WHO COOPERATES IN STANDARDS CONSORTIA – RIVALS OR COMPLEMENTORS?[1]

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ABSTRACT

Formal standard development is increasingly supplemented by standards consortia: informal and less inclusive alliances, in which firms coordinate standard-related research and development (R&D) and streamline standard development. In order to cast light on the economic function of these consortia, this article provides empirical evidence on the standards related to informal consortia, and on the R&D contributions of members and outsiders. We find that standards related to consortia are characterized by a more fragmented ownership of intellectual property rights (IPR) and a strong degree of technological rivalry. We also find that among the firms contributing to a standard, technological specialists are less likely to be member of a consortium. Companies are more likely to be member of the same consortium with companies specializing in R&D that is substitutable rather than complementary to their own patent portfolio. One possible interpretation of these findings is that a main benefit of standards consortia is to reduce the cost of standard development by eliminating wasteful R&D duplication and settling conflicts of interest upfront to formal standardization.

JEL O31, O32, L14

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I. INTRODUCTION

Information and communication technology (ICT) markets are highly competitive industries, where firms compete downstream on products and services and upstream on rival technologies. But ICT are also complex network technologies subject to a rapid technological progress. Interoperability of products is a crucial factor for market success. Firms increasingly must coordinate their innovation activities with other, often competing firms, through the development of common technology standards. In the field of ICT, standard setting is no longer merely a specification of compatibility standards, but in fact a joint development of sophisticated technologies. Thus, standardization often frames the process of simultaneous rivalry and coordination in the development of large systems of innovative technologies (GSM, UMTS, WiFi, DVD, Blu-Ray, MPEG, etc.). In this article, we analyze the driving factors of firm cooperation within this process of standardization. In particular, we analyze whether firms are more likely to coordinate their standard-related R&D programs with firms pursuing complementary or substitutable R&D. Analyzing membership of standards consortia, we find that firms are more likely to coordinate R&D with technological rivals.

There are various ways to achieve standardization. Standards are described as de facto standards when they are sponsored by single firms or industry alliances. De facto standards emerge from consumer choices in a particular market. In comparison, standards are described as de jure standards when they are specified by formal standard developing organizations (SDOs). SDOs are voluntary and non-profit organizations that coordinate the specification of commonly accepted standards. These organizations are very inclusive and attempt to gather all market participants to reach consensus on technology specifications.[4] Farrell and Saloner (1988)[5] show that the committee decision making operating through SDOs results in superior standards than de facto standardization in the market place. Especially in recent years SDOs increasingly gained importance.

SDOs coordinate the development of standard setting and provide a level playing field where firms may compete on the selection of standards components.[6] Firms that provide proprietary technologies are increasingly joining SDOs to value their often patented technology by having it approved as part of an industry-wide

[4] Bekkers, R., Iversen, E., Blind K. (2011): Emerging ways to address the reemerging conflict between patenting and technological standardization, INDUSTRIAL AND CORPORATE CHANGE, 10, 2011.

[5] Farrell, J., Saloner, G. (1988): Coordination through committees and markets, RAND JOURNAL OF ECONOMICS, 19-2,235-252

[6] Leiponen, A. (2008): Competing Through Cooperation: The Organization of Standard Setting in Wireless Telecommunications. MANAGEMENT SCIENCE 54-11,1904-1919.

standard[7]. As a result of this technological rivalry in standard development, the number of patents claimed on ICT standards has been increasing since the early nineties[8]. However, technological competition in formal standardization may generate costly R&D duplications and delays due to vested interests.[9] Firms may therefore also join less inclusive standards consortia to cooperate more closely with some other firms in the standard setting process.[10] While some consortia substitute for SDOs and issue their own standards (e.g., Blu-Ray alliance or W3C for web protocols[11]) many consortia follow up formal standardization and rather co-exist than compete[12] with SDOs.[13]

For SDOs, the cooperation with consortia is of increasing importance. ISO for example explicitly states the goal to strengthen its cooperation with informal consortia "when such partnerships add value to and increase the efficiency of the development of International Standards".[14] ISO and other SDOs cooperate with specific consortia ("Partner Standard Development Organizations") for instance through fast-tracking the specifications developed in such bodies. The increasingly active role of standards consortia bears the promise that formal standards are delivered more rapidly, and match more closely industry needs. On the other hand, there is also the

[7] Bekkers, R., Duysters, G., Verspagen, B. (2002): Intellectual property rights, strategic technology agreements and market structure: The case of GSM. RESEARCH POLICY 31, 1141–1161.

[8] Simcoe T., Explaining the Increase in Intellectual Property Disclosure. In: Sheri Bolin (Eds), The Standards Edge: Golden Mean. Ann Arbor: Bolin Communications (2007).

[9] Farrell J., Simcoe, T. (2012): Choosing the Rules for Consensus Standardization. RAND JOURNAL OF ECONOMICS, forthcoming; Simcoe, T. (2012): Standard Setting Committees: Consensus Governance for Shared Technology Platforms, AMERICAN ECONOMIC REVIEW 102-1, 305-336.

[10] Cargill, C., Weiss, M. (1992): Consortia in the Standards Development Process, Journal of the American Society for Information Science, 43(8), pp. 559 – 565; Lerner, J., Tirole, J. (2006): A model of forum shopping. AMERICAN ECONOMIC REVIEW 96, 1091-1113.

[11] also see Cargill, C., Weiss, M. (1992): Consortia in the Standards Development Process, JOURNAL OF THE AMERICAN SOCIETY FOR INFORMATION SCIENCE, 43(8), pp. 559 – 565

[12] Blind, K., Gauch, S. (2008): Trends in ICT standards: The relationship between European standardization bodies and standards consortia. TELECOMMUNICATIONS POLICY 32, 503-513.

[13] There are formal statements on direct ties between standards consortia and formal standards bodies, e.g. the PAS (Publicly Available Specifications) fast track agreement or JTC1's Approved References Specifications (ARS) or the Partner Standards Development Organization (PSDO). Most standards consortia also enter liaison agreements, which is a rather broad statement of cooperation with formal standard bodies on specific topics. David and Shurmer (1996) describe the case of the DVB (Digital Video Broadcasting) Group, a private industry consortium which was responsible for drafting specifications that were approved by ETSI (European Telecommunications Standards Institute). Gauch (2008) shows how ECMA (European Computer Manufacturers Association) specified DVD technologies that were approved at ISO (International Organization for Standardization).

[14] http://www.iso.org/iso/iso_strategic_plan_2011-2015.pdf.

risk that formal SDOs are captured by powerful special interest groups, bypassing the inclusive and consensual decision making procedures of SDOs. Against the background of the strengthened recognition of consortia, it is thus important to deepen our understanding of the economic role of consortia in standardization. Baron et al.[15] find that consortia increase the efficiency of R&D for standard development, and Delcamp and Leiponen[16] show that consortia increase the propensity of their members to build upon each other's technology. There is however a lack of understanding and empirical evidence on the actual nature of this coordination and on the incentives to join standards consortia that accompany formal standard development.

This article provides empirical results to fill this gap. We identify two very different conceptions of the role of standards consortia supplementing formal standard development in the economic literature. First, consortia can be a place to settle conflicts of interest. Companies with opposing stakes that nevertheless wish to decide on a common standard have a clear incentive to select an appropriate venue to settle their dispute before engaging in the more inclusive and formal processes at the SDO. From this point of view, we would expect consortia to bring together the fiercest technological rivals. In a different conception, consortia are alliances of firms joining forces in order to leverage their voting power in the SDO and obtain an advantage over rival firms that have not joined the consortium. Also in this case we would expect that consortia concentrate on standards experiencing fierce technological rivalry. We would however not expect rival firms to be members of the same consortium, but rather expect that firms choosing to collaborate have complementary R&D assets.

We hypothesize that consortia concentrate on standards characterized by strong technological rivalry. Furthermore, in order to test empirically the two different conceptions of the role of consortia, we analyze whether technological rivals are members of the same consortia or not. To this end, we first identify for each firm contributing technology to a particular standard its standard-related patents. We then construct empirical measures of the complementarity or substitutability between the standard-related patent portfolios of different firms. This analysis represents a major methodological innovation that builds upon the analysis of the technological classification of several millions of patents.

Our results suggest that consortia are more likely to be created for standards characterized by a high degree of technological rivalry. Furthermore, technological specialists seem less likely to be consortium members than firms facing direct technological competitors on a standard. Regarding the two different

[15] Baron, J., Ménière, Y., Pohlmann, T. (2013): Standards, consortia and innovation, *Working Paper*

[16] Delcamp, H., Leiponen, A. (2012): Innovating Standards Through Informal Consortia: The Case of Wireless Telecommunications, NBER Working paper No. 18179

conceptions of consortia, our results suggest that firms specializing on the same technological components of the standard are significantly more likely to jointly be members of the same consortium. This finding has interesting implications for the economic analysis of standards consortia. In their majority, standards consortia are not a device to coordinate the R&D programs of firms with complementary specializations. Rather, consortia appear to bring together firms specializing on the same standard components. These findings suggest that a major economic function of standards consortia is to reduce wars of attrition and the costs of technological rivalry through upfront coordination.

II. THEORETICAL BACKGROUND

The economic literature discusses both incentives to cooperate on R&D with rivals and complementors. The economic analysis of R&D cooperation hereby traditionally identifies spillovers as the main incentive to cooperate on R&D.[17] In presence of knowledge spillovers from private R&D collaboration allows firms to internalize the positive learning externality of their R&D. Hence, R&D collaboration increases both R&D efforts and productivity.[18] In order to best benefit from knowledge spillovers in R&D collaboration, firms predominantly cooperate with those firms whose focus of specialization is complementary, yet sufficiently similar to their own.[19]

Another important externality of private R&D is the competition externality. The R&D effort of each company decreases the profits of its competitors on the downstream product market.[20] Furthermore, in case of patent races, the R&D effort of a company reduces the chances of other firms to reap benefits from their own R&D. This rivalry spurs wasteful over-investment in R&D with respect to the collective interest of the firms and

[17] Katz, M.L., Ordover, J.A., (1990) R&D Cooperation and competition, in: Brookings Papers on Economic Activity: Microeconomics pp. 137-203; D'Aspremont, C. and Jacquemin, A. (1988): Cooperative and Noncooperative R&D in Duopoly with Spillovers, AMERICAN ECONOMIC REVIEW, 78(5), pp. 1133-1138.

[18] Romer, P. (1993): Implementing a National Technology Strategy with Self-Organizing Industry Investment Boards, BROOKINGS PAPERS ON ECONOMIC ACTIVITY, Microeconomics 2; Branstetter, L., Sakakibara, M. (2002): When Do Research Consortia Work Well and Why? Evidence from Japanese Panel Data. AMERICAN ECONOMIC REVIEW, 2(1): 143–159.

[19] Cantner, U., Meder, A. (2007): Technological proximity and the choice of cooperation partner, JOURNAL OF ECONOMIC INTERACTION AND COORDINATION, 2, pp. 45-65

[20] Bloom, N., Schankerman, M., Reenen, J. V. (2013): Identifying Technology Spillovers and Product Market Rivalry, ECONOMETRICA, forthcoming

even with respect to social welfare.[21] R&D collaboration among technological rivals can in this case efficiently reduce wasteful R&D duplication.[22]

Unlike Research Joint Ventures, collaborative standard development does not entail contracting or joint decision making on R&D investments. Nevertheless, there are some similarities between participation in standardization and other forms of collaborative innovation. Especially small firms often join the working groups of SDOs in order to learn from their competitors[23]. Firms' incentives to collaborate in these consortia are mutual exchange of information, access to complementary R&D, learning, influencing and advertising.[24] Bar and Leiponen (2012) consistently find that companies are more likely to integrate working groups in which other firms with complementary technological assets and access to different networks are predominant.

Knowledge spillovers and learning are however not the main drivers for participation in standards consortia accompanying a formal standardization project. These standards consortia are rather venues for limited groups of standardization participants to discuss on standard-related topics such as the development and selection of technological specifications, procedures for implementation and certification etc. Thereby consortia facilitate the emergence of a consensus regarding decision making in the more comprehensive standard body itself. This function of consortia is compatible with the descriptions of Axelrod et al.[25] and Weiss and Sirbu[26] who state that consortia are venues of likeminded peers where firms promote and develop a certain technology. The precise role of consortia in standard development differs substantially from standard to standard. For instance upstream consortia are active in the development of technical specifications to be submitted as proposals to the working groups of the SDO, while downstream consortia deal with the promotion, maintenance or enforcement of existing standards. In spite of this heterogeneity, all standards consortia have in common that

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[21] Reinganum, J. (1989): The Timing of Innovation: Research, Development and Diffusion, HANDBOOK OF INDUSTRIAL ORGANIZATION Vol. 1, pp. 849 – 908.

[22] Irwin, D., Klenow, P. (1996). High-tech R&D subsidies: Estimating the effects of Sematech, JOURNAL OF INTERNATIONAL ECONOMICS, vol. 40(3-4), pages 323-344.

[23] Fleming, L., Waguespack, D. (2008): Scanning the Commons? Evidence on the Benefits to Startups Participating in Open Standards Development, MANAGEMENT SCIENCE, 55(2).

[24] Leiponen, A., Bar, T. (2012): Committees and Networking in Standard Setting, working paper.

[25] Axelrod, R., S. Bennett, E. Bruderer, W. Mitchell, R. Thomas. (1995): Coalition formation in standard-setting alliances. MANAGEMENT SCIENCE 41, 1493–1508.

[26] Weiss, M. B. H., Sirbu M. (1990): Technological Choice in Voluntary Standards Committees: An Empirical Analysis, ECONOMICS OF INNOVATION AND NEW TECHNOLOGY, 111-133.

they consist in subsets of companies participating in a more inclusive formal standard development process, and that their objective is to coordinate their members' contribution to this shared technological standard. [27]

Also regarding the more narrow type of R&D collaboration in standards consortia, the economic literature provides a rationale for both cooperating with rivals and complementors. According to one view, consortia are alliances of like-minded peers.[28] In standards where firms compete in providing technology components, such coalition building may improve a firm's position in negotiations for technology selection.[29] Leiponen[30] for instance shows that membership in a related consortium increases the capacity of a firm to influence the voting behavior of other companies in the SDO. Consortia may thus be means for members to forge alliances and to increase the chances of their patented technology to be selected for inclusion into a formal standard.[31] Examples are for instance the alliances between companies specializing in such diverse industries as consumer electronics, software and media content in the development of (rivaling) optical disc standards. The members of these alliances forge a consensus regarding their preferred technological specifications, and align their R&D with the complementary R&D of other consortia participants.[32]

On the other hand, companies also have an incentive to cooperate with their immediate technological rivals. First, companies often develop substitutable patented technologies for selection into technological standards. Only the selected technology benefits from a strong increase in its value[33], while the non-selected alternatives are abandoned. Through upfront coordination, technological rivals can limit the extent of wasteful duplication in the development of technologies for selection into a standard. This way companies reduce their

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[27] Pohlmann (2011): Attributes and dynamic development phases of informal ICT standards consortia, TNS 2010, ISBN 978-972-8939-19-9.

[28] Axelrod, R., S. Bennett, E. Bruderer, W. Mitchell, R. Thomas. (1995): Coalition formation in standard-setting alliances. MANAGEMENT SCIENCE 41, 1493–1508; Weiss, M. B. H., Sirbu M. (1990): Technological Choice in Voluntary Standards Committees: An Empirical Analysis, ECONOMICS OF INNOVATION AND NEW TECHNOLOGY, 111-133.

[29] Rosenkopf, L., Metiu A. and George, V. (2001): From the Bottom Up? Technical Committee Activity and Alliance Formation. ADMINISTRATIVE SCIENCE QUARTERLY 46, 748-772.; Pohlmann, T., Blind, K. (2012): Cooperate to put in place. Firms' cooperative activities to promote patented contributions for ICT standards, working paper.

[30] Leiponen, A. (2008): Competing Through Cooperation: The Organization of Standard Setting in Wireless Telecommunications. MANAGEMENT SCIENCE 54-11,1904-1919.

[31] Pohlmann T. and Blind K. (2013): Cooperate to put in place. Firms' cooperative activities to promote patented contributions for ICT standards, working paper.

[32] Delcamp, H., Leiponen, A. (2012): Innovating Standards Through Informal Consortia: The Case of Wireless Telecommunications, NBER Working paper No. 18179.

[33] Rysman, M., Simcoe. T. (2008): Patents and the Performance of Voluntary Standard Setting Organizations, MANAGEMENT SCIENCE 54-11, 1920-1934.

risk and make sure that their R&D corresponds to the future evolution of the standard.[34] Baron et al.[35] find that in cases of wasteful over-investment in standard-related R&D, consortia can pro-efficiently reduce the extent of related patenting. Second, inclusive SDOs are notoriously ill-equipped to settle conflicts of interest. Simcoe[36] shows that companies with conflicting stakes in a technological standard can engage into wars of attrition. These costly hold-out games in the working groups of the SDO inefficiently slow down standard development. Practitioners interviewed for a EU study on patents and standards[37] also report cases in which standard development is substantially delayed or technological errors are introduced as a consequence of the vested interests of contributing firms. In order to avoid these costly adverse consequences of conflicts in SDOs, companies with conflicting stakes in a standard have the incentive to find an appropriate venue for solving their dispute. Companies can use forum shopping to select the standardization venue that best matches their needs.[38]

Consortia thus can be created either as a device for coordinating complementary R&D programs and improving the position of their members against outside technological rivals, or for settling conflicts of interest and mitigating wasteful R&D duplication resulting from technological rivalry. The effects of consortia on innovation incentives and the technological evolution of the standard are likely to be very different in the two different cases. While coordination among technological rivals reduces R&D duplication and overinvestment, coordination among firms with complementary specializations reduces risk and increases R&D profitability. As a first step to increase our understanding of the economic role and effect of standards consortia, it is therefore very important to find out whether these alliances are predominantly composed of technological rivals or companies with complementary specializations.

[34] Aggarwal, N.; Dai, Q.; Walden, E. A. (2011): The More, the Merrier? How the Number of Partners in a Standard-Setting Initiative Affects Shareholder’s Risk and Return, MIS QUARTERLY, (35: 2) pp.445-462.

[35] Baron, J., Ménière, Y., Pohlmann, T. (2013): Standards, consortia and innovation, *Working Paper*.

[36] Simcoe, T. (2012): Standard Setting Committees: Consensus Governance for Shared Technology Platforms, AMERICAN ECONOMIC REVIEW 102-1, 305-336.

[37] Blind, K.; Bekkers, R.; Dietrich, Y.; Iversen, E.; Müller, B.; Köhler, F. Pohlmann, T.; Verweijen, J. (2011): EU Study on the Interplay between Standards and Intellectual Property Rights (IPR), commissioned by the DG Enterprise and Industry, Tender No ENTR/09/015. OJEU S136 of 18/07/2009.

[38] The literature has so far mainly recognized forum shopping regarding the role of SDOs as technological certifiers; see Lerner, J., Tirole, J. (2006): A model of forum shopping. American Economic Review 96, 1091-1113; Chiao, B., Lerner, J., Tirole, J. (2007): The Rules of Standard Setting Organizations: an Empirical Analysis, RAND JOURNAL OF ECONOMICS, vol. 38, n. 4, p. 905-930.

III. EMPIRICAL METHODOLOGY

A. Data

Our empirical analysis draws on a comprehensive dataset of technological standards that are subject to essential patents. Our sample includes all ICT standards issued between 1992 and 2009 by one of the major formal SDOs (ISO, IEC, JTC1 – a joint committee of ISO and IEC – CEN/CENELEC, ITU-T, ITU-R, ETSI, and IEEE) that operate on an international level. This sample covers the most important and largest ICT standard setting project e.g. such as UMTS, LTE, WiFi, RFiD or MPEG. Our database however covers only standards mainly developed and ultimately agreed upon within a formal SDO. To the best of our knowledge, no available database reliably tracks and categorizes standards exclusively developed by other organizations, for instance more informal standard bodies (e.g. BluRay). We therefore cannot compare standards exclusively developed by either formal or informal standardization bodies. We can however compare different formal standard development processes. For instance we can compare standards developed in partnership between formal SDOs and informal alliances with standards exclusively developed within formal SDOs. This analysis could potentially be biased by the fact that standards exclusively developed by informal consortia do not enter the sample. We however focus upon consortia following up standard projects developed by the formal SDOs as the lead organization. For instance, we do not include standards that have been developed by consortia and upon completion submitted to SDOs for ratification. Therefore we believe that our comprehensive sample of formal standards is an acceptable representation of the population of standards "at risk" of being developed within such a partnership.

We furthermore restrict the analysis to standards including essential patents of at least four different companies, thereby limiting the sample to 121 standards. To retrieve information on patent declarations, we exploit publicly available data from all SDOs. SDOs suggest that firms declare all IPR that is potentially essential to standards[39]. All of these SDOs provide lists of patent declarations, including information on the declaring firm, the date of declaration, the relevant standards and the patent number. In sum we retrieved over 64,000 patent declarations, which represent all essential patents that have been declared to formal SDOs.[40]

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[39] Lemley, M. A. (2002) Intellectual Property Rights and Standard-Setting Organizations. California Law Review 90, 1889-1980.

[40] Blind, K.; Bekkers, R.; Dietrich, Y.; Iversen, E.; Müller, B.; Köhler, F. Pohlmann, T.; Verweijen, J. (2011): EU Study on the Interplay between Standards and Intellectual Property Rights (IPR), commissioned by the DG Enterprise and Industry, Tender No ENTR/09/015. OJEU S136 of 18/07/2009.

Nevertheless, essential patents only represent a very small amount of patenting around standards.[41] Indeed, especially in the case of standards characterized by strong technological rivalry, we expect that many companies have developed and patented competing technologies in view of inclusion into a standard. In this case, only one out of various rivaling technological solutions materializes in essential patents. To observe the full array of standard-related patenting, we thus build up a new measure of firms' standard-specific R&D investments. 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.[42]. We restrict the count of patent files to precise (4 digit) IPC[43] classes in the relevant technological field of each standard, identified by using the IPC classification of declared essential patents.[44] We use the approach as to Baron et al.[45] to weight the patent files by the relevance of their IPC class to the respective standard, and conduct several analyses to assess the reliability of this measurement method.

From the PERINORM database we retrieve information on the date of first release, releases of further versions and amendments, number of pages of the standard document and the technical classification of the standard. We then use the date of standard release to restrict our measure of standard-related patenting to patents filed between six and one year before the release of the first standard version. This way, we make sure that we measure the standard-related technological assets of the different standardization participants, which will eventually determine their likelihood to cooperate, but we do not capture any patent filings resulting from the effect of consortia or other standard-related coordination. Thus we rule out that our data captures the process of coordination in standards consortia.

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[41] Bekkers, R., Duysters, G., Verspagen, B. (2002): Intellectual property rights, strategic technology agreements and market structure: The case of GSM. RESEARCH POLICY 31, 1141–1161.

[42] 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.

[43] In the International Patent Classification (IPC) system, patent examiners assign patents to one or several very precise technological subcategories, which can be aggregated to more comprehensive technological categories and fields

[44] 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 Baron, J., Ménière, Y., Pohlmann, T. (2013): Standards, consortia and innovation, *Working Paper.*

[45] Baron, J., Ménière, Y., Pohlmann, T. (2013): Standards, consortia and innovation, *Working Paper.*

To identify standards 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.[46] These surveys cover a comprehensive sample of consortia responding to objective selection criteria, for instance openness and transparency. We identify approximately 250 active ICT consortia.[47] We categorize these consortia as to industry, function (e.g. spec producer or promoter) and years of activity. The connection to a standard in our sample is analyzed by using liaison agreements and information from consortia and SDO web pages. For instance, a connection was identified, when a consortium explicitly references a formal standard. 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).[48] 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.

B. Measuring complementarity

In economic analysis, patent data and in particular the distribution of patent portfolios over IPC classes is often used to identify the technological position of firms. Rosenkopf and Almeida[49] and Gilsing et al.[50] used patent data for measuring technological distance in alliances, Bar and Leiponen[51] in the context of standard setting. To analyze whether firms participating in standard development contribute complementary or substitutable technologies, we compare the distribution of the firms' standard-related patents over the different standard-relevant IPC classes. We identify the standard-relevant technology fields as being the main IPC classes (4 digit) of the declared essential patents per standard. We then count all independent patent families filed by the companies declaring essential patents in the identified IPC classes.

[46] http://www.consortiuminfo.org/links/linksall.php

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

[48] 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". Baron et al. (2013) provide a list of those consortia and standards for which a link could be established, as well as the narrower list of consortia contributing technologically.

[49] Rosenkopf, L., P. Almeida (2003): Overcoming local search through alliances and mobility, MANAGEMENT SCIENCE, 49,6,751-766.

[50] Gilsing, V., B. Nooteboom, W. Vanhaverbeke, G. Duysters and A. van den Oord. (2008): Network embeddedness and the exploration of novel technologies: Technological distance, betweenness centrality and density, RESEARCH POLICY 37, 1717-1731.

[51] Leiponen, A., Bar, T. (2012): Committees and Networking in Standard Setting, working paper.

Following Benner and Waldfogel[52], we use all IPC classes (instead of the main classification) of the patents, and rely upon a relatively aggregated level of technology (4 digit IPC). We weight the numbers of patent applications so that the relative weight of the different IPC classes in the count of related patents matches the weights in the group of declared essential patents. If a patent class represents a high percentage of the declared essential patents, we therefore give a high importance to the patent files in these patent classes, independently of how many patents the companies file in these classes. This way we make sure that our analysis is not too strongly driven by very large and generic IPC classes which are present in almost all standards in our sample.

We then use the IPC classes of the identified patents in the related technological field to map the technological portfolio of the different firms. The following tables exemplify the procedure using two stylized hypothetical standards. Each field in the tables represents the weighted number of patents filed by the respective firm in the respective class.

Table 1. Numeric example of firms' technology overlap for standards.

Standard 1				Standard 2			
	IPC k1	IPC k2	IPC k3		IPC k1	IPC k2	IPC k3
Firm A	100	20	200	Firm A	70	500	100
Firm B	200	100	300	Firm B	100	100	600
Firm C	500	200	600	Firm C	300	80	100

For each firm and standard, we obtain a vector that shows how many patents p the firm has filed in each of the k relevant technological classes. We can then analyze the similarity of the standard-related firm portfolios by two different widely accepted measures based upon the firm standard vectors.

Table 2. Numeric example of technology vectors of firms' technology overlap for standards.

Standard 1	Standard 2
$A_k = [100; 20; 200]$	$A_k = [70; 500; 100]$
$B_k = [200; 100; 300]$	$B_k = [100; 100; 600]$
$C_k = [500; 200; 600]$	$C_k = [300; 80; 100]$

Various methodologies are used in the literature to calculate the technological distance between firms based upon the distribution vector of their patent portfolios over a specified technological field. These different measures are generally viewed as conveying very similar information, and are highly correlated for large patent

[52] Benner, M., Waldfogel, J. (2008): Close to you? Bias and precision in patent-based measures of technological position, RESEARCH POLICY, 37, pp. 1556-1567.

samples[53]. Following Benner and Waldfogel (2008), we calculate the **angle *a*** and the **correlation coefficient *r*** between the respective vectors. Other measures used in previous analyses include the Min-Complement distance or the Euclidean distance[54]. Bar and Leiponen (2013) argue that the Min-Complement distance measure is superior to other measures, since it is insensitive to the distribution of patents in irrelevant classes (i.e. classes in which one of the firms in a pair does not patent) [55]. We believe that the independence of such irrelevant patent classes is desirable only for the purpose of analyzing spillovers and other learning effects, while for strategic effects it does matter how patents are distributed in all classes, including those in which the other firm is not active. Since the goal of our analysis is to analyze technological rivalry and not spillover effects, we opted for the more widely used angle and correlation measures. In almost all cases, we find similar results using the two different measures, and we do not interpret them as conveying different, specific information.

We thus calculate as a first step *the similarity scores* between pairs of two firms contributing to the same standard, calculated as angle ***a*** and correlation coefficient ***r***.

$$\boldsymbol{a_{A,B}} = \frac{\sum_k p_{A,k} p_{B,k}}{\sqrt{\sum_k p_{A,k}^2 \, p_{B,k}^2}}$$

$$\boldsymbol{r_{A,B}} = \frac{\sum_k (p_{A,k} - \frac{p_{A,k} + p_{B,k}}{2})(p_{B,k} - \frac{p_{A,k} + p_{B,k}}{2})}{\sqrt{\sum_k (p_{A,k} - \frac{p_{A,k} + p_{B,k}}{2})^2} \sqrt{\sum_k (p_{B,k} - \frac{p_{A,k} + p_{B,k}}{2})^2}}$$

Table 3. Numeric example of correlation scores of firms' technology overlap for standards.

	Standard 1			Standard 2	
	R	***A***		***r***	***a***
$A_k \# B_k$	0,99794872	0,97619048	$A_k \# B_k$	-0,444912 1	0,3687678
$A_k \# C_k$	0,941 259	0,96134064	$A_k \# C_k$	-0,61974188	0,42290864
$B_k \# C_k$	0,9607 892	0,99449032	$B_k \# C_k$	-0,4271211	0,48737524

[53] Bar, T. and A. Leiponen (2013): A Measure of Probability Distance and Its Application to Technological Proximity. Forthcoming in ECONOMICS LETTERS.

[54] Benner, M., Waldfogel, J. (2008): Close to you? Bias and precision in patent-based measures of technological position, RESEARCH POLICY, 37, pp. 1556-1567.

[55] Bar, T. and A. Leiponen (2013): A Measure of Probability Distance and Its Application to Technological Proximity. Forthcoming in ECONOMICS LETTERS.

For our hypothetical examples, we can see that in Standard 1, Firms a, b, and c have highly correlated patent portfolios and a high angle. In Standard 2, firms have negatively correlated patent portfolios, and the angle is much lower. It thus becomes apparent that the Correlation Coefficient and the angle carry similar information on the similarity between firms.

In addition to the pairwise information on the similarity between firm portfolios, we analyze the technological position of a firm with respect to the remainder of the standard. For instance we wish to identify technological specialists and generalists. Therefore, for each standard and firm, we count the patents filed by all the other firms active on the standard. We can then calculate the angle and the correlation coefficient between each firm vector and the vector for the respective remainder of the standard (the *specialization scores*):

Table 4. Numeric example of rivalry scores of standards.

	Standard 1			Standard 2	
	r	***a***		***r***	***a***
$A_k\#A'_k$	0,96786784	0,96720225	$A_k\#A'_k$	-0,78088686	0,44217823
$B_k\#B'_k$	0,98432414	0,99709339	$B_k\#B'_k$	-0,83409962	0,48681172
$C_k\#C'_k$	0,95190175	0,98758573	$C_k\#C'_k$	-0,96618556	0,55264489

In Standard 1, Firms A, B and C have all very high correlation coefficients and very high angle scores. They are thus all technology generalists for Standard 1. In Standard 2, all the firms have negative correlation coefficients and low angle scores. In Standard 2, the three firms are technology specialists (each specializing on a different technological field).

Based upon the specialization scores, we can finally calculate the weighted average score of specialization for a standard. We weight the specialization score of each firm with the share of the firm in the patents in the standard-related field, and sum the weighted scores to obtain the weighted average score, or the *rivalry score* of the standard.

Table 5. Numeric example of rivalry scores of standards.

	Standard 1				Standard 2		
	Share	***r****share*	***a****share*		*share*	***r****share*	***a****share*
Firm A	0,1441441	0,1395124	0,1394165	Firm A	0,3436	-0,2683	0,1519
Firm B	0,2702702	0,2660335	0,2694847	Firm B	0,4103	-0,3421	0,1997
Firm C	0,5855855	0,5574199	0,5783159	Firm C	0,2462	-0,2378	0,1360
Weighted Average	1	0,9629659	0,9872172	Weighted Average	1	-0,8483	0,4877

The *rivalry score* of Standard 1 is very high: all companies have their relative focus of specialization on the same technologies. There is thus potentially a very tough competition for including patented technologies into this standard. This pattern can induce patent races and wasteful excess patenting, as each firm does not take into account the negative effect of its R&D efforts on the profitability of the R&D of the other firms.[56] Standard 2 however is characterized by a very low rivalry score. Each firm is specializing on a different technological field. There is thus less risk of wasteful patent races, but there might be free-riding problems: each firm benefits from the R&D investments of the other firms, investing in technologies which are complementary, but not competing with the technological portfolio of the firm. Therefore firms underinvest in R&D, as they do not take into account the positive effect of their own R&D upon the profitability of the R&D programs of other firms.

IV. EMPIRICAL ANALYSIS

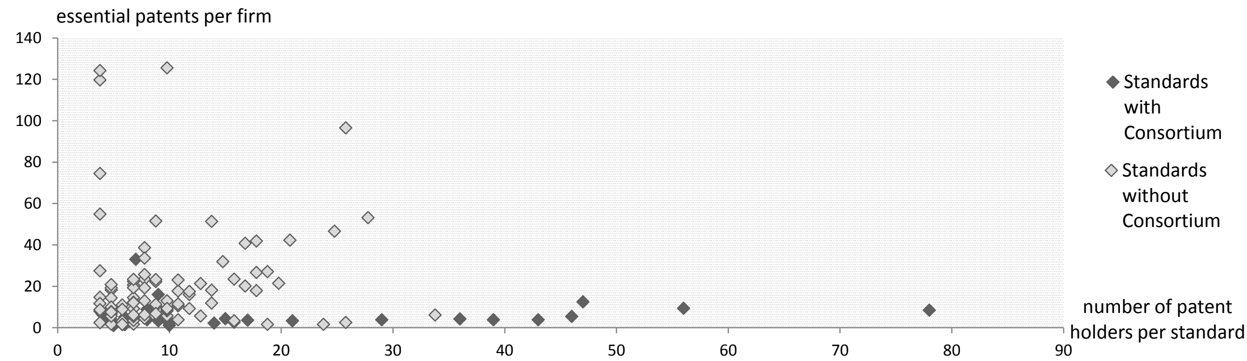
In the following empirical section we conduct several statistical tests to identify factors of consortia formation and consortia membership. As mentioned in our methodological section we use pre sample data to ensure that the patent distribution is independent of the event of analysis. The goal of this method is to identify similarities among firms independent from the treatment variable. We thus ensure that effects from coordination in standards consortia do not influence our analysis.

A. Fragmentation of patent holders and the existence of standards consortia

In our theoretical section we have discussed how the fragmentation of IPR ownership may result in coordination failures. To overcome these obstacles, firms may form standards consortia to solve conflicts of interest. We use two variables to test situations of fragmented IPR ownership among standard setting firms. First, we count the number of essential patent owning firms; second we relate the number of standard essential patents to the number of owners. Graph 1 illustrates the distribution of standards with and without consortia. Consortia have been formed for all standards with an unusually high number of patent holders. Furthermore for these standards the concentration of patents per firm is remarkably low. In comparison, standards where we could not identify a consortium show in some cases a very strong concentration of patents per firm, while the number of patent holders is lower.

[56] Baron, J., Ménière, Y., Pohlmann, T. (2013): Standards, consortia and innovation, *Working Paper*.

Graph 1. Comparison of standards with and without consortia liaison



The distribution graph indicates that consortia are particularly relevant to standards in situations of fragmented ownership of IPR. However, we seek to further test if these are also situations of technological rivalry.

B. Rivalry scores and the existence of standards consortia

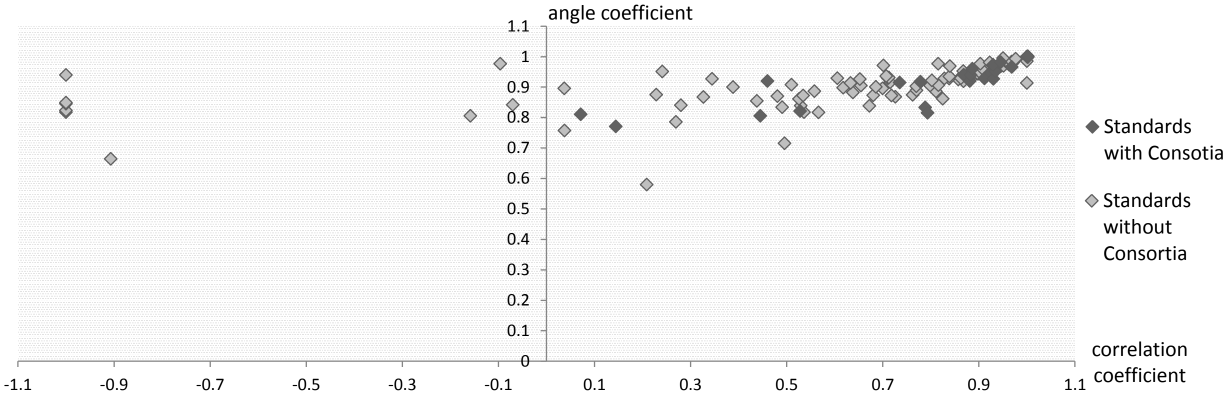
In a next step we compare the rivalry scores of standards that are in liaison with a consortium with other standards for which no consortium could be identified. For calculating the rivalry scores per standard we use the approach described in our previous methodological section. High rivalry scores indicate a high technological overlap among all firms that contribute to a particular standard. Table 7 shows the results of a t-tests analysis, comparing the mean rivalry scores between standards with and without consortia.

Table 6. Mean rivalry scores for standards with and without consortia.

Rivalry Scores		**Angle coefficient**	**Correlation coefficient**
Standards with consortia	Mean	0.9269	0.7575
	Obs.	28	22
Standards without consortia	Mean	0.9102	0.5544
	Obs.	97	86
t-statistics	T	1.0726	1.8364
	Pr(T < t)	0.8572	0.9654
	Pr(T > t)	0.1428	0.0346

The rivalry scores are successively calculated using the angle and the correlation coefficient. Table 6 shows that the rivalry scores of standards related to consortia are higher than the scores of other standards. However, only the comparison of the rivalry scores using the correlation coefficient reveals significant differences. We further graph the distribution of rivalry scores per standard in a matrix of correlation and angle coefficients. Graph 2 shows that correlation and angle coefficients strongly correlate. The angle coefficient shows just a slightly different distribution for standards with and without consortia. The correlation coefficient rivalry scores however is clearly differently distributed for standards related to informal consortia: these standards never display negative rivalry scores, and concentrate on the top level of the distribution.

Graph 2. Comparison of the rivalry score distribution of standards with and without consortia in a matrix of correlation and angle coefficients.



Results of our t-statistics as well as our distribution graph indicate that consortia are more likely to be formed in situations of high technological rivalry and fragmented ownership of IPR. We further test our descriptive findings and count the number of consortia in several intervals of coefficients for the two rivalry scores. In addition we conduct a pair wise correlation analysis (results can be consulted in appendix 1). Both analyses again confirm our previous results. Standards consortia are more frequent in higher intervals of rivalry scores. The correlation matrix indicates a significant positive connection of consortia existence with our rivalry scores and with the number of patent holders. In comparison, consortia formation and the number of essential patents per firm negatively correlate.

C. Specialization scores and consortia membership

In a next step, we compare consortia members and other companies as to their specialization scores. A high angle or correlation coefficient indicates that a firm's standard-specific patent portfolio is very similar to the portfolio of other firms, whereas a low score characterizes strong technological specialization different form other firms. The following table compares future consortia member with firms that will contribute to standards without consortia liaison (firms that contribute to standards where we do not identify a consortium) and future consortia outsiders (firms contributing to a standard for which at least one consortium exists, but which are not member).

Table 7. Mean specialization scores for consortia members and non-members.

Specialization Scores		**Angle**	**Correlation Coefficient**	**Angle**	**Correlation Coefficient**
Consortia Members	Mean	0.918	0.876	0.918	0.876
	Obs.	118	118	118	118
Firms on Standards without	Mean	0.875	0.598		
Consortia	Obs.	746	716		
Consortia Outsiders	Mean			0.854	0.664
	Obs.			163	163
t-statistics	T	2.4945	4.5940	3.1991	4.311
	Pr(T < t)	0.9936	1.0000	0.9985	1.0000
	Pr(T > t)	0.0064	0.0000	0.0015	0.0000

The comparison of both, the calculated angle and the correlation coefficient indicates that technological specialists will less likely be consortium members. Furthermore we show that firms that contribute to standards where we do not identify consortia are more specialized and thus have less technological overlap to other standard setting firms. We further test these findings with a logit regression:

Table 8. Logit regression models explaining consortia membership

	M1-A	M1-B	M2-A	M2_B	M3-A	M3-B
DV=Consortium Member	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)
Correlation Coefficient	2.170** (0.902)		2.016** (0.959)		2.272** (1.002)	
Angle Coefficient		4.380*** (1.666)		4.093** (1.839)		4.382** (1.804)
Rel. Patent Portfolio			0.105 (0.119)	0.095 (0.118)	0.106 (0.139)	0.097 (0.133)
Rel. Patent Declaration			-1.231 (2.824)	-1.272 (2.711)	-1.71 (3.049)	-1.782 (2.947)
Relative Employee	0.319*** (0.113)	0.270** (0.117)	0.284*** (0.108)	0.244** (0.106)	0.354*** (0.115)	0.300*** (0.115)
Relative R&D Expenditure	0.067 (0.291)	0.11 (0.277)	0.016 (0.310)	0.061 (0.300)	0.001 (0.314)	0.042 (0.301)
Firms on Standard	0.150*** (0.034)	0.153*** (0.031)	0.147*** (0.034)	0.150*** (0.031)	0.096*** (0.023)	0.106*** (0.021)
Cons	-5.670*** (1.064)	-7.920*** (1.631)	-5.448*** (1.004)	-7.562*** (1.642)	-4.186*** (0.842)	-6.559*** (1.444)
Technology class dummies (ICS)	YES	YES	YES	YES	YES	YES
Consortia Exists Restriction	**NO**	**NO**	**NO**	**NO**	**YES**	**YES**
N_clust	108	108	108	108	15	15
N	816	816	816	816	196	196
Pseudolikelihood	-95.924	-96.215	-95.493	-95.833	-82.382	-83.551
Pseudo R2	0.717	0.716	0.718	0.717	0.373	0.364

Note: Dependent variable is whether or not a firm becomes consortium member. An observation is company-standard pair. All models apply a cross section logit-analysis with clustered robust standard errors in parenthesis. Standard errors are robust and clustered by standard. ***,**,and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively.

We run estimations on two different samples, successively estimating the likelihood of consortium membership in general (M1-M2) and consortium membership conditional upon the existence of at least one consortium (M3). We control for firm characteristics relative to the average characteristics of firms active on the specific standard (firm size in terms of employees; R&D expenditures, patent portfolio, number of declared essential patents), and for the fragmentation of IPR ownership (Firms on standard). Variable descriptions and summary statistics can be consulted in Appendix 2.

Results of the logit model confirm our previous descriptive findings. Technological specialists – firms with a low angle and correlation coefficient with respect to the remainder of the standard – are less likely joining a consortium. In all models, the number of firms that hold patents on the standard has a positive influence on becoming consortium member. This again confirms that situations of fragmented IPR ownership increase incentives to coordinate. We furthermore find that firms with a higher number of employees than the average of the firms contributing to the same standard are more likely to be consortium members for this standard.

D. Similarity scores and joint consortia membership

In a final step, we compare pairs of companies contributing to the same standard and analyze how the similarity scores of the standard-specific patent portfolios relate to the likelihood of becoming a member of the same consortium. The following table compares the similarity scores (calculated using the angle and the correlation coefficient) of company-pairs where both companies are members of the same consortium with other pairs of companies contributing to the same standard.

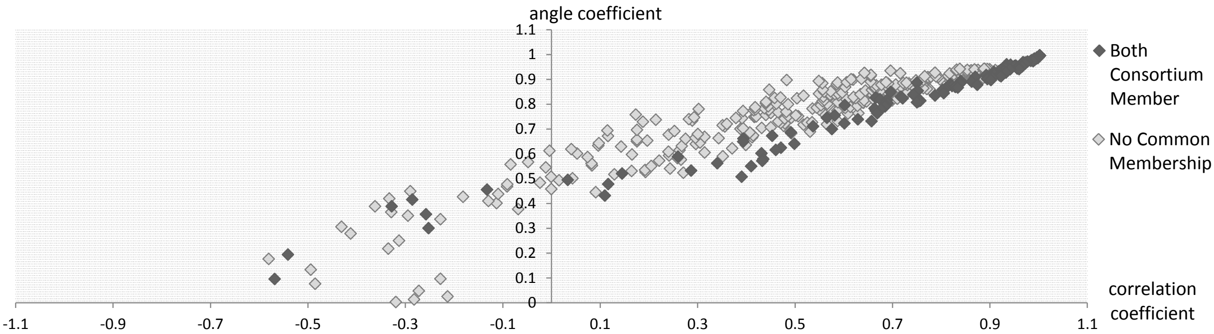
Table 9. Mean similarity scores for consortia co-members and non-members.

Similarity Scores		**Angle**	**Correlation Coefficient**
Pairs of companies which are member of the same consortium	Mean	0.8472	0.7844
	Obs.	1,954	1,954
Remaining pairs of companies active in the same standard	Mean	0.7887	0.5994
	Obs.	5,028	5,028
t-statistics	T	11.4342	18.5344
	Pr(T < t)	1.0000	1.0000
	Pr(T > t)	0.0000	0.0000

The t-test mean comparison indicates that companies with similar patent portfolios have a significant higher likelihood to be members of the same consortium. Technological overlap between firms' patent portfolios for a particular standard thus seems to increase their incentives to become co-members in standards consortia. To better illustrate the distribution of our estimated coefficients we graph a scatter plot.

Graph 3 plots the scores of our similarity measure in a matrix of correlation and angle coefficients. In situations where both firms become members, the scores seem to rather concentrate on higher levels, compared to situations where firms will not become co-members. However, the distribution also shows cases where the similarity score of co-members are rather low.

Graph 3. Comparison of the similarity score distribution of situations of co-membership and no membership in a matrix of correlation and angle coefficients.



Once again, we test these results using a logit regression model. We control for measures of firm similarity or dissimilarity, such as variables indicating whether the companies are active in the same industry, or whether the companies have the same business model (classified by manufacturer, network provider or non-practicing entity). In addition, we control for the difference in firm size, in R&D expenditures, in the size of the patent portfolio and in the number of declared essential patents. These measures are constructed by dividing the larger value by the lower value. We furthermore include ICS (International Classification of Standards) dummies, restrict the sample to standards with at least one consortium, and cluster standard errors by standards and firms. Variable descriptions and summary statistics can be consulted in Appendix 3.

Regression results are consistent with the mean comparison. The similarity score (calculated with the angle and correlation coefficient) has a positive effect on the likelihood of membership in the same consortium. Even though we have identified situations where co-members' patent portfolios are less similar compared to non-members, our statistical estimations conform a higher likelihood of joint membership when similarity scores are high.

Our control variables show that companies with the same business model are more likely to be members of the same consortium. Differences in the amount of R&D expenditure or the total number of the firms' patents are negatively correlated with co-membership.

Table 10. Logit regression models explaining consortia co-membership.

	M1-A	M1-B	M2-A	M2_B	M3-A	M3-B
DV = Both Member	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)
Correlation Coefficient	1.350*** (0.182)		1.286*** (0.188)		0.709*** (0.181)	
Angle Coefficient		2.704*** (0.364)		2.611*** (0.381)		1.184*** (0.385)
Diff. Employee	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)	0 (0.001)	0 (0.001)
Diff. R&D Exp.	-0.014*** (0.003)	-0.014*** (0.003)	-0.015*** (0.003)	-0.015*** (0.003)	-0.014*** (0.003)	-0.014*** (0.003)
Same Business Model			0.796*** (0.239)	0.835*** (0.24)	1.082*** (0.258)	1.127*** (0.257)
Same Industry			0.155 (0.6)	0.178 (0.572)	0.189 (0.637)	0.184 (0.608)
Diff. Patent Portfolio					-0.002*** (0.001)	-0.002*** (0.001)
Diff. Patent Declaration					0.004 (0.007)	0.005 (0.007)
Cons	-0.017 (0.192)	-1.392*** (0.308)	-0.430* (0.247)	-1.798*** (0.376)	0.133 (0.278)	-0.371 (0.422)
N Clustered	675	675	675	675	675	675
N	1256	1256	1256	1256	1256	1256
Log Pseudolikelihood	-445.927	-449.125	-435.661	-437.721	-407.567	-410.171
Pseudo R2	0.3023	0.2973	0.3184	0.3152	0.3623	0.3583

Note: Dependent variable is whether or not two firm become member of the same consortium. An observation is company-company-standard. All models apply a cross section logit-analysis with clustered robust standard errors in parenthesis. Standard errors are robust clustered by firm pair. ***,**,and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively.

V. DISCUSSION AND OUTLOOK

In this article we provide novel empirical evidence on standards consortia accompanying formal standard development. While the earlier literature has discussed standards consortia as an alternative to formal standardization, more recent research has revealed many examples of complementarity between consortia and formal standard development. Nevertheless, until now, our understanding of the precise role of standards consortia in the standardization process is limited. For instance, an important limitation is the lack of empirical analysis of the incentives to join or not to join these consortia. In this article, we have for the first time produced a large database, which allows analyzing the driving factors of consortia membership. The motivation for this analysis is the expectation that the effect and the very nature of R&D coordination among technological competitors differ from R&D coordination among firms specializing in rather different, complementary technological fields.

Recent research indicates that coordination in standard setting is especially difficult to accomplish, when the ownership of IPR is fragmented and when firms have vested interests in a particular standard.[57] Standards consortia may be a means to solve coordination failures and smooth down conflicting interests. However, standards consortia may also be a venue where firms coordinate their R&D decisions to strengthen their positions against outside competitors.[58] In both cases standards consortia are formed in situations where the ownership of IPR is fragmented among several market participants and when the level of technology rivalry among firms is high. Results of our estimations confirm both theoretical implications. Our findings suggest that standards consortia are especially created when a high number of firms hold a similar number of patents. Furthermore our results indicate that in situations of higher technological overlap among standard setting firms, consortia formation is more likely.

The literature has thus identified two reasons for joining standards consortia. First, consortia may solve coordination failures and reduce wasteful duplication of R&D investments. Thus, we would expect that firms with a high technological overlap join the same standards consortia. Second, firms participate in standards

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[57] Farrell J., Simcoe, T. (2012): Choosing the Rules for Consensus Standardization. RAND Journal of Economics, forthcoming; Simcoe, T. (2012): Standard Setting Committees: Consensus Governance for Shared Technology Platforms, AMERICAN ECONOMIC REVIEW 102-1, 305-336.

[58] Leiponen, A. (2008): Competing Through Cooperation: The Organization of Standard Setting in Wireless Telecommunications. MANAGEMENT SCIENCE 54-11,1904-1919.

consortia to increase their influence on standard developing against outside solutions.[59] This may be especially beneficial when joining consortia with firms that have a rather complementary patent portfolio.[60]

Our results indicate that firms with substitutable R&D programs are more likely to be members of the same consortium. Technological specialists, i.e. companies specializing on different technological components of the standard, are less likely to participate in a consortium. As to the interpretation of our results consortia are predominantly mechanisms coordinating the R&D of direct competitors. A potential explanation for this finding is that analogously to earlier examples of research alliances[61], the major benefit of standards consortia for their members is to save the costs of wasteful R&D duplication. Indeed, through upfront R&D coordination, companies with substitutable research capacities can better anticipate technology selection decisions in SDO working groups, evaluate the strength of rivaling technological proposals and dissuade potential competitors from entering into patent races.

This finding is likely to fuel further debates regarding the welfare implications of the increasing role of standards consortia in the process of standard development. On the one hand, Baron et al.[62] point out that standards consortia in the cases of strong technological rivalry are welfare-enhancing, resulting in a reduction of wasteful R&D investments. On the other hand, consumers and other standard users benefit from technological competition among standard setting participants. If the major economic function of consortia is to reduce technological rivalry, SDO cooperation with standards consortia should be monitored carefully by competition authorities. This is especially important as several large SDOs currently develop more permissive policies to encourage a larger role of consortia in the upfront coordination of R&D for standards (see for instance the ISO Strategic Plan 2011-2015)[63]. In contrast to the great interest for patent pools, the competitive effects of standards consortia, seeking upfront R&D coordination, have received so far only limited attention from economic researchers.

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[59] Leiponen, A. (2008): Competing Through Cooperation: The Organization of Standard Setting in Wireless Telecommunications. MANAGEMENT SCIENCE 54-11,1904-1919; Pohlmann, T., Blind, K. (2012): Cooperate to put in place. Firms' cooperative activities to promote patented contributions for ICT standards, working paper.

[60] Leiponen, A., Bar, T. (2012): Committees and Networking in Standard Setting, working paper.

[61] Irwin, D., Klenow, P. (1996). High-tech R&D subsidies: Estimating the effects of Sematech, JOURNAL OF INTERNATIONAL ECONOMICS, vol. 40(3-4), pages 323-344.

[62] Baron, J., Ménière, Y., Pohlmann, T. (2013): Standards, consortia and innovation, *Working Paper*.

[63] http://www.iso.org/iso/iso_strategic_plan_2011-2015.pdf

In spite of these concerns, our findings alone do not justify advocating a restrictive stance with respect to standards consortia. Further empirical research on the driving factors and economic function of consortia on formal standard development is warranted. First, in this article we do not analyze the effects of consortia or of consortium membership. Even if consortia predominantly serve to reduce excessive technological rivalry and avoid wasteful R&D duplication, the effect on consumer and social welfare can nevertheless be beneficial. Irwin and Klenow[64] argue that R&D alliances whose main purpose is to reduce the costs of duplication must not be inefficient; however there is no economic justification for subsidizing such alliances. Given the complexity of forces that drive firm cooperation in standards consortia, the effect on standard quality and social welfare is an open research topic for empirical analysis.

[64] Irwin, D., Klenow, P. (1996). High-tech R&D subsidies: Estimating the effects of Sematech, JOURNAL OF INTERNATIONAL ECONOMICS, vol. 40(3-4), pages 323-344.

APPENDIX

Appendix 1

Table 11. Mean similarity scores for consortia co-members and non-members.

Rivalry Score: **correlation** coefficient (interval)		Number of Standards in Interval	Consortia connected to Standards
-1	0.344745	20	4
0.388332	0.652659	20	3
0.654504	0.798965	20	5
0.802343	0.885222	20	7
0.887512	0.950764	20	13
0.950764	1	10	9

Table 12. Intervals of angle coefficients and the existence of consortia.

Rivalry Score: **angle** coefficient (interval)		Number of Standards in Interval	Consortia connected to Standards
0.579933	0.840531	20	8
0.841466	0.895696	20	0
0.897691	0.926574	20	4
0.927145	0.944235	20	12
0.945642	0.976391	20	6
0.976691	1	20	12

Table 13. Pairwise correlation analysis on the formation of consortia.

Pairwise correlation analysis							
		1	**2**	**3**	**4**	**5**	**6**
1	consortia formation	1					
2	correlation coefficient	0.162*	1				
3	angle coefficient	0.096	0.562***	1			
4	number of standard essential patents	-0.117	0.149	-0.034	1		
5	number of patent holders per st.	0.372***	0.314***	0.217**	0.381***	1	
6	essential patents per firm	-0.259***	-0.042	-0.176	0.700***	-0.042	1

Note: ***,**,and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively.

Appendix 2

Table 13. Variable description comparing firm participation in a standard consortium and characteristics to mean values of other participating firms.

Variable	Description	Obs.	Mean	Std. Dev.	Min	Max
Consortium Member	Denotes one if firm is member of the consortium, 0 if not.	971	0.153	0.361	0.000	1.000
Correlation Coefficient	Correlation of a firm's patent portfolio compared to all other firms' patent portfolios contributing to the particular standard. Calculated as described in the method section.	867	0.649	0.473	-1.000	1.000
Angle Coefficient	Correlation of a firm's patent portfolio compared to all other firms' patent portfolios contributing to the particular standard. Calculated as described in the method section.	970	0.893	0.138	0.039	1.000
Relative Patent Portfolio	Relation of the number of a firm's patents to the mean number of firms' patents on the same standard.	971	1.000	1.172	0.000	9.107
Relative Patent Declaration	Relation of the number of a firm's essential patents to the mean number of firms' essential patents on the same standard.	942	0.099	0.148	0.000	0.981
Relative Employee	Relation of the number of a firm's employees to the mean number of firms' employees on the same standard.	953	1.018	1.031	0.002	5.590
Relative R&D Expenditure	Relation of the amount of a firm's R&D expenditure to the mean amount of firms' R&D expenditure on the same standard.	944	1.028	0.720	0.001	3.786
Firms on Standard	Number of firms that hold essential patents for the particular standard.	970	13.769	10.521	4.000	49.000

Appendix 3

Table 14. Variable description of firm pairs comparing joint participation in a standard consortium and firm characteristics.

Variable	Description	Obs.	Mean	Std. Dev.	Min	Max
Both Member	Denotes one if both firms are member of the same consortium, 0 if not.	5,138	0.248	0.432	0.000	1.000
Correlation Coefficient	Correlation of the firm's patent portfolio compared to the other firm's patent portfolio. Calculated as described in the method section.	4,636	0.617	0.423	-1.000	1.000
Angle Coefficient	Correlation of the firm's patent portfolio compared to the other firm's patent portfolio. Calculated as described in the method section.	5,138	0.827	0.191	0.000	1.000
Diff. Patent Portfolio	Relation of the number of a firm's patents to number of the other firm's patents on the same standard.	5,138	59.715	256.143	1.000	7,320.140
Diff. Patent Declaration	Relation of the number of a firm's essential patents to the number of the other firm's essential patents on the same standard.	5,138	10.144	15.739	1.000	190.000
Diff. Employee	Relation of the number of a firm's employees to the number of the other firm's employees on the same standard.	4,884	50.529	161.379	1.015	1,349.333
Diff. R&D Exp.	Relation of the amount of a firm's R&D expenditure to the amount of the other firm's R&D expenditure on the same standard.	4,790	36.961	202.037	1.000	3,665.503
Same Business Model	Denotes one if both firms have the same business model, 0 if not.	5,138	0.563	0.496	0.000	1.000
Same Industry	Denotes one if both firms are active in the same industry, 0 if not.	5,138	0.053	0.223	0.000	1.000