Innovating standards through informal consortia: The case of wireless telecommunications

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Abstract

We empirically examine the effects of industry consortia on the coordination of innovation strategies of the members. Our analyses utilize membership data from 32 consortia in variety of wireless telecommunication technology subfields from 2000 to 2005 and cross-citations between patents declared essential by the consortium participants in the context of the third-generation wireless telecommunication system UMTS and the members' earlier patents. Our results shed new light on the role of consortia in enabling the coordination of innovation in a network-technological industry. We find that connections among firms in informal technical consortia significantly increase the likelihood that firms cite each other's patents in subsequent UMTS essential patents. In other words, inventions that are likely to become part of the UMTS telecommunication system tend to build on inventions by peers that were members in the same consortia, controlling for patent or firm fixed effects, technology class, and other characteristics. On one hand, consortia may enhance productivity of innovation and increase the incentives to invest in R&D by internalizing potential innovation externalities. They may also enhance efficiency of standardization by facilitating the interaction of committee and market processes. On the other hand, our results suggest that consortia structure and constrain the process of innovating standardized technologies. This growing role could be problematic if the process is not be truly accessible for all the interested parties. Policymakers thus need to balance these two effects. For managers, the results show that participation in a variety of technical consortia enables influencing peers' innovation strategies related to the relevant compatibility standards.

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1. Introduction

This paper examines the effects of firms' participation in wireless telecommunications industry consortia on their subsequent innovations that become declared essential patents in the global UMTS standard for mobile communication. We explore the increasingly central role that these types of technical consortia play in coordinating technology development in many different technology fields and industries. Consortia are particularly prevalent in, but not limited to, industries with compatibility standards.

Compatibility standards are common technology norms that ensure interoperability between communication products and services[3]. Information and Communication Technology (ICT) standards, in particular, embody an increasing number of patented elements. In many ICT fields, particularly in telecommunications, standards have traditionally been defined cooperatively by governments or industry actors within formal Standard Setting Organizations[4] (SSOs). However, these formal SSOs are often perceived to be slow and bureaucratic, particularly when intellectual property rights have become part of the negotiation (Simcoe, forthcoming; Bekkers et al. 2001). For instance, the 3G wireless telecom standard studied here contains around 16 000 essential patents and its development took most of a decade.

To accelerate the process, sub-groups of firms have increasingly begun to create less formal upstream alliances or consortia. These types of collaborative organizations offer opportunities to discuss, test, or promote certain technologies, or they can be used to actually develop new technical specifications that will subsequently be submitted to formal SSOs for official approval. The effects of these consortia have been debated in policy circles (e.g., Cargill, 2001) but there is little empirical research evidence. Leiponen (2008) suggests that ICT firms' participation in such consortia enhances their ability to influence formal standard-setting outcomes. However, there is no evidence to date about the broader implications of informal consortia for coordination of innovation in network industries. The purpose of this paper is to address this research gap and conduct an empirical analysis of the effects of ICT consortia on the coordination of R&D strategies of the participants.

[3] E.g., mobile phones, DVD content and players, and internet protocols.
[4] E.g., International Standard Organization, International Telecommunication Union, European Telecommunication Standards Institute.

The question of whether consortia facilitate coordination of subsequent innovations related to communication standards is interesting from both policy and managerial perspectives. From a policy standpoint, our results may inform competition policy. The economic literature (Katz and Ordover, 1990; Jorde and Teece, 1990; and Choi, 1993) often considers collaborative industry organizations as a potential threat to competition because of excessive market coordination. However, consortia can be socially desirable if they reduce coordination problems around innovation. In this case, consortia might mitigate wasteful duplication of effort and increase incentives to invest in R&D by internalizing potential externalities (d'Aspremont and Jacquemin, 1988). These arguments could lead competition authorities to adopt a supportive policy with respect to standardization consortia,[5] because they might, overall, increase R&D efforts and productivity.

Our analyses of industry consortia in wireless telecommunications shed new light on the process through which communication standards are being created. Development of "open standards" through a process that is not truly accessible for all the interested parties may be viewed as problematic. To the degree that essential innovations that become incorporated in the formal standard are coordinated and agreed in informal and semi-private consortia, policymakers may find it worthwhile to better understand and provide rules of the game regarding meeting procedures, membership fees particularly for small firms, terms of access, and public release of relevant information. Indeed, if consortia are used to coordinate innovation in advance of formal standard setting, there is a trade-off between speed in the process work and representation of the different stakeholders. Monopolization of technologies underpinning a widely used standard is likely to lead to excessive royalties and potential holdup that can slow down technology adoption and reduce social welfare. This would be equivalent to monopolization of an upstream market in a long and complex value chain.

From a strategic viewpoint, participation in standardization consortia may offer a venue for firms to promote their technologies and become a central and powerful player in a technological field (Ballester et al. 2006). For instance, from a sociological perspective, Pfeffer (1981) suggests that consortium participation helps firms to access and control strategic knowledge. Nevertheless, there is little empirical evidence for this assertion. Our

[5] For instance, a balanced approach such as the one adopted on patent pools, cooperative agreements that also presents advantages in terms of innovation diffusion and drawbacks in terms of competition. On patent pools, competition authorities recognize their positive effects provided they meet certain strict rules of operation (for instance on the nature of patents included).

research aims to highlight strategies that firms may deploy to influence innovation by others – particularly that related to compatibility standards.

This paper utilizes a network-analytical approach and combines membership data from 32 ICT consortia to identify consortium network ties between firms involved in formal standardization through Third Generation Partnership Project, or 3GPP. 3GPP is the international standard-setting organization driving the specification development for the Universal Mobile Telecommunication System, UMTS, which is one of the third-generation mobile communication systems. Additionally, we compile and analyze citations of 16 000 essential patents filed by member firms in the 3GPP standardization process for UMTS. These data will be used to econometrically assess the effects of firms' participation in consortia on cross-citations of subsequent inventions. To properly empirically identify the causal relationship, we use a merger in the network of consortia as a natural experiment that exogenously changed consortium connections of dozens of member firms.

Our empirical analysis demonstrates that the patent holder's involvement in consortia has an impact on the likelihood that their patents are cited by other consortium members in subsequent patents that are declared essential for the UMTS standard. This result is particularly strong for consortia that are formally allied with and thus directly related to 3GPP. The result is weaker but still positive and statistically significant for consortia that are not allied with 3GPP. However, this relationship is significant only for informal consortia and does not hold for more formal organizations such as other formal standard-setting organizations (e.g., regional SSOs). It also does not hold for other patents than those subsequently declared as essential for the UMTS standard. The significant relationship we find thus appears to involve informal technical consortia and patents closely related to a standard. Finally, a change in the network caused by a merger of several consortia had a significant impact on the strength of this coordination effect. Our main results are supported by a difference-in-differences analysis utilizing this source of exogenous variation.

Our results highlight technical industry consortia as an organization form that enables sharing of knowledge and coordination of R&D efforts related to compatibility standards. The remainder of this paper is organized as follows. Section 2 presents a literature review of R&D consortia and discusses the conceptual foundations of our research. Section 3 explains the data collection process and the empirical methodology. Section 4 presents our main empirical results and section 5 concludes.

2. Literature on technical consortia and the intended empirical contribution

Research and development consortia have been studied extensively in various strands of literature. The advantages and drawbacks of these organizations as well as their formation process and possible impact on future alliances are now relatively well understood. Here, we will review the benefits and costs of participation as discussed in earlier studies, and finish by discussing the distinct features and implications of consortia focused on standardization rather than just R&D.

Scholars have found substantial positive effects of consortium participation on innovation by firms. For instance, an early stream of research analyzes R&D consortia from a theoretical standpoint and underlines financial incentives to participate therein. Katz (1986), Katz and Ordover (1990), and d'Aspremont and Jacquemin (1988) view consortia primarily as a means to share and reduce R&D expenses. Consortia may facilitate realization of scale economies among participants and avoidance of effort duplication. This stream of literature assumes symmetric contributions of consortium members in terms of R&D investments and competencies, and firms are assumed to sell substitutable products.

Complementary to this idea, another strand of literature discusses incentives to participate when firms have asymmetric contributions (e.g., Kamien, Muller and Zang, 1992). Here, the main idea is that R&D investments create knowledge spillovers. Spillovers are positive externalities that enhance the social benefits of R&D investments but they lead to socially suboptimal investments because private incentives do not take spillovers into account. Consortia may be a way to internalize these spillover effects. This potentially positive effect of consortia has led some scholars to support public funding of these organizations (Romer and Griliches, 1993).

The notion of consortia as a way to internalize R&D externalities is in line with the resource-based view of the firm in strategic management. For instance Chung, Singh and Lee (1999) analyze investment banking firms' syndication in underwriting corporate stock offerings during the 1980s and point out that that the likelihood of investment banks' alliance formation is positively related to the complementarity of their capabilities. Firms' participation in consortia or other forms of cooperation is then viewed as a method to share skills and benefit from other members' competencies. This argument implies that the diversity of members enhances consortium efficiency, because it increases the potential for spillovers and ultimately has a positive effect on the level of R&D expenditures in the field.

Two empirical papers confirm that R&D consortia lead to increased R&D investments and productivity. First, Branstetter and Sakakibara (1998) analyze a sample of Japanese consortia and find that the marginal effect of consortium participation is about two percent increase in total R&D spending and between four and eight percent increase in patenting per R&D dollar (research productivity). In a subsequent paper, Sakakibara (2001) confirms an even more substantial effect of consortium participation on R&D expenses (around 9%) and also tests the hypothesis that diverse competencies of members enhance the efficiency of the consortium. Her paper examines a sample of publicly sponsored Japanese consortia involving 213 firms over 13 years and confirms that consortium diversity is associated with greater R&D expenditures by participants.

An organization-theoretic literature suggests that participation in R&D consortia facilitates obtaining a strategic advantage over competitors. In this view, consortia are not necessarily formed to share costs or reduce potential market failure but to create competitive advantages over other competitors. Pfeffer (1981) proposes that consortium participation helps firms to access and control strategic knowledge. Aldrich et al. (1998) also argue that R&D consortia could help to orient research in the industry in a way that supports the firm's strategy. This hypothesis is supported empirically by Leiponen (2008) who examines consortia around the Third Generation Partnership Project (3GPP), a formal standards-development organization. This study finds that participation in technical consortia significantly enhances firms' contributions to new standard specifications in 3GPP committees. Firms that are central in the consortium network are better able to ultimately influence the standard-setting outcome. From a social point of view, this result suggests that industry consortia may also have adverse effects and are potentially a way to foreclose competition. This potential negative effect of consortia on competition (implicit collusion) has also been discussed in a series of earlier papers (e.g. Brodley (1990), Katz and Ordover (1990), Jorde and Teece (1990) and Choi (1993).

Finally, a set of studies identifies consortia as a channel for signaling strategies within the industry. In a longitudinal study of 87 cellular service providers and equipment manufacturers, Rosenkopf, Metiu and Georges (2001) show that participation in technical committees helps to identify potential alliance partners and opportunities for collaboration. The authors also find that the marginal effect of consortium participation on alliance formation is decreasing with the number of alliances already formed and varies according to interpersonal bonds. This importance of interpersonal bonds is also underlined by Dokko and Rosenkopf (2010), who examine how job mobility of individuals affects firms' abilities to influence others in a technical standard-setting committee for U.S. wireless telecommunications. The authors suggest that recruitment of employees with abundant social capital from consortium committees increases a firm's power to influence standard setting through such committees.

As described above, cooperative research arrangements can be very beneficial, but consortium participation may also be associated with risks and costs. First, firms have to support expenses such as membership fees, and travel, meeting, and human resource costs. Sakakibara's (2001) empirical analysis of Japanese consortia and Hawkins' study of ICT consortia (1999) present empirical evidence that consortium participation engenders substantial costs. Hawkins' estimate of membership fees for a typical technology firm in mid-1990s was in the order of 1.5 million US dollars. This number does not include the travel and human resource costs of participation. Moreover, in the years since this study, membership fees and the number of consortia have considerably increased.

Consortia can also present risks of technology leakage. Sharing R&D knowledge in technical meetings with other participants that have sufficient skills to understand and absorb these competencies strongly increases the risks of imitation. Indeed, Kodama (1986) suggests that firms participating in consortia may create internal research groups just to absorb knowledge from consortium work.

Consortium participation may also reduce the set of potential appropriation strategies available to firms. For consortium members, secrecy is no longer an effective protection method and therefore member firms may need to follow alternative appropriation strategies and define which competencies can be shared and which ones protected according to the firm's overall strategy. This idea is supported by empirical studies that analyze the means of protecting innovation in a cooperation context. For instance, Leiponen and Byma (2009) stress that small firms cooperating in innovation with horizontal partners (direct competitors) tend to prefer speed to market over secrecy or patents to protect their innovations. However, in the wireless telecommunication context studied in this paper, patenting may be a prerequisite for innovative firms, independent of their size.

To summarize, extant literature on R&D consortia has identified many potential strategic benefits and drawbacks of participation, and their implications for competition policies. However, most of the work on consortia has examined general-purpose R&D consortia, whereas here the focus is on standardization-related consortia. These types of collaborative structures are increasingly common. We found dozens within wireless communications alone; computing is another field where pre-standardization is often organized through informal consortia. The well-known battle for high-definition DVD format dominance also featured competing consortia.

As discussed by Farrell and Saloner (1988: 237), standardization committees do many things. They share information, design product features, negotiate technical solutions, and carry out performance and compliance tests of the proposed standards. Informal technical consortia do many of the same things, to varying degrees. Some consortia may only share information and promote a specific set of technologies, whereas others may be additionally actively engaged in joint R&D – feature design and technical specification development – the results of which may subsequently be submitted for approval in formal standardization organizations such as 3GPP.

Rules, decision-making processes and antitrust implications of (more) formal standard-setting organizations have been discussed in academic literature (e.g., Lemley, 2002; Anton and Yao, 1995; Chiao, Lerner, and Tirole, 2006) and also scrutinized in antitrust enforcement (e.g., see legal references in Lemley, 2002). In contrast, informal industry consortia have rarely been examined in detail either by either by academics or policymakers. In fact, it is often difficult to get information about their inner functioning. Because informal consortia are private organizations, little is known about the nature and topics of discussion, decision-making procedures, or forms of information exchange.. Some technical consortia may primarily attempt to leverage and coordinate efforts in promoting a specific set of novel technologies with respect to the rest of the industry and the world (collective marketing), and other consortia might be involved in more strategic R&D and alignment.

Strategic knowledge sharing, co-development, and alignment may have long-term implications for an industry. In contrast to general-purpose R&D consortia that also develop technologies for the participant firms to offer in their new products or processes, pre-standardization consortia may develop technologies and make decisions that not only the participants but also the rest of the industry will have to abide by if they build products for the same compatibility standard. Early-stage standardization consortia may thus provide a somewhat opaque route to domination of a standard for a small subset of firms in the industry.

The focus of our empirical work is on the hypothesis that pre-standardization consortia facilitate coordination of subsequent R&D that results in essential innovations related to a compatibility standard. If this is true, then these types of consortia provide a structure for identifying which early-stage investments enable controlling the standard later on. In the language of Farrell and Saloner (1988), consortia may be viewed as a "hybrid" coordination structure that combines market-based and committee-based processes of standardization. We argue that consortia indeed facilitate firms' attempts to both ignite a market bandwagon and, at the same time, to negotiate with rivals to coordinate specifications. Technical meeting discussions enable negotiation and coordination, whereas competition among consortia and broader adoption of their proposals may generate a bandwagon effect. Farrell and Saloner's theoretical work then suggests that consortia can be welfare improving because they are likely to speed up coordination. However, their analysis does not account for the potential lack of access to the early-stage processes or monopolization of the IP market (but see Simcoe and Farrell, 2011).

Policy makers such as those in the European Commission have expressed concerns that private consortia tend to be closed and undemocratic (Egyedi, 2001). Industry practitioners have also suggested that informal consortia tend to be founded by a core group of members who fix the agenda and rules of the game before others are allowed to join, often preserving membership tiers that separate founders from general members. Alternatively, many consortia such as tne Open Mobile Alliance included in the sample here specify multiple levels of membership differentiated by a steep fee structure, whereby it can be prohibitively expensive for smaller firms to participate in the "sponsor" levels, whereas members on lower levels are likely to be excluded from committee chairpersonships, formal votes, or the right to submit technical appeals.

As discussed by Anton and Yao (1995), agenda control alone can be a significant source of power. Then, although open membership is required for consortia that, for example, propose formal specifications for standard-setting organizations such as 3GPP, their basic technological approaches have already been selected to support the competitive advantages of the founders. Dispute resolution mechanisms analyzed by Chiao, Lerner and Tirole (2006) are usually missing from informal consortia (such as WAP Forum that is included in their analyses and in the sample here), and, hence, it can be difficult to change the technical specifications already under way.

Aldrich et al. (1998) and Hawkins (1999) have previously discussed closely related ideas. Hawkins notes that, in telecommunications, “an international system has evolved in which communication and co-ordination is achieved primarily through inter-organisational alliances[…]”. However, systematic empirical evidence regarding firms’ strategies and their implications remains scarce. Our paper targets this research gap by examining the role played by consortia as a vehicle for knowledge transfer and coordination of innovation in the context of standardization. Specifically, we are interested in the degree to which communication in early-stage technical consortia drives innovation that becomes incorporated in formal standard specifications in a later stage.

3. Data and Methods

Our main empirical test is whether consortium participation by a firm increases the likelihood that its patent is cited by other members of the same consortia in their patents that are declared as essential for the wireless telecommunication system UMTS. We thus analyze whether the likelihood that a patent is cited depends on the position and centrality of the patent holder in the network of consortia during the year in which the citing patent was applied. We focus on citations by UMTS essential patents because we are interested in the ability of consortium participants to influence the set of technologies that become incorporated in the standard, but we will also test the effects on a broader set of patents by the same firms.

This paper relies on a combination of data on consortium co-membership links between firms involved in the third-generation mobile standards and cross-citations of patents filed by these participants. First of all, we gathered data on 16 000 patents declared essential for the UMTS standard[6]. We retrieved these data in October 2010 using the ETSI online patent database[7]. We then merged these data with information on citations using the 1976/2006 National Bureau of Economic Research database[8] and used the EPIP database to identify the patent holders of the cited patents[9]. Appendices 1 and 2 present some information about the timing of application and technological class of patents in our sample. As we can see, the citing patents are very concentrated in terms of technological class, whereas the cited patents are quite diverse. The cited patents were granted between 1976 and 2004 but the majority of them were granted in the late 1990s or early 2000s.

Next, we created a database on consortium membership links between firms involved in third-generation mobile standards. This database is partly based on Leiponen (2008). Using the website Internet Archive, we obtained data on the memberships of the patent holders (owners of the citing and the cited patents) in consortia in the ICT field from 2000 to 2005. Some of these consortia are formally allied with 3GPP and others are unrelated or even directly competing with 3GPP. A list of these consortia is presented in Appendix 3.

As we have information on participation in consortia from 2000 to 2005, we will restrict our analysis of citing patents applied in this period. We organize our database around the cited patents over six years. This database consists of 1046 patents that were cited at least once by a UMTS essential patent between 1998 and 2005. These patents were held by 43 different firms[10]. The database connects the cited patents with 1962 citing patents, held by 17 firms.

Our main dependent variable is a binary indicator for whether a patent was cited by a patent application that was subsequently declared as "essential" for the UMTS wireless telecommunication system developed in 3GPP. We focus on citing patents held by members of 3GPP. We use two different explanatory variables to capture firms' participation in pre-standardization consortia. These two variables measure the patent holder's general level of

[6] The projects included are : 3GPP, 3GPP release 7, 3GPP/AMR-WB+, UMTS, UMTS Release 5, UMTS Release 6, UMTS Release 7, UMTS Release 8, UMTS/CDMA
[7] Available at: http://ipr.etsi.org/
[8] Available at: http://www.nber.org/patents/
[9] Available at: http://www.epip.eu/datacentre.php
[10] A list of the patent holders of the cited patents is presented in appendix 4.

participation in consortia of the ICT field: the number of consortium memberships, (*total memberships*) and the number of unique connections to peers from consortia (*consortium connections*). A consortium connection is formed if two firms meet at least in one of the consortia during the year. In network-analytical terms these are two-mode and one-mode degree centrality measures, respectively. We include a control variable to proxy for firms' standardization strategies with data on patent holders' participation in the relevant formal standards-development organization (3GPP). We trace patent holders' activities in formal standards-development committees[11] and create a variable *3GPP connections* that equals the number of unique connections (one-mode degree centrality) to other firms through work-item committees. This variable allows us to take into account the centrality of the firm in formal standard setting and thus to distinguish the effects of informal and formal standardization strategies on cross-citations. We also include patent age dummies to control for the evolution of citation patterns over time.

Table 1 describes the main estimation variables.

Table 1: Name and description of the main explanatory variables

Variable	Description	Mean	Std. dev.	Min	Max
Total membership$_{it}$	Number of cited firm's annual memberships (two-mode network degree) in consortia	8.11	6.65	0	24
Consortium connections$_{it}$	Number of cited firm's annual unique connections (one-mode network degree) through consortia	124.16	99.23	0	280
3GPP connections$_{it}$	Number of unique (one-mode degree) connections to other firms through 3GPP work-item (formal standardization) committees	16.02	17.73	0	63
Patent applications	Number of patent applications	651.65	614.91	0	5312
Patent age dummies	Set of dummies for the age of the cited patent				

We thus work with a panel database of patents cited by (at least one) UMTS essential patents and estimate a fixed-effect conditional logit model with the likelihood to be cited at year t for a patent p as the dependent variable. Table 2 presents the numbers of years in which our patents are cited from 1998 to 2005. We have a small number of patents that were cited every year during the period of study (2000-2005).

[11] Using the website http://www.3gpp.org/

Table 2: Number of years the patent is cited (1998-2005)

Number of years the patent is cited	Observations
1	547
2	268
3	86
4	43
5	64
6	12
7	23
8	3

Our main explanatory variables measure consortium participation, and we control for the patent holder's centrality in 3GPP and the patent's age. Other (permanent) patent characteristics are accounted for in the patent fixed effects. We thus estimate the following model:

$$\Pr(Citation_{pit}) = \alpha_0 + \alpha_1 Consortium\_participation_{it} + \alpha_2 3GPP\_connections_{it} + \alpha_3 Patent\_age_{pt} + \varepsilon_{pt}$$

[1]

$\Pr(Citation_{pit})$ = Probability of patent p held by firm i being cited by another 3GPP participant's patent application in year t

Consortium participation$_{it}$ = Participation in consortia of firm *i*, using the variables *total membership and consortium connections* in year *t*

3GPP connections$_{it}$ = Firm *i*'s one-mode centrality in formal standardization in 3GPP committees in year t

Patent age$_{pt}$ = Set of dummies for the cited patent age

ε_{pt} = Error term

The main empirical issue is to disentangle the effects of participation in consortia and technological strategies of firms. A patent can be highly cited because of the patent holders' participation in consortia or because the patent is technologically central in the UMTS wireless system being standardized within 3GPP, for which reason its holder may participate in many consortia. In order to control for these confounding factors, we deploy a number of empirical tactics: we include a control variable for firms' formal standardization strategies; we utilize panel-data methods to remove time-invariant unobserved heterogeneity; and we utilize an exogenous natural experiment to reduce potential time-variant unobserved heterogeneity. However, the last approach only works for our main result regarding whether industry consortia influence subsequent standards-related innovation, but for identification of the additional results on the types of consortia, we need to rely on the two former approaches.

Our initial estimation approach utilizes standard panel-data methods (fixed effects estimation). We then explore whether a natural experiment occurring in the data allows us to isolate sufficient exogenous variation in the main explanatory variables to control for possible time-varying unobserved effects and estimate a differences-in-differences type model. Our concern is that innovations emerging during the period of study might make firms more likely to both attend certain consortia and cite their central members. This event is the merger of a set of industry consortia of mobile services that, we argue, exogenously shifted the consortium contacts of some but not all firms in our dataset. In late 2002, seven of the consortia in our database[12] merged to create the Open Mobile Alliance (OMA). OMA was formed by nearly 200 companies including mobile operators, device and network suppliers, information technology companies and content and service providers. Therefore we argue that individual firms were unlikely to have substantial influence in the merger. The stated reasons for the merger were increasing interactions and synergies between the technology fields of the seven component consortia: "The purpose of OMA is to address areas that previously fell outside the scope of any existing organizations, as well as streamline work that may have been previously duplicated by multiple organizations."[13] As a result of the merger, consortium connections of some firms increased and those of other firms decreased. We use this merger to estimate a diff-in-diff model and examine the robustness of our fixed-effects results.

[12] Wap Forum, Wireless Village, SyncML Initiative, MGIF, LIF, MWIF, and UMTS Forum.
[13] http://www.openmobilealliance.org/AboutOMA/FAQ.aspx, retrieved 8/2/2002.

4. Estimation results

We first run a fixed-effect model estimating the likelihood of a patent to be cited by a patent that was declared as essential for the UMTS standard, held by another consortium participant. We control for the age of the cited patent. The results of this model are presented in Table 3.

Table 3: The effect of consortium participation on the likelihood of citation

	(1)		(2)	
	Coef. (SE)	Odds Ratios	Coef. (SE)	Odds ratios
Total memberships	0.0341*	1.0347*		
	(0.019)	(0.019)		
Consortium connections			0.0028**	1.0028**
			(0.001)	(0.001)
3GPP connections	0.0128 ***	1.0129***	0.0168***	1.0169***
	(0.003)	(0.003)	(0.003)	(0.003)
Patent age dummies	Y		Y	
Observations	6184		6184	
Groups	1043		1043	
Chi^2	685.09		689.66	
Prob > chi^2	0		0	
Log Likelihood	-1575.19		-1572.85	
Cited firms	43		43	

Notes: Dependent variable is an indicator for whether a patent was cited by an essential patent applied in year t. Estimation method is conditional logit with fixed effects at the patent level. Unit of analysis is the cited patent. Standard errors, clustered on patents, in parentheses under the coefficients. * p<.10; ** p<.05; *** p<.01

According to the basic fixed-effects results at the level of the cited patent as shown in table 3, the two main explanatory variables, the cited patent holder's *total number of memberships* in wireless industry consortia and their *unique connections* to peers in those consortia both have at least weakly statistically significant and positive effects on the likelihood of a patent to be cited by another consortium participant. Odds ratios suggest that one additional membership increases the odds of citation by 3.5%, whereas one additional connection increases the odds of citation by 0.3% . These effects are aligned in the sense that one additional membership may generate dozens of new connections. The coefficient of *3GPP connections* that controls for firms' formal standardization activities is significant and positive, suggesting that similar information is exchanged in formal standards committees (cf. Bekkers et al. 2011).

Next, we use a natural experiment, a merger of seven consortia in 2002 to examine the robustness of our main result. When Mobile Games Interoperability Forum (MGIF), UMTS

Forum, WAP Forum, Wireless Village, SyncML Initiative, Location Interoperability Forum (LIF) and Mobile Wireless Internet Forum (MWIF) merged to form Open Mobile Alliance, the *consortium connections* of the members of the seven consortia were exogenously shifted. Firms included in the control group who were members of none of the consortia affected by the merger are listed in appendix 5. Using this exogenous event to identify the causal effect of firms' consortium connections on patent citations, we dissect the participation effect found in table 3 with respect to timing and OMA vs. other consortia. The results are presented in table 4.

Table 4: Impact of the OMA merger on subsequent citations

	(1)		(2)	
	Coef. (SE)	Odds Ratios	Coef. (SE)	Odds Ratios
OMA connections	0.0028**	1.0028**	0.0036***	1.0036***
	(0.001)	(0.001)	(0.001)	(0.001)
Other consortia connections	0.0003	1.0003	0.0001	1.0001
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
OMA connections after	0.0045**	1.0045**	0.0042*	1.0042*
	(0.002)	(0.002)	(0.002)	(0.002)
Dummy after	-2.0055***	0.1346***	-2.0851***	0.1243***
	(0.262)	(0.035)	(0.266)	(0.033)
3GPP connections			-0.0097**	0.9904***
			(0.004)	(0.004)
Dummy Cited Age	Y		Y	
Observations	6184		6184	
Groups	1043		1043	
Chi 2	742.75		785.07	
Prob > chi2	0		0	
Log Likelihood	-1500.01		-1479.32	
Cited firms	43		43	

Notes: Dependent variable is an indicator for whether a patent was cited by an essential patent applied in year t. Estimation method is conditional logit with fixed effects at the patent level. Standard errors, clustered on patents, are in parentheses under the coefficients. * p<.10; ** p<.05; *** p<.01

The variable *OMA connections* (number of unique connections through OMA or its constituent consortia) has a positive and statistically significant effect on citations. OMA and the component consortia were thus probably central venues for discussing ongoing innovation. In fact, the effect of connections from other consortia (*other connections*) is statistically insignificant here. The most relevant coefficient in table 4 is that on the variable *OMA connections after* that measures the additional effect of OMA-related connections after the merger. This effect is statistically borderline significant at the 5% level in the two specifications.

In table 5 we return to the fixed-effect approach to further distinguish the effects of different types of consortia, which we cannot examine with the diff-in-diff method. We distinguish between formal and informal consortia and between consortia that are related and unrelated to 3GPP. Formal consortia draft and certify standard specifications whereas informal ones typically discuss and test technological alternatives. We expect informal consortia to be more conducive to influencing peers, because their fundamental purpose is usually to discuss and promote a set of technologies, hence these types of less structured discussions can be more easily used to promote the members' technologies that might be utilized or built on in the standard-setting context of 3GPP. Consortia can also be formally allied (related) with 3GPP or unrelated with 3GPP. We expect consortia that are allied with 3GPP to provide more fruitful venues for influencing peers' innovation activities related to technologies that 3GPP standardizes, because the technologies concerned are more likely to be related, too.

We also examine the interaction effect of the technological resources of the patent holder using an interaction variable, *consortium connections*patent apps,* that is, *consortium connections* multiplied the number of patents applied by the cited firm during the year. This variable allows us to assess the potential moderating impact of the (technological) size of the patent holder on the consortium participation effect. We expect that larger technology firms are more effective at translating consortium connections into opportunities to influence others' innovation activities. The sheer volume of technological resources such as patents and experts is expected to enhance the power to influence peers.

Regarding the types of consortia, the results confirm expectations. When OMA consortia are included in the informal group of consortia, memberships in these organizations are driving the effect. The coefficient of memberships in formal standardization organizations is insignificant. The strategic and technological scope of the consortium also has an impact on the intensity of the effect. The consortium participation effect is much stronger for consortia that are related to 3GPP than for unrelated consortia. The effect is still positive and statistically significant at 10% level for unrelated consortia, but the impact on the odds of citation is much smaller. One additional membership in a related consortium increases the citation odds by 17% whereas one additional membership in an unrelated consortium increases them by 3% only.

Table 5: Effects of different types of consortia and the moderating effect of technological resources

	(1)		(2)		(3)	
	Coef. (SE)	Odds ratios	Coef. (SE)	Odds ratios	Coef. (SE)	Odds ratios
Informal consortium memberships	0.0325* (0.020)	1.0330* (0.007)				
Formal consortium memberships	-0.0880 (0.058)	0.9157 (0.053)				
Related consortium memberships			0.1583*** (0.054)	1.1715*** (0.064)		
Unrelated consortium memberships			0.0309* (0.017)	1.0314* (0.018)		
Consortium Connections					-0.00008 (0.001)	0.9999 (0.001)
Cons. connections* patent apps					2.829e-06** (1.14e-06)	1.0000** (1.14e-06)
Patent apps					-0.0005* (0.0002)	0.9995* (0.0002)
3GPP connections	0.0104*** (0.003)	1.010***4 (0.003)	0.0126*** (0.003)	1.0127*** (0.003)	0.0133*** (0.004)	1.0134*** (0.004)
Patent age dummies	Y		Y		Y	
Observations	6184		6184		5864	
Groups	1043		1043		1041	
LR chi^2	672.50		740.01		631.59	
Prob > chi^2	0		0		0	
Log Likelihood	-1571.35		-1571.18		-1535.47	
Cited firms	43		43		43	

Notes: Dependent variable is an indicator for whether a patent was cited by an essential patent applied in year t. Estimation method is conditional logit with fixed effects at the patent level. Unit of analysis is cited patent. Standard errors, clustered on patents, are in parentheses under the coefficients. * p<.10; ** p<.05; *** p<.01

We also find that firms' technological resources (measured by patent applications) significantly moderate the consortium participation effect on the likelihood to be cited in subsequent patents by peers. Thus, our hypothesis that larger technology firms are more effective at translating consortium connections into opportunities to influence others' innovation activities is supported. The odds ratios seem economically insignificant because the mean number of patent applications is in the hundreds and many of the sampled firms have thousands of annual applications. Thus, a single additional patent application has only a negligible effect on the odds of citation.

In robustness analyses, we tested whether the consortium coordination effect also matters for 3GPP members' patents that are not declared as essential for the UMTS standard. We found no significant effect on non-essential patents, even though we focused on patents in the same wireless technology classes. Thus, our results suggest pre-standardization consortia are an effective way to coordinate R&D around the relevant compatibility standard but not more generally to influence innovation in the same technological classes.

As fixed-effects estimation considerably reduces the number of observations, we also estimated with a random-effects specification taking into account the overall sample and using mean variables to control for permanent characteristics (Wooldridge, 2002, pp. 487-488, 679). This Chamberlain-style procedure includes the means of the time-varying explanatory variables as additional regressors in the random-effects procedure, assuming that the permanent characteristics are normally distributed conditional on the explanatory variables. According to Wooldridge (2002), this method is less robust but more efficient than the conditional fixed-effects approach. The results are presented in appendix 6 and confirm the findings of the fixed-effects estimation. We also checked the robustness of our results using a linear probability model. These results are presented in appendix 8 and confirm the findings presented in the body of the paper, with one exception: according to the linear probability model, formal consortia are more important for subsequent innovation than are informal consortia. The sources of this discrepancy will need to be further analyzed. Finally, we checked whether our results are driven by patents that are cited only once over the study period by other 3G participants. Excluding these patents in a robustness tests did not change our results.

To summarize our analyses at the patent level, our main hypothesis that participation in technical consortia facilitates coordination of firms' innovation policies is supported. This result is robust to the choice of method and variable used to capture the participation effect. However, the magnitude of the effect depends on the nature of the consortium. In the logit estimations, the coordination effect is insignificant for formal consortia and positive and statistically significant for informal consortia, but this result is not completely robust to estimation method, as in the linear probability models the effect is stronger for formal consortia and weaker for informal ones. Additionally, the coordination effect is greater when consortia are technologically and strategically related to 3GPP, although it remains significant also when consortia are unrelated to 3GPP. This result is fully robust to the method of estimation. Finally, we exploited a merger in the set of consortia to check the statistical identification of the main coordination effect. Exogenous changes in consortium connections caused by the merger positively and statistically significantly influenced subsequent citations by peers.

We next conduct an analysis at the firm-pair level of the impact of co-memberships in informal industry consortia on the likelihood of cross-citation. This approach follows the cooperation analysis of universities by Agrawal and Goldfarb (2008). The dataset is now set up as a panel of possible firm pairs from the list of 47 firms that ever cite other 3GPP members' patents or whose patents ever get cited by other members. The full panel has six years and 47*47-47 observations each year (we account for the direction of citation and exclude self citations). We thus have almost 13000 firm pair years in total, but in estimations we narrow this sample down to more relevant observations. We also restrict the analysis to the years between 2000 and 2003 to focus on the OMA merger "treatment" impact.

In all specifications, we exclude pairs where the potentially cited firm has never actually been cited during the period of study, because these may include firms that did not have relevant intellectual property prior to the study period. We then have 7912 firm-pair observations over the four-year period. Table 6 provides means and cross-tabulations for these data. Citation from firm j to firm i is a rare occurrence; only 4.6% of the firm-pair-year observations are associated with a citation. Consortium activities, in contrast, are quite common. 50.5% of firm pairs include firms that are co-members of either OMA (after 2001) or a consortium that merged with OMA in 2002 (for 2000-2001). 60.9% of firm pairs have firms that are both members in the same informal consortia, other than OMA or its constituent consortia. The cross-tabulations show a strong correlation between citation and OMA-related co-membership, and between OMA and other consortia co-memberships. The correlation between co-membership in other consortia and cross-citation is also positive but less pronounced.

Table 6 Sample statistics for the firm-level co-membership analysis (2000-2003; N=7912)

		OMA co-membership		Other consortia co-membership		Citation	
Variable	Mean	0	1	0	1	0	1
Citation	0.046	0.033	0.058	0.037	0.051	NA	NA
OMA co-membership	0.505	NA	NA	0.214	0.691	0.498	0.642
Consortia co-membership	0.609	0.380	0.834	NA	NA	0.605	0.680

In table 7 we present differences-in-differences results from the analysis of the impact of consortium co-memberships on the likelihood of citation from patent of firm j to a patent of firm i. The empirical base is not ideal because of the few positive observations of the dependent variable (4.6%) and for this reason the estimation model is kept as simple as possible. We find that the key explanatory variable capturing OMA co-membership after 2001 is positive and statistically significant in most specifications. Thus, two firms that became OMA co-members because of the merger were significantly more likely to cite each other's patents. According to odds ratios for specification 1 (not reported), compared to a situation where firms are not both members of OMA consortia, a co-membership in OMA or its predecessor consortia increases the odds that a firm pair experiences a cross-citation by 33%, whereas a co-membership in OMA after 2001 increases these odds by 90%. These numbers appear to be very high, but considering that the raw probability of citation is very low, then even with the increased odds the risk of citation remains fairly low. These results are more or less robust to the exclusion of pairs where the potential citing firm has never actually cited another 3GPP member firm's patents in its essential patents (accounting for the concern that some firms may not be "at risk" of sending a citation to 3GPP peers) and to the addition of fixed effects for cited firms. These results are reported in specifications 2 and 3.

In all specifications we control for co-memberships in other informal consortia, because they will reflect the general tendency of firms in this field to join industry consortia. In earlier estimations, and also in correlation analyses within the current sample, the relationship between other informal consortium connections and cross-citations is rather strong, but in the estimation models here, the coefficient of co-memberships in other consortia is usually insignificant. This is in part influenced by the multicollinearity between OMA and other consortia co-memberships: firms that join OMA-related consortia are also likely to join other informal consortia. The collinearity between OMA and other co-memberships is less severe in earlier years of the study period, because of the lesser concentration of citing firms (see below). Hence, if we exclude the year 2003 from the analyses, this variable becomes statistically significant. Nevertheless, even when this variable is excluded, the coefficients of OMA variables retain their levels of significance, and hence the main results are not affected by the correlation.

The last specification 4 includes dummies (fixed effects) for the citing firms. Whereas there are 44 firms whose patents were cited during our period of study, there are only 17 firms from which citations originate, so this end of the cross-citation network is quite concentrated. Bekkers, Bongard and Nuvolari (2011) make similar observations about these data. In table 7, we are able to identify 13 citing firm dummies for the period 2000-2003. In this specification, the *OMA co-membership* and the other *consortia co-membership* variables have positive and statistically significant effects, but the coefficient of OMA co-membership after the merger becomes insignificant. This seems to be driven by the concentration of citing firms, particularly after 2001. In our essential patent database, we have 367 essential patents applied in 2002 with citations to earlier patents by 3GPP members. Of these 367 citations, full 87% are made by one of two firms, InterDigital and Qualcomm. In 2003 the share of citations by these two firms is even higher, 96%.[14] Thus, their firm dummies capture all the statistically relevant information about the likelihood of citation among firm pairs after 2001. Nevertheless, the other co-membership variables still suggest that there is a strong relationship between consortia and citations.

Although the statistical analysis of the effects of firm-pair co-memberships is hampered by the data concentration, these data are interesting from the perspective of firms' strategies. Qualcomm and InterDigital are not the most active citing firms by chance; they are the firms in the sample that have followed a business model most focused on commercialization of intellectual property (although Qualcomm also produces chipsets that are components for mobile phones). Whereas the likes of Nokia, Matsushita, and Ericsson are very active in IP enforcement and trading, they are primarily manufacturers of network or terminal equipment. At the time of study, Qualcomm was primarily an IP provider, and InterDigital was purely so. Hence, we have indirect evidence of the implications of different business models through strategic behavior in terms of essential patent declarations. One interpretation for these data and estimation results is that InterDigital and Qualcomm actively utilize discussions in industry consortia to assess how the UMTS compatibility standard will evolve in the near term, and then attempt to place their own stakes in the IP space by patenting inventions and declaring them (potentially) essential for the standard.

[14] Before 2002, the shares of InterDigital and Qualcomm were somewhat smaller; for example, in 2000, there were 12 citing firms and the shares of InterDigital and Qualcomm were 30% and 31%, respectively.

Table 7 Probability of citation between firms i and j: differences-in-differences approach

	(1)			(2)			(3)			(4)		
Citation	Coef.		Std.	Coef.		Std.	Coef.		Std.	Coef.		Std.
Constant	-2.805		0.164	-1.277	***	0.166	-3.853	***	0.713	-3.036	***	0.471
OMA co-membership	0.290	**	0.139	0.259		0.169	0.196		0.167	0.437	**	0.220
OMA co-membership after 2001	0.642	**	0.265	0.532	*	0.280	0.644	**	0.270	-0.137		0.322
Consortia co-membership	0.208		0.153	0.222		0.184	-0.250		0.170	1.208	***	0.248
Year dummies												
2001	-0.342	***	0.091	-0.424	***	0.107	-0.317	***	0.094	-0.685	***	0.152
2002	-1.206	***	0.216	-1.281	***	0.228	-1.163	***	0.218	-1.447	***	0.293
2003	-1.872	***	0.238	-1.991	***	0.251	-1.873	***	0.251	-2.278	***	0.306
Firm dummies												
Coding Technologies										0.511		0.616
Ericsson										1.027	**	0.423
InterDigital										4.265	***	0.524
IP Wireless										-0.210		0.742
Matsushita										1.219	***	0.460
Mitsubishi										-1.522	**	0.665
Motorola										-1.091	*	0.560
NEC										-0.338		0.513
Nokia										1.275	***	0.413
Nortel Networks										0.872	*	0.451
Qualcomm										3.099	***	0.461
Tantivy Communications										0.186		0.479
Texas Instruments										(omitted)		
Observations	7912			2196			7912			2196		

Notes: Dependent variable: binary for citation from j to i. Excluding pairs where the firm i was never cited during 2000-2003. Specification (2) also excludes pairs where firm j never cited patents of other 3GPP members in 2000-2003. Specification (3) adds fixed effects (dummies) for cited firms. Specification (4) adds dummies for citing firms that are listed on the lower part of the table. Estimation method is logit with differences-in-differences variables to utilize the exogenous variation from the merger of consortia that led to Open Mobile Alliance (OMA) in 2002. 2000-2001 is the pre-merger period and 2002-2003 is the post-merger period.

We conclude these analyses by noting that co-memberships in consortia, particularly those related to Open Mobile Alliance, are significantly associated with the likelihood of cross-citation among 3GPP member firms in their essential patents. If a firm attended a relevant technical consortium, other members of the same consortium were significantly more likely to cite its earlier patents in their own current patents that eventually led to essential IP declarations. Thus, this analysis highlights the mechanism that generates the results in the earlier patent-level panel analyses. However, there are some empirical challenges with these analyses. First, the raw probability of citation is very low because relatively few firm pairs generate cross-citations. Second, the citing behavior is highly concentrated, which hinders the statistical analysis. Most firms in the dataset (firms whose patents ever cite or get cited) have rather few cited patents or cite few patents of other firms, whereas the two leading IP firms, Qualcomm and InterDigital, dominate the picture and thus are associated with enormous fixed effects. Nevertheless, their strategies highlight the implications of the firms' chosen business models. With respect to wireless communication technologies, these two firms operate almost exclusively in the IP market rather than the product market, for which reason their strategic drivers are very different from most other firms who also manufacture products. Nevertheless, industry consortia appear to be central venues in which these and other firms learn about technologies related to the UMTS standard on which they subsequently build further inventions.

5. Conclusion

This paper analyzes the impact of firms' participation in ICT consortia on knowledge sharing and coordination of innovation strategies related to compatibility standards. We use data on participation in 32 ICT consortia and prior art citations in essential patents filed by participants in the 3GPP standardization process. To empirically identify the effect of consortium connections, we exploit a merger in the network of consortia as a quasi-experiment that exogenously changed consortium connections of members.

Our empirical analysis highlights the impact of the patent holder's position in the consortium network on the likelihood of having its patents cited by other participants in subsequent research. The more central the firm is in the consortium network, the greater the likelihood of its patents being cited by other firms in subsequent patents that are declared essential for the UMTS standard. This result is stronger for consortia that are formally allied with (related to) 3GPP, whereas the result is weaker but still positive and statistically significant for consortia unrelated to 3GPP. Our findings also suggest that informal consortia are a more effective vehicle for coordinating standards-related innovation. Whereas participation in informal consortia has a positive and statistically significant impact on the likelihood to be cited by subsequent research, the same does not hold for more formal consortia such as other standard-setting organizations, although this result is not completely robust to different estimation methods.

The main result that consortium participation facilitates coordination of firms' innovation activities is confirmed by a difference-in-difference analysis using a merger in the network of consortia as a source of exogenous variation. The result is also corroborated with a firm-pair-level approach where we highlight the knowledge transmission mechanism through the effect of firm pairs' co-memberships in specific consortia. It lends support for an earlier literature on the effects of R&D cooperation on managing knowledge transfer between rivals. The firm-pair level analyses also highlight the implications of firms' chosen business models. The two firms, InterDigital and Qualcomm, that dominate the citing behavior operate under an IP-based business model, whereas other firms also participate in the product markets.

Thus, we argue that consortia potentially improve incentives for R&D because they enable the internalization of knowledge-creation externalities. They may also speed up standardization by facilitating both committee and market dynamics. However, in the standard-setting context our findings also raise questions. Our results demonstrate that standardization takes place not only in the marketplace and in formal standard-setting organizations, but also in informal upstream consortia.

First, transparency and openness of informal consortia may be an issue for less prominent innovators. It can be difficult for an innovating entrant to understand who makes decisions about standardization, where, and through what process. During and preceding the period of study, many consortia were formed by a small group of industry leaders, and the consortia tended to have a pre-set agenda and a tiered membership structure where the founding firms had a more powerful position than latecomers. Moreover, we found evidence of technological resources enhancing the effect of consortium connections on subsequent innovation. Even if smaller innovators can find their way to the right meetings, their impact is likely to be weaker.

Second, when standard setting is effectively distributed to dozens of consortia, each with substantial membership fees and frequent meeting schedules, participation can become prohibitively costly for cash-constrained firms. Small firms are likely to have few (if any) technical experts who are able to travel to consortium meetings, and with dozens of potentially relevant consortia, this may simply not be possible.

Finally, major firms have justified consortia as a method of speeding up standards development. Whereas this is a laudable goal for any industry, the actual cause of accelerated outcomes from consortia may be exactly that smaller firms and those who disagree with a subset of industry leaders are not participating. Further research would need to be conducted to properly understand the welfare implications of the effect of upstream consortia in potentially narrowing down the pool of innovations that are subsequently incorporated in the ex-ante compatibility standard.

We suggest that these novel results on the organization of compatibility standardization call for a rethinking of standard-setting policies. Innovation and competition policymakers might include informal upstream consortia in their frameworks for standardization policy, because this is where a significant part of coordination is done. Simple requirements for open membership, publicly available meeting and decision documents, and public disclosure of decision-making rules and rights of different members might go a long way toward dispelling the undemocratic reputation of informal consortia. By the same token, our results show that innovating firms who want to commercialize new products or technologies in network industries must design a standard-setting strategy that involves participation not only in formal standard-setting organizations but also in informal consortia to optimize opportunities to influence and align strategies with peers.

The main limitation of our study is the well-known issue related to inference drawn from patent cross-citations (Alcacer and Gittelman, 2006 ; Thompson and Fox Kean, 2004). In particular, it is not clear whether the consortium effect actually demonstrates knowledge flows and coordination of innovation, or whether participation in consortia simply makes firms aware of each other's patents and, by courtesy, include citations to peers' earlier patents. Corroborating the results with other than patent data, such as meeting documents or interview-based case studies might be desirable.

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Appendix 1: Description cited patents

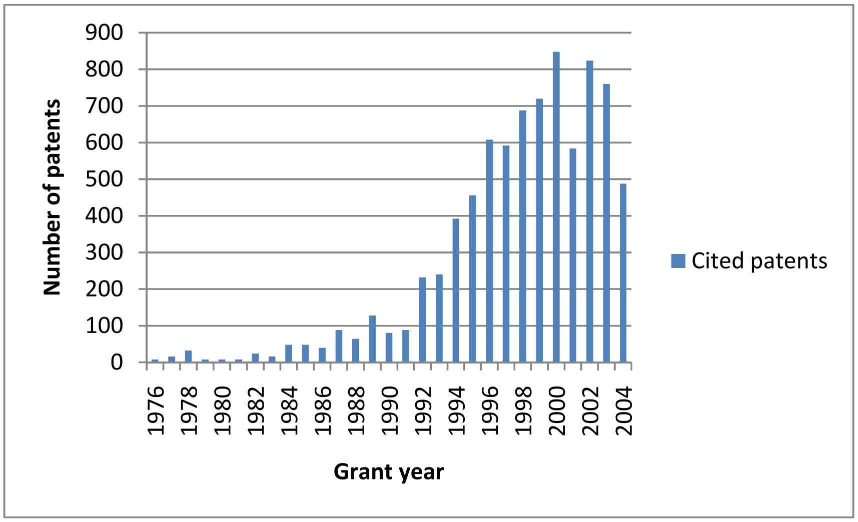

Figure 1: Grant year of the cited patents

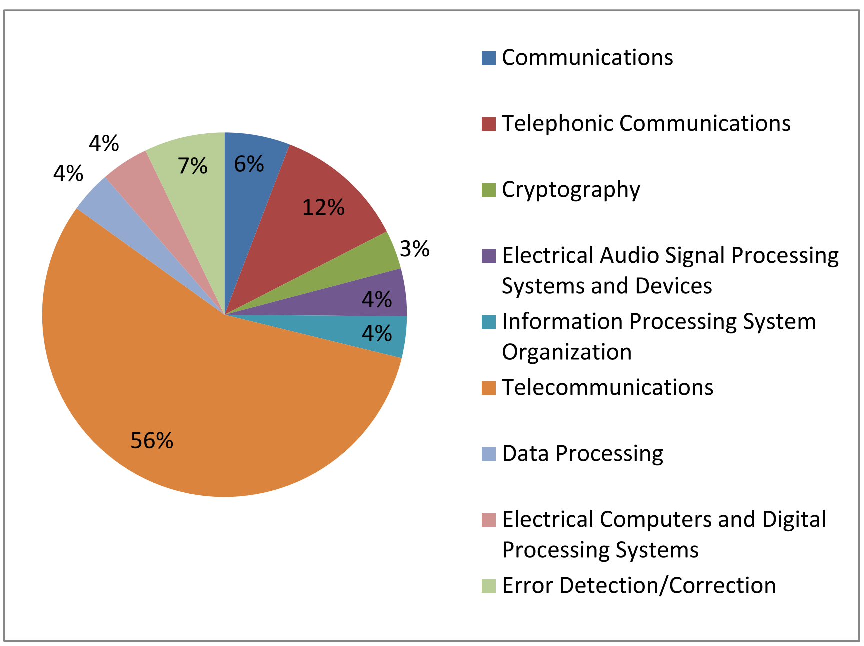

Figure 2: Technological class of the cited patents

Appendix 2 : Description citing patents

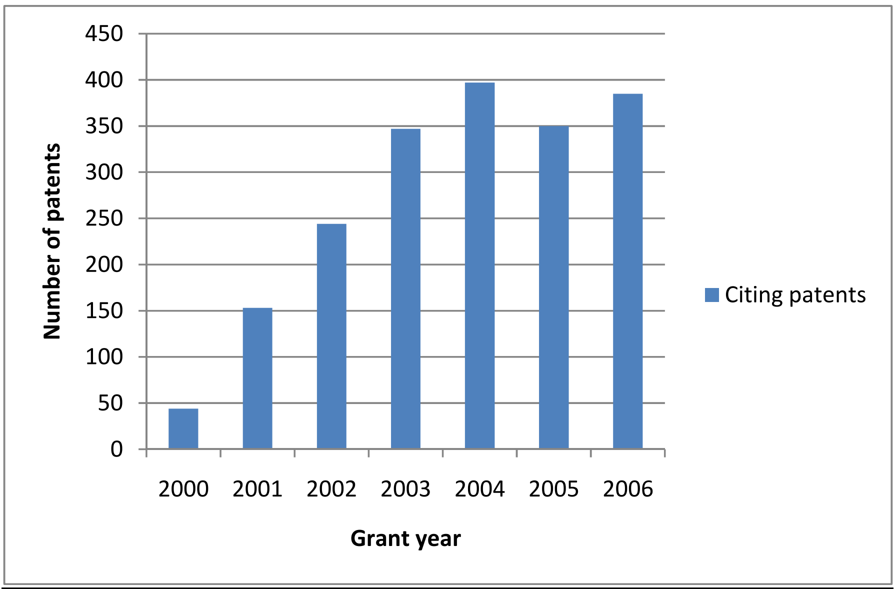

Figure 3: Grant year of the citing patents

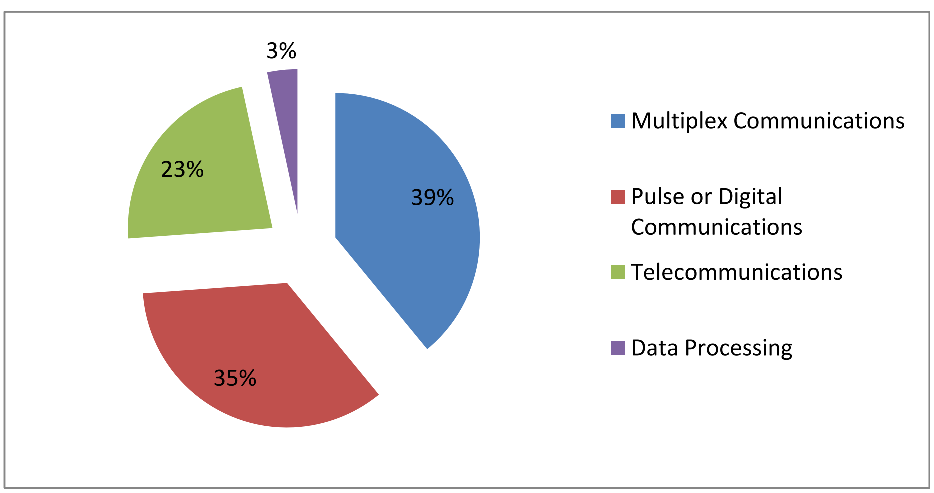

Figure 4: Technological class of the citing patents

Appendix 3 : List of consortia

Consortium Name	3GPP related	Affected by the OMA merger
MET	No	No
WLANA	No	No
SA Forum	No	No
ATIS	No	No
3G Americas	No	No
CDG	No	No
VoiceXML	No	No
IPv6 Forum	Yes	No
Hiperlan 2	No	No
WiFi Alliance	No	No
GSA	Yes	No
TTC	Yes	No
Bluetooth	No	No
GPP 2	No	No
UMTS Forum	Yes	Yes
T1	Yes	No
SyncML	No	Yes
TTA	No	No
UWCC	Yes	No
WAP Forum	No	Yes
Wireless Village	No	Yes
3GIP	No	No
ARIB	Yes	No
BWIF	No	No
CWTS	No	No
ETSI	Yes	No
GSM Association	Yes	No
MGIF	No	Yes
MWIF	No	Yes
OMA Alliance	No	No
Symbian	No	No
WECA	No	No

Appendix 4 : Cited patent holders

ID	Company Name
50020	Agere
50040	Alcatel
50100	ArrayComm
50120	AT&T Wireless
50180	Bell South
50220	BT (British Telecom)
50250	BULL S.A.
50360	Cisco Systems
50411	3Com
50421	Infineon Technology
50520	Ericsson
50580	France Telecom
50590	Fujitsu Limited
50630	Golden Bridge Technology
50640	Hewlett Packard
50670	Hughes Network
50710	ICO Global
50750	Intel
50760	InterDigital
50860	LG Electronics
50880	Lucent
50940	Matsushita
50950	Matra
51000	Microsoft
51010	Mitsubishi
51060	Motorola
51090	NEC
51130	Nokia
51140	Nortel Networks
51200	OKI Electrics
51280	Panasonic
51340	Qualcomm
51360	Racal Instruments
51400	Rogers Wireless
51440	Samsung
51490	Seiko Epson
51540	Sharp
51560	Siemens
51640	Sony
51880	Texas Instruments
51900	Thomson
51920	Toshiba

Appendix 5 : Control group for the OMA merger

Company Name
Hughes network
Agere
ArrayComm
BT (British Telecom)
Bull S.A.
Comneon
Golden Bridge technology
ICO Global
Matra
Racal Instruments
Rogers Wireless
Shanghai Bell

Appendix 6: Results using a random effects estimation

	(1)		(2)		(3)	
	Coef. (SE)	Odds ratios (SE)	Coef. (SE)	Odds ratios (SE)	Coef. (SE)	Odds ratios (SE)
			DV= Dummy patent cited/year			
Total memberships	0.139***	1.149***				
	(0.018)	(0.021)				
Mean memberships	-0.215***	0.806***				
	(0.061)	(0.049)				
Consortium connections			0.002***	1.002***		
			(0.0002)	(0.0002)		
Mean consortium Connections			-0.002	0.998		
			(0.001)	(0.001)		
Co-membership					3.162***	23.610***
					(0.168)	(3.976)
Mean Co-membership					6.463***	640.071***
					(0.645)	(412.579)
3GPP connections	0.007	1.007	0.021***	1.021***	-0.002	0.998
	(0.006)	(0.006)	(0.005)	(0.005)	(0.006)	(0.006)
Mean 3GPPconnections	-0.037	0.964	-0.081***	0.922***	-0.035***	0.965***
	(0.023)	(0.022)	(0.016)	(0.015)	(0.010)	(0.010)
Patent age	-0.109*	0.896*	-0.076	0.926	-0.039	0.962
	(0.053)	(0.048)	(0.053)	(0.049)	(0.064)	(0.062)
Mean patent age	0.305***	1.357***	0.276***	1.318***	0.199**	1.220***
	(0.052)	(0.070)	(0.051)	(0.068)	(0.062)	(0.075)
Patent quality	-0.068***	0.934***	-0.067***	0.935***	-0.074***	0.929***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.008)	(0.007)
Mean patent quality	0.080***	1.083***	0.079***	1.082***	0.079***	1.082***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)
Dummy 0/3/6/9	Y		Y		Y	
Observations	6276		6276		6276	
Number of groups	1021		1021		1021	
Chi2	418.96		421.75		539.77	
Prob > chi2	0		0		0	
Log Likelihood	-1554.269		-1558.675		-1142.618	
Unit of analysis	Cited patent		Cited patent		Cited patent	
Number of cited firms	43		43		43	

Legend: * p<.05; ** p<.01; *** p<.001

Notes: Dependent variable is an indicator for whether a patent was cited by an essential patent applied in year t. Estimation method is logit with random effects. Dummy 0/3/6/9 are nonlinear effects for patent age. Means are computed at the cited patent level.

Appendix 7: Regression results with a linear probability model

Table 7.1 Main results

	(1)	(2)
	Coef. (SE)	Coef. (SE)
Total memberships	0.0050***	
	(0.0007)	
Consortium connections		0.0002***
		(0.00004)
Co-membership		
3GPP connections	0.0003	0.0007**
	(0.0003)	(0.0002)
Dummy Age Cited	Y	Y
Observations	7297	6276
Number of groups	1021	1021
R-sq	0.1071	0.0975
Unit of analysis	Cited patent	Cited patent
Number of cited firms	43	43

Notes: Standard errors, clustered on patents, in parentheses under the coefficients. Legend: * p<.05; ** p<.01; *** p<.001

Table 7.2 Types of consortia

	(1)	(2)
	Coef. (SE)	Coef. (SE)
Informal consortium memberships	0.0022* (0.0008)	
Formal consortium memberships	0.0172*** (0.0032)	
Related consortium memberships		0.0191*** (0.0022)
Unrelated consortium memberships		-0.0013 (0.0008)
Consortium Connections		
Cons. connections* patent apps		
Patent apps		
3GPP connections	0.0006 (0.0003)	0.0001 (0.0003)
Dummy Cited Age	Y	Y
Observations	6276	6276
Number of groups	1021	1021
R-sq	0.0516	0.1049
Unit of analysis	Cited patent	Cited patent
Number of cited firms	43	43

Notes: Standard errors, clustered on patents, in parentheses under the coefficients.

Table 7.3 Differences-in-differences estimation of the effects of OMA merger

	(1)	(2)
	Coef.	Coef.
OMA connections	0.0007***	0.0006***
	(0.0001)	(0.0001)
Other consortia connections	-0.0001*	
	(0.00005)	
Formal consortia connections		-0.00009
		(0.00005)
Informal consortia connections		0.0014**
		(0.0005)
OMA connections after	0.0005***	0.0005**
	(0.0001)	(0.0001)
Dummy after	-0.1831***	-0.1811***
	(0.018)	(0.018)
3GPP connections	-0.0014***	-0.0014***
	(0.0003)	(0.0003)
Dummy Cited Age	Y	Y
Number of obs	6276	6276
Number of groups	1021	1021
R-sq	0.1109	0.1169
Unit of analysis	Cited patent	Cited patent
Number of cited firms	43	43

Notes: Standard errors, clustered on patents, in parentheses under the coefficients.