargill, 2001; Lerner & Tirole, 2006). Such informal 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 obtain essential patents (Leiponen, 2008; Pohlmann and Blind, 2012).

The purpose of this paper is to assess whether such consortia effectively address R&D coordination failure 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 consortium members, and then test them 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.

Our model indeed highligts 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-

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

[2] While some of them substitute for the lack of formal SDOs and issue their own standards (e.g., Blu-Ray alliance or W3C for web protocols), most of these consortia actually accompany formal standardization. ISO has for instance a formal fast track agreement, the PAS (Publicly Available Specifications), which allows sponsoring organization to receive a formal accreditation of their specification within six and nine months. JTC1 has a similar policy of featuring Approved References Specifications (ARS).

compliant products. Conversely, a wasteful *Rent Seeking* pattern prevails when licensing revenues are sufficient to cover their 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 thereby mitigate coordination failure at the SSO level.

We use a panel of XXX ICT standards over XXX years to test these predictions empirically. For this purpose, we have developed an original dataset of standard-related, citations-weighted patent applications at firm level and matched these observations with information on firms' participation in XXX parallel consortia. Drawing on our theoretical framework, we use the participation of pure R&D firms in the standard setting process as a proxy to track standards that are subject to a *Rent Seeking* pattern. Our results are consistent with the predictions. In most cases, firms strongly increase their patent applications after joining a consortium. However this is not true for standards that are subject to a strong *Rent Seeking* pattern. The pro-innovation effect of consortia then disappears, and eventually reverses as the participation of pure R&D firms increases.

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 works on standard essential patents. Reisman 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. Against this background, our work suggests that patent-related incentives do not have the same weight across standards and SSOs, and may therefore lead to either *Public Good* or *Rent Seeking* patterns.

Our theoretical framework follows the literature on R&D joint ventures (REFs) 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) and Farrel and Simcoe (2012) model consensus standard setting as a war of attrition 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. Ganglmair and Tarantino (2012) study the incentives for firms to disclose inventions and related patents to other participants of the standard-setting process. They show that firms may be inclined to delay disclosure if they expect other participants to contribute[3].

A few papers also explore the articulation between consortia and standard setting. Lerner and Tirole (2004) and Lerner, Strojwas 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. They find in particular that sponsors of high quality technology tend to opt for fora that impose less restrictions in terms of IP disclosure and licensing. Our approach differs in that we consider consider consortia as potential complements rather than substitutes to formal SSOs. Although more restrictive, this definition is consistent with a large subset of existing consortia that submit standards to formal SSOs. An important example is the 3rd Generation Partnership Project (3GPP), a consortium that develops wireless communication standards to be later endorsed by formal SSOs such as ETSI and ITU. Empirical work by Leiponen (2008) shows that connections with peers in this consortium enabled members to better influence the design of formal standards. Delcamp & Leiponen (2013) also find that joining 3GPP leads increases cross-citations between the members' patents. These results are thus consistent with our approach of 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 is jointly developed by n firms and 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[4]. 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 consider r as exogenous, and focus the analysis on the number of inventions contributed by firms under different profit appropriation regimes. For simplicity of notation we will therefore write $v(x)$ from now on.

The number of patented inventions embodied in the standard and originating from firm i is denoted by x_i, with $x = \sum x_i$. In line with actual industry practices, we posit that aggregate licensing revenues rv are split according to the firms' shares of essential patents, that is x_i/x for $i = 1, n$. The remaining part of

[3] This result suggests that patent disclosures in SSOs are not a reliable indicator of innovation in standards. We address this problem in our empirical section by developing an alternative measure of standard-related patents.

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

aggregate profits–that is $(1-r)\,v$–is split between manufacturers in proportion of their shares s_i of the product market. Taking into account both sources of profits, the expected revenue of firm $i=1,n$ is then:

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

Standard setting is a co-opetitive process whereby participants have to agree on a final set of specifications while at the same time seeking to have their own technology included in the standard. We therefore allow for some degree of cooperation by giving a (small) weight $\epsilon > 0$ to the other firms' revenue in each firm's objective. Noting $c_i \in [0,1]$ firm i's unit cost per invention, the programme of firm i is then

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

where $\epsilon = 0$ denotes the fully non-cooperative scenario, while setting $\epsilon = 1$ would imply a fully cooperative scenario[5].

Public Good versus Rent Seeking Solving (1) gives the first order condition below:

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

The firm's non-cooperative incentives to contribute are captured in the first and second terms on the LHS. The first term reflects the public good nature of the standard, of which firm i appropriates only a share. The second term denotes a strategic appropriation effect: to obtain licensing profit, firm i needs to invest more the higher the number of essential patents held by its competitors.

Summing the FOC of all firms $i=1,n$ and rearranging, we derive the number of inventions x^* embodied in the standard in equilibrium.

$$\frac{1}{n}\left\{v_x\left(x^*\right) + \left(n-1\right)\frac{rv\left(x^*\right)}{x^*} + \left(n-1\right)\epsilon\left[v_x - \frac{rv\left(x^*\right)}{x^*}\right]\right\} = \overline{c} \tag{3}$$

where $\overline{c} = \sum c_i/n$. The aggregate marginal profits (LHS) again combine the properties of public good investment (marginal benefits are diluted when the number of firms increases) and strategic appropriation for $r > 0$ (second term on the LHS). The latter might in particular induce firms to continue developing inventions even though they have no incremental value for the standard anymore (that is, when $v_x\left(x^*\right) = 0$). The last term on the LHS captures marginal social cost or benefit on invention by firm i when there is some degree of cooperation between the firms ($\epsilon > 0$).

[5] Obviously, this scenario is not realistic given the absence of contract between the firms. Note also that in this case it would imply that the whole standard be developed by the firm with the lowest cost per innovation.

On the RHS of (3), x^* depends on the average of the firms' unit costs, but not on their distribution between firms. Accordingly, we can use the outcome $\widehat{x}$ of a fully cooperative scenario ($\epsilon = 1$) with average cost $\overline{c}$ as a benchmark to assess the firms' incentives to innovate in a co-opetitive equilibrium ($\epsilon < 1$). By simply comparing the LHS of (3) with $v_x(x^*)$, we derive the following result.

Proposition 1 *Two different equilibrium patterns may occur in a co-opetitive scenario:*

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

Proof. See Appendix 1.a ■

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 $\overline{c}$ is profitable only in a *Rent Seeking* equilibrium:

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

Since pure R&D firms monetize their innovations through licensing only, their business model is indeed hardly compatible with *Public Good* standards. One would 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 ϵ. However, it is clear from (3) that a stronger ability to cooperate in the SDO reduces the magnitude of the coordination failure, by eroding private incentives towards either Free Riding or Rent Seeking.

Consortia yet involve only a subgroup of firms seeking to converge on specifications that they will jointly submit in the SDO. Accordingly, we consider that $k < n$ firms form a consortium K to cooperate more closely. Since consortia do not involve any formal contracting on joint R&D decisions, we posit a higher yet 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

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

while the program of non-member firms remains unchanged. Summing the n FOC and comparing with (3), we obtain that the consortium induces more innovation if

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

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 (5) is reversed[6]. When the joint contributions of consortium members reflect their market shares ($x_K^*/x^* = s_K$), it is 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 ($s_K x^* < x_K^*$)[7] if the inefficiency pattern (as measured by the LHS of (5)) is small. 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 the RHS of (5) is zero in a pure Public Good pattern ($r = 0$) or, in a Rent Seeking pattern, when the value of the standard is saturated ($v_x(x^*) \to 0$).

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.b ■

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 or Public Good patterns.

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[6] See Appendix 1.b for the full demonstration

[7] This bias 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.

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 strong (strong Rent Seeking pattern) or inexistent (strong Public Good pattern).

Hypotheses 2: *A firm's entry 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 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.

3 Empirical analysis

This section in turn presents an empirical analysis of patent filings around a large panel of ICT standards. Our purpose is to assess whether joining a consortium changes the volume of patents filed by firms involved in standard development, and what is the direction of this change. Drawing on the results of our theoretical analysis, we assess this effect separately for standards corresponding respectively to a *Public Good* or *Rent Seeking* pattern.

3.1 Data and indicators

Our empirical analysis draws on a comprehensive dataset of technological standards including essential patents[8]. Our sample includes all ICT standards issued between 1992 and 2009 by one of the major formal SSOs which operate on an international level[9]. Since we aim to focus on the interaction between formal standardization and companion consortia, we exclude standards that are exclusively developed by informal standards consortia (e.g. BluRay).

We furthermore restrict the analysis to standards including essential patents of at least two different companies, thereby limiting the sample to 578 standards. Companies that own IPRs which are essential to a standard provide this information to the respective SSO. We downloaded these patent declarations at the websites of the above-mentioned SSOs in March 2010. From the PERINORM[10] database we retrieve information on the date of first release, releases of further versions and amendments, number of pages from the standard document such as the technical classification of the standard.

Our sample includes 242 different companies declaring essential patents, observed over the whole period. For each firm, we collect yearly information on

[8] A summary of all relevant variables with description and sample statistics can be consulted in Appendix 1

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

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

the amount of sales, R&D expenditure, employees and market to book ratio (Tobin's Q[11]). In addition we distinguish between pure R&D firms, manufacturer and net provider[12] and classify our sample by main active industry using SIC codes.

We connect the firm level data to the specific standard information and built up a panel of 1,720 company-standard pairs observed over a time span of 18 years (1992-2009). For each company-standard pair, we observe the amount of 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. Other time-variant control variables are either company- or standard-specific. Time-invariant factors affecting the firm, the standard or the relationship between both are captured by company-standard pair fixed effects.

Matching between informal consortia and formal standards To identify informal consortia accompanying the formal standardization process, we use data from 15 editions of the CEN survey of ICT consortia and a list of consortia provided by Andrew Updegrove. We identify approximately 250 active ICT consortia[13]. We categorize these consortia as to industry, function (spec producer, promoter) and years of activity (see Appendix 1). The connection to a standard in our sample is analyzed by using liaison agreements and information from consortia and SSO web pages. For instance, a connection was identified, when a consortium explicitly references a formal standard, or when a standard has been submitted to the formal SSO by an informal consortium. We are conservative in establishing the connections, resulting in a narrow list of 54 consortia. We use supplementary information for the selected consortia and further restrict the list to 21 consortia that technologically (spec producer) and significantly contribute to this specific standard (excluding pure promoting consortia)[14]. Using information on the websites of the consortia as well as internet archives (www.archive.org) and internet databases (www.consortiuminfo.org), we inform consortium membership over time and connect this information with the company standard pairs of our sample.

Standard-specific patents The most intuitive approach to track firms' R&D investments in standards is to count the patent declarations they state for

[11] We used the Thomson one Banker database to match the respective firm level data.

[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 (2010).

[13] This is coherent with the identification of the CEN survey which reports approximately 250 standards consortia in ICT.

[14] Assisting this rather broad distinction we conduct a word count analysis on the consortia self-description abstracts, kindly provided by Andrew Updegrove. We use keywords such as "developing", "creates", "set standard" or "standardizes". Appendix 1 provides a list of those consortia and standards for which a link could be established, as well as the narrower list of consortia contributing technologically.

these standards. However, former empirical analyses have shown that the timing of declaration is not connected to the dynamics of standardization (Baron and Pohlmann, 2010). Moroever essential patents only represent a very small amount of patenting around standards (Bekkers et al., 2012). To avoid these shortcomings, we thus build up a new measure of firms' standard-specific R&D investment. In a first step we count 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 the company assignee merging methods of Thoma et al. (2010). We restrict the count of patent files to IPC classes in the relevant technological field of each standard, identified by using the IPC classification of declared essential patents[15]. We measure the dynamics of patenting over the standard lifecycle (details can be consulted in Appendix 3). Our mean value analysis shows a patenting increase before standard release and a decrease thereafter. This finding reassures us that our variable captures the innovation for a specific standard, which indeed is expected to culminate in the period immediately preceding standard release.

Public good **and** ***patent race*** **patterns** One contribution of our analysis is the comparison of over- and under investment in standardization. As shown in the theroretical model, the *patent rac*e pattern can be identified when pure R&D firms take part in the standard development. We use this prediction as our identification strategy for the empirical sampling of standards. By labeling over- and underinvestment as to the classification above, we compare the residual results of a regression of standard related patent files against technical characteristics of the standards(details can be consulted in Appendix 4). A t-test analysis suggests that our classification of overinvestment is an appropriate measure. Results show that residual values of the regression are in average positive for standards where pure R&D firms participate to a standard and in average negative for those where pure R&D firms are not involved.

3.2 Descriptive Statistics

Pairwise correlations In the following Table 1, we provide pairwise correlations of firm-specific, standard-specific and firm-standard-specific variables at the company-standard-pair level.

Insert Table 1 about here

The volume of patents around standards is negatively correlated with both consortium membership and the existence of a consortium on the standard. This could indicate that consortia attract companies with smaller standard-related

[15] This method is a novel way of measuring standard-specific R&D investment. We apply tests of timing, estimate technological positions of standards as well several test of size measures to prove our proposed variable to be a sufficient indicator of standard-related R&D investment. 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 3.

patent portfolios. On the other hand, consortium membership is positively correlated with the value of sales and the number of employees. The existence of consortia is positively correlated with the number of firms per standard and with standard age. As to the correlation analysis effects are yet not strong enough to derive conclusive interpretations.

Difference in means In the following Table 2, we present differences in the volume of patents, the number of employees, the value of sales and the book-to-market ratio between consortia member observations and the rest. Membership observation is associated with a lower volume of standard-specific patents, but a higher number of employees and a higher value of sales.

Insert Table 2 about here

3.3 Multivariate Analyses

Estimation methodology We use our panel dataset to estimate how consortium membership affects the volume of patents filed around the related standard. Our dependent variable is the number of patent priority filings by firm i for standard j in year t. Our first key explanatory variable, $member_{ijt}$, is a dummy equal to one for years where the firm i participates in a consortium supporting standard j. Following the theoretical model, we expect its effect to depend upon whether the standard is initially characterized by over- or underinvestment. We therefore also interact the consortium membership dummy with the $over\_investment_j$ variable, denoting the share of pure R&D firms involved in the develoment of standard j.

To account for unobserved heterogeneity of standards and companies, we systematically include fixed effects for company-standard pairs. As our dependant 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[16]. We furthermore cluster standard errors by companies in order to exclude that unobserved shocks to a company's patenting level bias the standard errors and lead to an insufficiently restrictive confidence interval[17]. Unsurprisingly, we found strong evidence for persistent effects of transitory shocks to our explained variable, as indicated by positive autocorrelation of standard errors. We therefore include the lagged dependent variable as explanatory variable in all models.

[16] We prefer the poisson estimator with robust standard errors over a negative binomial estimator with fixed effects, because the negative binomial estimator cannot totally control for fixed effects and thus account for unobserved heterogeneity.

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

Our basic regression model has the following specification:

$$\begin{aligned} st\_patents_{ijt} &= \exp\big(\alpha_1.st\_patents_{ijt-1} \\ &+\beta_1.member_{ijt} \\ &+\beta_2.member_{ijt} * over\_investment_j \\ &+\beta_3.st\_activity_{jt-1} \\ &+F'_{it-1}\beta_4 + X'_t\beta_5 + c_{jt} + \varepsilon_{ijt}\big) \end{aligned}$$

where $st\_activity_{jt-1}$ counts version releases and amendments per year, F_{it-1} is a vector of firms specific change such as a measure of Sales and Tobins's Q, X_{jt-1} denotes other control variables for time trends such as the overall ICT patent files and the count of patent declarations, c_{jt} are standard age dummies and ε_{ijt} is an idiosyncratic error term.

We use the standard age dummies, each indicating a one year period in the standard lifetime, to control for the timing of standardization. Downstream innovation and patenting (taking place after the first release of the standard) is indeed likely to peak around periodical revisions of standards. The release of new standard versions or amendments to existing versions is labeled as standard activity and included as a control variable. In order to exclude immediate feedback (amendments or version releases explained by prior innovation), we include this control variable with a one-year lag.

We furthermore wish to account for external shocks such as the business cycle or technology-related policy. As we already control for standard fixed effects and standard age, it is impossible to include year dummies as a further control because of a collinearity problem. We therefore control for external shocks 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 that are more specifically relevant to essential patents.

Models 1-4 Consortia are more likely to be created for important or technologically complex standardization projects. Furthermore, the organization of R&D can be different if a consortium is created for a standard. For these reasons, the timing of standardization is likely to be affected by the existence of consortia. It is thus preferable to estimate all coefficients, including controls for standard timing, only on the sample of standards related to an informal consortium. This strategy could however bias downwards the estimated effects of consortia, if some of these effects are systematically captured by control variables. We therefore present results based upon the whole sample in model M1. As expected, the coefficients on consortia variables are higher in the larger sample, but the fit of the model is much lower. This indicates that heterogeneity between standards with consortia and other standards is large. We therefore only estimate standard with accompanying consortia in all following models (M2-M4), while acknowledging a potential downward bias on our consortia coefficients.

In our second model (M2), consortium membership has a significant positive effect on the volume of standard-specific patents, but the level of this effect decreases with the level of overinvestment. This result is however potentially subject to an endogeneity bias. 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. External factors jointly affecting consortium membership and related patenting are particularly likely to occur in periods of turmoil, like the internet bubble in 2001. While desirable in order to reduce within-groups bias on weakly endogenous variables (Nickell, 1981; Bloom et al., 2005), the long period of observation (relatively to the fast-evolving world of ICT standards) increases the vulnerability to this type of biases.

Insert Table 3 about here

In order to deal with these concerns we restrict the observation period to 8 years from 2002 to 2009. Furthermore, we also reduce the cross-section dimension of the panel, by restricting the sample to stock-market listed companies. These companies are more likely to react in a similar fashion to external events. Finally, we identify positive or negative shocks to the number of employees in a one year period[18], indicating mergers, acquisitions, restructuring etc. 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. Companies with more than one shock are dropped altogether for our third model (M3), reducing the sample to 174 groups and 999 observations.

In our last model M4 we furthermore tackle endogeneity more directly by including time-varying firm characteristics as control variables. We choose to include the value of sales, and Tobin's Q as a measure of expected profits (both lagged by one year to exclude immediate feedback). We opt for not including employees, which is highly correlated with sales in the within dimension (both reflecting company growth). Furthermore, the number of employees, with respect to the value of sales, is likely to be more important for determining whether a company has the possibility to participate in a consortium, but less important in independently determining the evolution of patenting[19]. By including the value of sales as a control, we nevertheless face the risk to bias downwards the estimates of the consortia effects for smaller companies refraining from joining an expensive consortium. We therefore divide the level of consortia member fees[20] by the value of sales of the company at the time of consortium creation. The first percentile of observations according to this value (the companies-standard pairs characterized by the highest consortia fees relative to the value of sales) is

[18] distribution, the lower 5% are labeld as negative shocks.

[19] The primary cost of consortium participation is workload, while the cost of patenting is primarily financial

[20] Since our goal is to estimate the financial burden to join a consortium we use the low range of membership fees (find an overview of highest and lowest membership fees in the appendix 1).

most at risk to be affected by this effect. We therefore decide to exclude these observations, leaving us with 158 company-standard pairs and 884 observations in model 4.

M1-M4 show robust results. The magnitude of the coefficients decreases but the effects are yet more significant, and the signs of the coefficients are unchanged.

Further robustness checks We check for robustness of our results to a correlation of our main explanatory variables with past outcomes of the dependent variable. It is plausible that a company's decision to join a consortium depends upon its stock of related patents. In this case, the regressors are predetermined, and the poisson fixed effect estimator yields inconsistent results (Blundell et al., 1999). In order to account for this problem, we take advantage of the fact that we have information on pre-sample levels of our dependent variable and adopt the methodology suggested in Blundell et al. (1999), substituting pre-sample means for fixed effects. The results displayed in Appendix 5 are mainly consistent with the results from the fixed effect analysis.

Effect of consortium member share So far we have estimated the effect of consortium membership on the volume of patents of the respective company. In this section, we will estimate the effect of the consortium member share (indicating how many of the firms contributing to the standard are member of the consortium) on the volume of patents filed by members and outsiders. Finally, by estimating the effect of consortium member share on patents filed by all companies, we obtain a measure of the net effect of consortia.

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 relatively unrelated to a firm's own current or expected future R&D efforts. We are therefore less restrictive regarding the sample, and only drop observations for 2001 or earlier and of standards with no consortium within the observation period. On the other hand, the member share is sensitive to the membership decision of the firm itself, especially if the number of firms on the standard is low[21]. In order to check for robustness to this sensitivity, we present all results for a narrower subsample of standards including at least 6 contributing firms.

We estimate the effects of consortium member share separately for consortium members and non-members and for both. For the purpose of this analysis, a firm is labeled as a member over the whole period of observation, if it is consortium member at least once within this period. It is labeled consortium outsider if it has never been consortium member over the period of observation. We control for time-variant firm characteristics, standard-company fixed effects, the lagged dependent variable and external shocks. Results are displayed in Table 4.

[21]If we substracted the company itself from the consortium size variable, this count would be nevertheless sensitive to company membership, as we estimate the effects separately for consortium members and non-members.

Consortium members react to increasing consortium member share by inflating their patent filings, but this effect decreases with the level of overinvestment (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 patents is positive and significant, but this effect decreases significantly with the level of over-investment (model 7).

Insert Table 4 about here

Net effects Our results suggest that nearly all effects of consortia depend upon the initial level of overinvestment. In order to be able to discuss the effect of consortia on patenting, one should therefore relate the estimated coefficients to the sample values of the overinvestment indicator. We calculate the net effects from the results of model 5 (for the effect of consortium membership) and model 7 (the overall effect of consortium member share in the whole sample). We find that the effect of consortia membership is positive for any share of non-practicing entities not exceeding 6 %. This is the case for 92,12% of the observations. The effect of consortia member share on overall volume of patents is positive for any share of non-practicing entities below 9 %. This is the case for 94,13% of the observations. These results indicate that the effects of consortia membership and consortia member share on standard-specific R&D are positive in a broad majority of standards[22]. However, they also suggest that consortia can have a deflating effect in a minority of standards that are characterized by a particularly strong patent race pattern.

4 Conclusion

The purpose of the paper is to assess 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' private incentives to develop innovations for a standard in a context of weak cooperation. This model shows highlight two possible types of coordination failure depending on the structure of the firms' incentives. When incentives are 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. Concversely, a wasteful *Rent Seeking* prevails when incentives mainly proceeds 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.

[22] The negative effect of consortia membership and relative consortia size on R&D investment in situations of overinvestment is however stronger than this positive effect.

We test and validate this prediction empirically against 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. Our results then show that in the general case, new consortium memberships induces firms to develop more innovations, as indicated by a rise in patent files. However, this result does not hold anymore for standards involving pure R&D firms. The pro-innovation effect of consortia then disappear, and is even reversed as the participation of pure R&D firms increases.

References

[1] Baron, J., Pohlmann, T. (2010) "Patent Pools and Patent Inflation – The effects of patent pools on the number of essential patents in standards", Cerna working paper

[2] Bekkers,R., Catalini, C., Martinelli, A., Simcoe, T. (2012) "Standardizing Intellectual Property Disclosure Data", NBER Working Paper Series.

[3] Benner, M., Waldfogel, J. (2008) "Close to you? Bias and precision in patent-based measures of technological position", Research Policy, 37: 1556-1567.

[4] Blind, K., Gauch, S. (2008) "Trends in ICT standards: The relationship between European standardization bodies and standards consortia", Telecommunications Policy 32 (2008) 503– 513.

[5] Bloom, N., Schankerman, M., Van Reenen, J. (2005) Identifying technology spillovers and product market rivalry, Proceedings, Federal Reserve Bank of San Francisco

[6] Blundell, R., Griffith, R., Windmeijer, F. (2002) Individual Effects and Dynamic Feedback in Count Data Models. Journal of Econometrics, 87, pp. 115-143

[7] Branstetter, L., Sakakibara, M. (2002) "When Do Research Consortia Work Well and Why? Evidence from Japanese Panel Data", American Economic Review, vol. 92, no. 1, March 2002, pp. 143-159.

[8] Cargill, C., Weiss, M. (1992) "Consortia in the Standards Development Process", Journal of the American Society for Information Science, Volume 43 Issue 8, 559 – 565.

[9] Cargill, C. (2002) "Intellectual Property Rights and Standards Setting Organizations: An Overview of failed evolution", A Report Issued By the U.S. Department of Justice and the Federal Trade Commission, March 2002.

[10] Chiao, B., Lerner, J., Tirole, J. (2007) "The Rules of Standard Setting Organizations: an Empirical Analysis" RAND Journal of Economics, 38:4, pp. 905-930.

[11] David, Paul A, Shurmer, Mark (1996) "Formal standards-setting for global telecommunications and information services. Towards an institutional regime transformation?", Telecommunications Policy, Volume 20, Issue 10, December 1996, Pages 789-815.

[12] Delcamp, H., Leiponen, A. (2012) "Innovating Standards Through Informal Consortia: The Case of Wireless Telecommunications" NBER Working Paper Series.

[13] Egyedi, T.M. (2003) "Consortium Problem Redefined: Negotiating 'Democracy' in the Actor Network on Standardization", International Journal of IT Standards & Standardization Research, 1(2), 22-38.

[14] Farrell, J., Saloner, G. (1988) "Coordination through Committees and Markets" The RAND Journal of Economics, 19(2), 235–252.

[15] Farrell, J., Simcoe, T. (2012) "Choosing the Rules for Consensus Standardization" The RAND Journal of Economics, 43(2), 235–252.

[16] Fleming, L., Waguespack. D (2009) "Evidence on the Benefits to Startups Participating in Open Standards Development". Management Science, 55(2), pp. 210-223

[17] Ganglmair, B., Tarentino, E. (2012) "Patent Disclosure in Standard Setting" NBER Working Paper No. 17999.

[18] Hawkins, Richard (1999) "The rise of consortia in the information and communication technology industries: emerging implications for policy" Telecommunications Policy, Volume 23, Issue 2, March 1999, Pages 159-173.

[19] Layne-Farrar, A., Lerner, J. (2011) "To join or not to join: Examining patent pool participation and rent sharing rules," International Journal of Industrial Organization, 29:2, pp. 294-303.

[20] Leiponen A. E. (2008) "Competing Through Cooperation: The Organization of Standard Setting in Wireless Telecommunications", Management Science Vol. 54, No. 11, November 2008, pp. 1904–1919.

[21] Lerner, J, Tirole, J. (2004) "Efficient Patent Pools". American Economic Review, 94:3, pp. 691-711.

[22] Lerner, J., Strojwas, M., Tirole, J., (2007) "The design of patent pools: the determinants of licensing rules", The RAND Journal of Economics 38, 3.

[23] Lerner, J, Tirole, J. (2006) "A Model of Forum Shopping". American Economic Review, 96, pp. 1091-1113.

[24] Pohlmann, T. (2010) "Attributes and Dynamic Development Phases of Informal ICT Standards Consortia", Working Paper

[25] Rey, P., Salant, D. (2012) "Abuse of dominance and licensing of intellectual property," International Journal of Industrial Organization, vol. 30(6), pages 518-527.

[26] Rysman, M., Simcoe, T. (2008) "Patents and the Performance of Voluntary Standard Setting Organizations", Management Science, 54:11, pp. 1920-1934,

[27] Shapiro, C. (2001) "Navigating the Patent Thicket: Cross Licences, Patents Pools, and Standard Setting", in A. Jaffe, J. Lerner et S. Stern (Ed.), Innovation Policy and the Economy, Vol 1, MIT Press.

[28] Shapiro, C. (2010) "Injunctions, Hold-Up, and Patent Royalties" American Law and Economics Review 12, no. 2 509-557.

[29] Simcoe, T. (2007) "Explaining the Increase in Intellectual Property Disclosure", Pages 260-295, in Standards Edge: The Golden Mean. Bolin Group, 2007.

[30] Simcoe, T. (2012) "Standard Setting Committees: Consensus Governance for Shared Technology Platforms", American Economic Review, 102:1, pp. 305-336.

[31] Swanson, D., Baumol, W. (2005) "Reasonable and Nondiscriminatory (RAND) royalties, standards selection, and control of market power", Antitrust Law Journal 73, 1.

[32] Thoma G., S. Torrisi, Gambardella, A., Guellec, D., Hall, B. H., Harhoff, D. (2010) "Harmonizing and Combining Large Datasets – An Application to Firm-Level Patent and Accounting Data", NBER Working Paper No. 15851, March 2010.

[33] Updegrove, A. (1995) "Consortia and the Role of the Government in Standard Setting", in B. Kahin & J. Abbate (Eds.). Standards Policy for Information Infrastructure, Cambridge: MIT Press, 321-348.

Appendix 1.a

Comparing $v_x(x)$ with the right hand side of (3), we obtain 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

$$(1-\epsilon)\frac{rv(x)}{x}>(1-\epsilon)v_x(x)$$

dividing both sides by $(1-\epsilon)$ and rearranging gives finally

$$\frac{rv(x)}{x}>v_x(x)$$

Observe moreover that the marginal benefit of firm i writes:

$$\frac{rv(x)}{x}>v_x(x) \tag{6}$$

Using again (3) we can now express $v_x(x^*)$ as follows

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

Thus we have

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

and

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

Appendix 1.b

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

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

The first order condition is

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

which simpilfies into

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

After summing all FOCs, we obtain

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

which simplifies into

$$\begin{aligned}
& v_x(x^*)+(n-1) \frac{r v(x^*)}{x^*}+(n-1) \epsilon\left[v_x-\frac{r v(x^*)}{x^*}\right] \\
& \Delta(k-1) \frac{x_K^*}{x^*}\left\{v_x(x^*)\left[r+(1-r) s_K \frac{x^*}{x_K^*}\right]-\frac{r v(x^*)}{x^*}\right\} \\
= & \ n \bar{c}
\end{aligned}$$

We now posit that consortium members have cost and market share parameters c_i and s_i such that $\sum_{j\in K} x_j^* = (k-1)\, x^*/n$. The equilibrium x^* is then defined by

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

The only difference with (3) due to the consortium is the third term on the LHS. It clearly implies that the consortium induces a largler (respecytively, smaller) equilibrium contribution x^*if a Public Good (Rent Seeking) pattern prevails in equilibrium.

Consider now the reaction function of firm $i \in K$, as given by (7), under the above assumptions:

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

It is clear from the above expression that:

1) Starting from $\Delta = 0$, a 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

Table 1: *Pairwise correlations on the company-standard level*

		1	2	3	4	5	6	7	8
1	St. R&D Invest.	1.00							
2	Member	-0.10***	1.00						
3	Consortia Exists	-0.14***	0.67***	1.00					
4	Standard Event	-0.07***	0.39***	0.58***	1.00				
5	Tobin's Q	0.02	0.01	-0.04*	-0.05*	1.00			
6	Sales	0.11***	0.06***	0.01	-0.01	-0.25***	1.00		
7	Em-ployees	0.10***	0.06**	0.01	0.02	-0.33***	0.87***	1.00	
8	Number of Firms	0.05**	0.34***	0.60***	0.62***	-0.09***	-0.02	0.00	1.00
9	Standard Age	-0.07***	0.17***	0.29***	0.32***	-0.20***	0.00	0.05**	0.25**

Table 2: *Differences in variable means between consortia members and others*

t = 4.1256			**Standard Specific Patent Files**			
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	261	2,238.6	190.8	3,081.9	1,862.9	2,614.2
not consortium members	1,571	12,092.8	972.8	38,559.2	10,184.6	14,001.0
t = -2.4585			**Employees**			
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	272	125,635.0	6,929.8	114,289.8	111,991.9	139,278.2
not consortium members	1,645	106,528.7	2,945.1	119,448.5	100,752.2	112,305.2
t = -2.6035			**Sales**			
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	272	40,119.1	1,774.0	29,257.4	36,626.5	43,611.6
not consortium members	1,644	35,211.2	708.4	28,721.6	33,821.8	36,600.6
t = -0.2502			**Book-To-Market Ratio**			
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	243	1.7	0.1	1.5	1.5	1.9
not consortium members	1,240	1.7	0.0	1.4	1.6	1.8

Table 3: *Results of the multivariate analysis – testing consortia membership (firm level)*

Unit of Observation = Company Standard Pair DV = Standard Specific R&D Investment (Patent Files)

	M1		M2		M3		M4		M5	
	Coef.		Coef.		Coef.		Coef.		Coef.	
Member	0.470	***	0.208	**	0.188	*	0.193	**	0.194	**
	(0.175)		(0.108)		(0.105)		(0.098)		(0.077)	
Member * Over Investment	-1.746	***	-1.135	*	-1.172	*	-1.203	*	-1.349	***
	(0.981)		(0.636)		(0.705)		(0.685)		(0.506)	
Lag1 Standard Activity	-0.061	*			-0.022	***	-0.022		-0.021	**
	(0.032)				(0.008)		(0.008)	**	(0.009)	
Lag1 Patent Files[1]	0.002	***	0.072	***	0.044	**	0.04	*	0.022	**
	(0.001)		(0.017)		(0.021)		(0.022)		(0.004)	
ICT Patent Files[1]	0.003	**	0.007	***	0.006	**	0.007	**	0.008	***
	(0.002)		(0.001)		(0.003)		(0.003)		(0.003)	
Patent Declarations[1]	-0.001		-0.003		0.002	***	0.004		0.008	
	(0.006)		(0.006)		(0.009)		(0.01)		(0.009)	
Lag1 Tobin's Q									0.088	
									(0.059)	
Lag1 Sales[1]									-0.011	***
									(0.003)	
Standard Year Dummies	Incl.		Incl.		Incl.		Incl.		Incl.	
Log Likelihood [2]	-17,820		-490.82		-68.55		-59.35		-114.06	
AIC [2]	35,600		981		137		118		228	
BIC [2]	35,600		981		138		118		228	
Observations	16,390		4,181		999		884		884	
Groups	1,046		298		174		158		158	

Note: 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 heteroskedacity and allow for serial correlation through clustering by firm. Model 2-4 are restricted to a limited time period 2002-2009. ***, **,and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible. [2] Values are reported in thousand.

Table 4: *Results of the multivariate analysis – testing consortia member share (consortia net effect)*

Unit of Observation = Year DV = Standard Specific R&D Investment (Patent Files)

	M6				M7				M8			
	Coef.		Marg. Effekt		Coef.		Marg. Effekt		Coef.		Marg. Effekt	
Member_share	0.884	***	0.884	***	0.337		0.337		0.903	***	0.903	***
	(0.328)		(0.328)		(0.445)		(0.445)		(0.233)		(0.233)	
	-5.489	***	-5.489	***	-3.65		-3.65		-5.532	***	-5.532	***
Member_share * Over Investment	(1.923)		(1.923)		(2.177)		(2.177)		(1.346)		(1.346)	
	-0.022	**	-0.022	**	-0.035	**	-0.035	**	-0.027	***	-0.027	***
Lag1 Standard Activity	(0.011)		(0.011)		(0.012)		(0.012)		(0.009)		(0.009)	
Lag1 Patent Files [1]	0.013		0.013		0.078	***	0.078	***	0.022		0.022	
	(0.018)		(0.018)		(0.028)		(0.028)		(0.021)		(0.021)	
ICT Patent Files [1]	0.008	***	0.008	***	0.004		0.004		0.007	***	0.007	***
	(0.002)		(0.002)		(0.003)		(0.003)		(0.002)		(0.002)	
	0.009	*	0.009	*	0.008		0.009		0.007		0.007	
Patent Declarations[1]	(0.005)		(0.005)		(0.017)		(0.017)		(0.005)		(0.005)	
	-0.003		-0.003		0.003		0.003		-0.002		-0.002	
Lag1 Sales [1]	(0.004)		(0.004)		(0.003)		(0.003)		(0.003)		(0.003)	
Standard Year Dummies	Incl.				Incl.				Incl.			
Consortium	Member				Outsider				Both			
Log Likelihood [2]	-140.39				-29				-175			
AIC [2]	280				58				351			
BIC [2]	281				57				352			
Observations	1,288				735				2041			
Groups	169				107				276			

*<u>Notes:</u> 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 heteroskedacity and allow for serial correlation through clustering by firm. ***, **,and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible. [2] Values are reported in thousand.*

Appendix 1: *Summary of relevant variables*

Variable	Description	Level of Obs.	Obs	Mean	Std. Dev.	Min	Max
Standard Specific R&D	Triadic Patent Priority Filings by this firm in the standard-related IPC classes	Firm-Standard-Year	31,020	1,072	4,022	0	91,121
Member	Membership of this Company in the Consortium related to this standard	Firm-Standard-Year	39,816	0.058	0.234	0	1
Over Investment	The share of non-producing entities for this standard	Standard	31,312	0.120	0.138	0	1
Standard Event	Sum of Amendments and version Releases	Standard-Year	36,918	0.292	0.979	1	37
ICT Patent Files	Triadic patent priority filings by all firms in either Telecom or IT	Standard-Year	37,621	223,320	52,748	132,721	301,890
Patent Declarations	Number of patent declarations to all formal standards	Year	39,834	3,538	4,038	78	13,938
Tobin's Q	Market-to-book ratio of the firm	Firm-Year	11,740	1.702	1.598	0.076	8.257
Sales	Value of sales per year in Million USD	Firm-Year	17,780	35,694	30,172	895	199,925

Appendix 2: *Linkages between standards and informal consortia*

Consortia Name	MatchStandard	Incl	Consortia Name	MatchStandard	Incl	Consortia Name	MatchStandard	Incl
EPCglobal	EN300220	No	WiMax	IEEE802.16	Yes	MPEGIF	ISO/IEC14496-14	Yes
DVB	EN300468	No	Cable Laboratories	IEEE802.1Q	Yes	MPEGIF	ISO/IEC14496-15	Yes
DVB	EN301192	No	FCIA - Fibre Channel Industry Association	IEEE802.1Q	No	MPEGIF	ISO/IEC14496-16	No
DVB	EN301199	Yes	MEF	IEEE802.1X	No	MPEGIF	ISO/IEC14496-18	Yes
DVB	EN301790	No	IETF	IEEE802.21	Yes	MPEGIF	ISO/IEC14496-19	No
DVB	EN301958	Yes	(GEA	IEEE802.3	No	ISMA	ISO/IEC14496-2	Yes
EPCglobal	EN302208	No	AUTOSAR	IEEE802.3/ISO IEC8802-3	No	MPEGIF	ISO/IEC14496-2	No
DVB	EN302304	No	FCIA	IEEE802.3/ISO IEC8802-3	No	MPEGIF	ISO/IEC14496-20	No
DVB	EN302307	No	HGI	IEEE802.3/ISO IEC8802-3	No	ISMA	ISO/IEC14496-3	Yes
DVB	EN302583	No	IETF	IEEE802.3/ISO IEC8802-3	Yes	MPEGIF	ISO/IEC14496-3	Yes
DVB	EN302755	No	MEF	IEEE802.3/ISO IEC8802-3	No	MPEGIF	ISO/IEC14496-4	Yes
DVB	ES200800	Yes	ODVA	IEEE802.3/ISO IEC8802-3	No	MPEGIF	ISO/IEC14496-5	Yes
IETF	ES201108	Yes	OIF	IEEE802.3/ISO IEC8802-3	No	MPEGIF	ISO/IEC14496-6	Yes
IETF	ES202050	Yes	Rapidio	IEEE802.3/ISO IEC8802-3	No	TAHI	ISO/IEC14543-2-1	No
IETF	ES202212	Yes	IETF	IEEE802.5/ISO IEC8802-5	No	IETF	ISO/IEC15444-1	No
WORLDDAB FORUM	ETS300401	Yes	INCITS	ISO/IEC10118-2	No	IETF	ISO/IEC15444-12	No
DVB	ETS300814	Yes	INCITS	ISO/IEC10118-3	Yes	IETF	ISO/IEC15444-2	No
DVD	ETSIEN300468	No	INCITS	ISO/IEC10536-3	No	IETF	ISO/IEC15444-3	Yes
IETF	G.711	Yes	INCITS	ISO/IEC10918-1/ITU-TT.81	Yes	IETF	ISO/IEC15444-5	No
IETF	G.722	Yes	TOG	ISO/IEC10918-1/ITU-TT.81	No	EPCglobal	ISO/IEC15693-2	No
IETF	H.263	Yes	INCITS	ISO/IEC11172-1	No	EPCglobal	ISO/IEC15693-3	No
IMTC	H.323	Yes	DVD	ISO/IEC11172-2	No	EPCglobal	ISO/IEC18000-1	No
IMTC	H.324	No	INCITS	ISO/IEC11172-2	No	EPCglobal	ISO/IEC18000-2	No
IETF	IEC6183411	No	DVD	ISO/IEC11172-3	No	EPCglobal	ISO/IEC18000-3	No
TOG	IEEE1003.1/ISOIEC9945	Yes	INCITS	ISO/IEC11172-3	Yes	EPCglobal	ISO/IEC18000-4	No
PICMG	IEEE1101.1	Yes	INCITS	ISO/IEC11693	No	EPCglobal	ISO/IEC18000-6	Yes
OCP-IP	IEEE1149.1	Yes	INCITS	ISO/IEC11694-1	No	AIM	ISO/IEC18000-6	No
BPMI	IEEE1226.5	No	INCITS	ISO/IEC11770-3	No	AIM	ISO/IEC18000-7	No
OMG	IEEE1226.5	No	INCITS	ISO/IEC11889-1	Yes	EPCglobal	ISO/IEC18000-7	Yes
PWG	IEEE1284	Yes	INCITS	ISO/IEC11889-2	Yes	ECMA	ISO/IEC18092	No
1355 Association	IEEE1355	No	INCITS	ISO/IEC11889-3	Yes	EUROSMART	ISO/IEC18092	No
1394TA	IEEE1394	Yes	INCITS	ISO/IEC11889-4	Yes	NFC Forum	ISO/IEC18092	Yes
AUTOSAR	IEEE1394	No	DMPF	ISO/IEC13818-1/ITU-TH.220.0	No	INCITS	ISO/IEC19794-3	No
DVD	IEEE1394	No	DVD	ISO/IEC13818-1/ITU-TH.220.0	No	INCITS	ISO/IEC19794-6	Yes
HAVi	IEEE1394	No	INCITS	ISO/IEC13818-1/ITU-TH.220.0	Yes	ECMA	ISO/IEC23651	No
PWG	IEEE1394	No	DVD	ISO/IEC13818-2/ITU-TH.262	No	GS1 – (Formerly EAN)	ISO/IEC24730-2	No
ODVA	IEEE1588/IEC61588	Yes	INCITS	ISO/IEC13818-2/ITU-TH.262	Yes	ECMA	ISO/IEC28361	No
ACCELLERA	IEEE1800/IEC62530	No	TOG	ISO/IEC13818-2/ITU-TH.262	No	TAHI	ISO/IECDIS29341	No

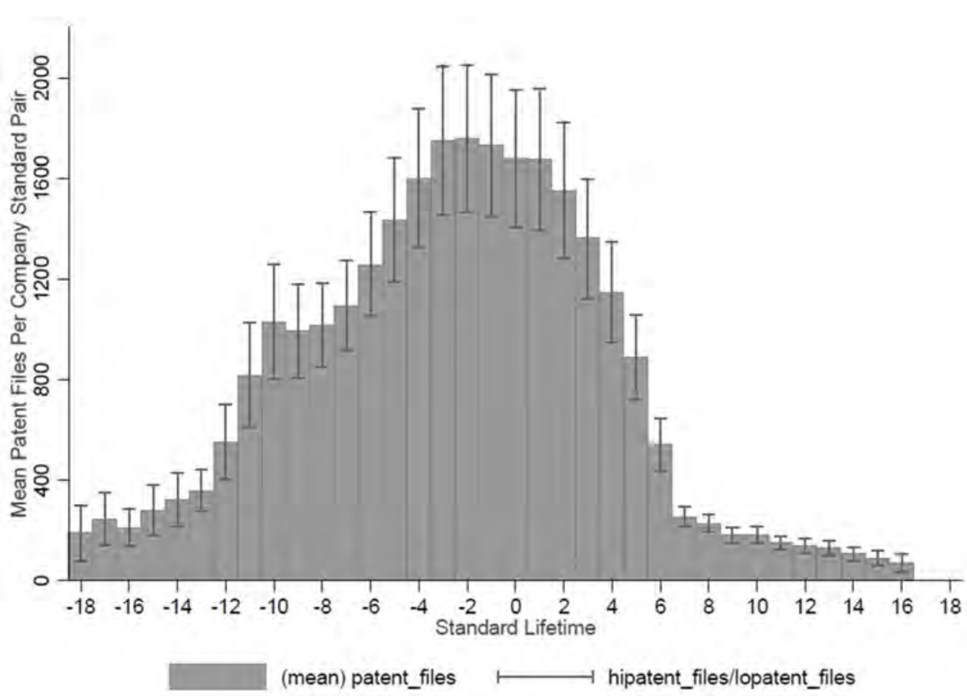
ACCELLERA	IEEE1801	Yes	DVD	ISO/IEC13818-3	No	UPnP Forum	ISO/IECDIS29341	Yes
Homeplug	IEEE1901	No	INCITS	ISO/IEC13818-3	Yes	ECMA	ISO/IECDIS29500	No
IVI	IEEE488.1/IEC60488-1	No	INCITS	ISO/IEC13818-7	No	3GPP2	Q.703	No
ASTM	IEEE802.11/ISOIEC8802-11	No	EUROSMART	ISO/IEC14443-1	No	DVB	TS102474	No
Bluetooth	IEEE802.11/ISOIEC8802-11	No	INCITS	ISO/IEC14443-1	No	DECT Forum	TS102527	No
DLNA	IEEE802.11/ISOIEC8802-11	No	NFC Forum	ISO/IEC14443-1	No	DVB	TS102584	No
ewc	IEEE802.11/ISOIEC8802-11	No	EUROSMART	ISO/IEC14443-2	No	DVB	TS102611	No
HGI	IEEE802.11/ISOIEC8802-11	No	INCITS	ISO/IEC14443-2	Yes	TV Anytime Forum	TS102822	No
IETF	IEEE802.11/ISOIEC8802-11	No	NFC Forum	ISO/IEC14443-2	No	DVB	TS102825	No
Wi-Fi Alliance	IEEE802.11/ISOIEC8802-11	Yes	EUROSMART	ISO/IEC14443-3	No	IMS FORUM	TS123002	No
100VG-Anylan Forum	IEEE802.12	No	INCITS	ISO/IEC14443-3	Yes	3GPP2	TS123401	No
IETF	IEEE802.12/ISOIEC8802-12	No	NFC Forum	ISO/IEC14443-3	No	3GPP2	TS123402	No
Bluetooth	IEEE802.15.1	No	EUROSMART	ISO/IEC14443-4	No	3GPP2	TS133402	No
WiMedia Alliance	IEEE802.15.3	Yes	INCITS	ISO/IEC14443-4	Yes	DRM	TS201980	No
DISA	IEEE802.15.4	No	NFC Forum	ISO/IEC14443-4	No	IETF	V.44	No
IETF	IEEE802.15.4	No	ISMA	ISO/IEC14496-1	Yes	3GPP2	X.509	No
TAHI	IEEE802.15.4	No	MPEGIF	ISO/IEC14496-1	No	ASTM	X.509	No
ZigBee	IEEE802.15.4	No	ISMA	ISO/IEC14496-10	Yes	Cable Laboratories	X.509	Yes
IETF	IEEE802.16	No	MPEGIF	ISO/IEC14496-10	No	ISMA	ISO/IEC14496-10/ITUH.264	Yes
			MPEGIF	ISO/IEC14496-12	Yes			

Appendix 3: *Empirical Methodology for measuring standard-related R&D*

We identified the relevant technological field for each standard by using the 7-digit IPC[1] classification of the declared standard essential patents, to then count patents filed by each company in the identified IPC classes. We counted 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 aggregated these patents to INPADOC patent families and informed the IPC classification and the year of priority. To create our explained variable, we computed 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 (figure1). The resulting pattern is a convincing description of the innovation process around standardization: the number of patents filed is highest in the 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.

Figure1: *mean number of patents filed in years before and after standard release*



[1] International Patent Classification

Appendix 4: Empirical Methodology for sorting standards into cases of over- and underinvestment

Based upon the theoretical model, we use the contribution of pure R&D firms to indicate overinvestment in a standard. We observe contribution of pure R&D firms in a standard using our database of companies that declare patents. Only firms that declare at least one patent on a standard are considered as contributors. Firms are classified as pure R&D firms using the business description database of Thomson One Banker and the companies identified by Layne-Farrar and Lerner (2011).

Using this classification, we create two sub samples, one where pure R&D firms contribute to the standard and one where pure R&D firms are not at place. We test over- and underinvestment by predicting the residual values of our specification. We run a linear fixed effect regression of our firm-standard pairs explaining patent files per year, controlling for standard dynamics and year trends and estimate the linear residual values[2]. We then compare the means of our residual values in both subsamples (pure R&D firms participate or not) conducting a t-test analysis.

The result of the t-test analysis in table 5 shows that in the case of overinvestment (pure R&D firms contribute), the mean residual value is positive and significantly higher compared to the subsample of underinvestment (pure R&D firms do not contribute). The estimated residual values indicate the level of patenting predicted upon our estimation equation. The differences of residual values among our observations thus reflect the heterogeneity of patent behavior among observations and help us to find proof for different outcomes of patenting when pure R&D firms contribute to a standard or not. Our findings indicate to confirm predictions from our theoretical model that pure R&D firms would only participate in standardization, when the licensing of the standard is characterized by a situation of overinvestment (positive residual values).

Table5: *T-test of residual values from a fixed effect regression on patent files controlled for standard dynamics and year trends*

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	16,121	-0.2435	0.0193	2.4512	-0.2814	-0.2057
pure R&D firms contribute	11,441	0.1145	0.0237	2.5347	0.0680	0.1609
combined	27,562	-0.0949	0.0150	2.4924	-0.1244	-0.0655
diff		-0.3580	0.0304		-0.4176	-0.2984

t = -11.7797
degrees of freedom = 27560
Ha: diff != 0 Pr(|T| > |t|) = 0.0000

[2] We change our poisson specification to a liner regression, since residual values of poisson estimators will not produce conclusive results. We log transform our count variable of patent files and run a linear OLS fixed effect regression model to then predict the linear residual values in a post estimation analysis.

Appendix 5: *Robustness check substituting pre-sample means for fixed effects*

We apply the methodology developed by Blundell et al. (1999) to control for predetermined regressors. The authors suggest substituting the pre-sample averages of the dependent variable for the group fixed effect. While the fixed effects are estimated over the sample period, and are thus affected by the feedback of predetermined regressors, the pre-sample means are exogenous to the sample period values of the regressors. Analogous to our previous analysis, we set the period of observation from 2002 to 2009. In choosing the appropriate pre-sample period (1982-1992 or 1992-2001), we have to trade off endogeneity (several consortia memberships observed in the sample period have already existed in the period from 1992 to 2001) against heterogeneity (closer pre-sample values are a better approximation of the sample fixed effect than more remote pre sample information). As this model is intended to complement a fixed effect analysis, we choose the average of the period from 1982 to 1992 as pre-sample values[3]. We control for the same variables and operate the same sample restrictions as in the main models of our empirical tests. As our dependent variable is over-dispersed with respect to a poisson distribution and we no longer include group fixed effects, we now opt for a negative binomial regression. This allows us to further add standard dummies. The results are displayed in table 6. The coefficients of the consortia membership variables of models 11-1 and 11-2 as well as 12-1 and 12-2 are similar to our previous poisson fixed effect analysis with clustered standard errors. Models 11-1 and 11-2 estimate the firm level membership effect, while models 12-1 and 12-2 estimate the overall membership net effect. We run two models including and excluding the lagged sales variable and restricting the observations to 2002-2009. Our estimations provide significant results for the consortia variables in all models. 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 important.

[3] Additionally including the closer pre-sample information (1992 to 2002) does not alter significantly the reported results.

Table 6: *Robustness analysis with mean scaling and negative binominal estimation*

	M11-1	M11-2	M12-1	M12-2
	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)
Member	0.474***	0.186*		
	(0.094)	(0.101)		
Member *	-1.969***	-1.273**		
Over Investment	(0.62)	(0.635)		
Member_share			1.162***	1.947***
			(0.212)	(0.269)
Member_share *			-5.931***	-12.757***
Over Investment			(1.418)	(1.823)
Lag1 Patent Files[1]	0.117***	0.105***	0.117***	0.103***
	(0.006)	(0.007)	(0.005)	(0.006)
ICT Patent Files[1]	0.002***	0.006***	0.002***	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
Patent Declarations[1]	0.001	0.011***	0.006	0.011***
	(0.001)	(0.003)	(0.001)	(0.003)
Pre Sample Means	0.162***	0.427***	0.173***	0.457***
(1982-1992)	(0.055)	(0.089)	(0.052)	(0.081)
Lag1 Sales[1]		-0.007***		-0.007***
		(0.001)		(0.001)
Constant	-0.730***	-1.014***	-0.908***	-1.277***
	(0.158)	(0.298)	(0.162)	(0.297)
Standard Dummies	Incl.	Incl.	Incl.	Incl.
Standard Age Dummies	Incl.	Incl.	Incl.	Incl.
Log Likelihood	-26,487.9	-13,642.7	-26,492.5	-13,622.5
AIC	53,071.9	27,383.5	53,081	27,343.1
BIC	53,369.9	27,653.3	53,379	27,612.8
Observations	3,671	1,819	3,671	1,819
Groups	262	246	262	246

Notes: All models estimated with the conditional fixed-effects negative binominal estimator. Model 11-2,12-2 are restricted to a limited time period 2002-2009. ∗∗∗, ∗∗,and ∗ imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible.