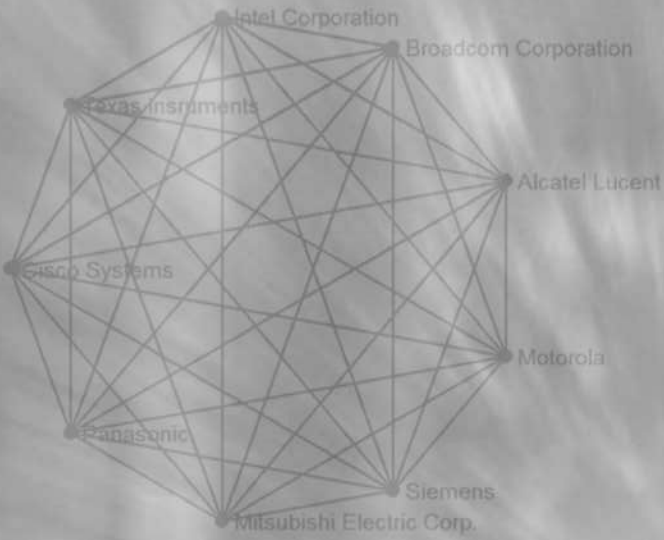
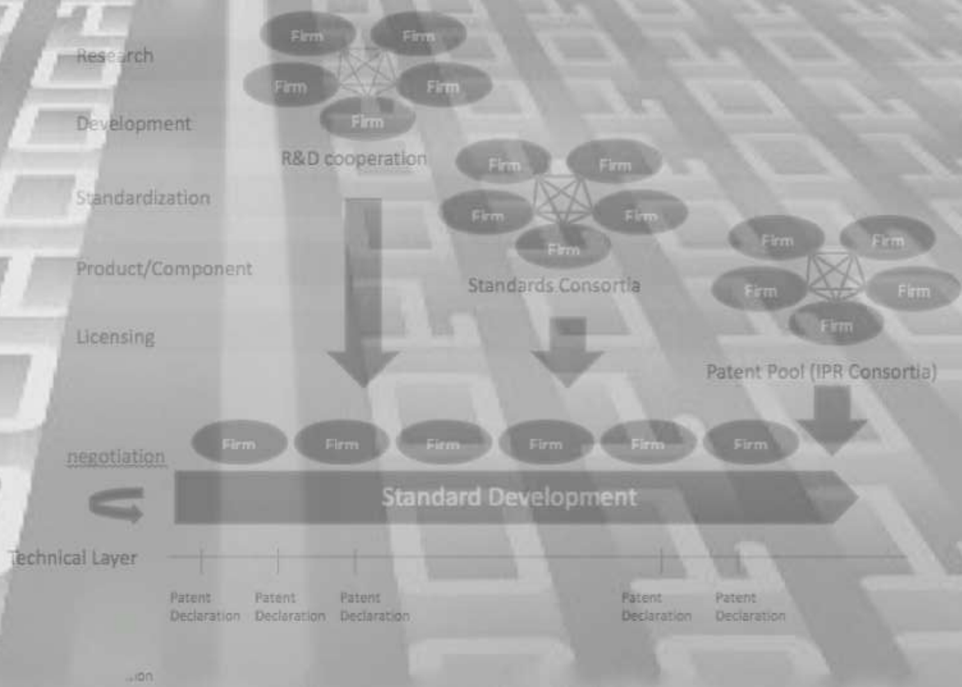


Six essays on patenting and coordination in ICT standardization: Empirical analyses of essential patents, patent pools, and standards consortia

Tim Pohlmann



$$\underbrace{P(X)[s_i(1-\theta)V}_{\text{Market Profit}} + \underbrace{\frac{x_i}{X}\theta V]}_{\text{Licensing Profit}} - \overbrace{cx_i}^{\text{R\&D Cost}}$$

Six essays on patenting and coordination in ICT standardization:

Empirical analyses of essential patents, patent pools, and standards consortia

vorgelegt von Dipl-. Kaufmann

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Publication and Submission Record

The essay *Essential Patents and Standard Dynamics* is coauthored by Justus Baron and Knut Blind and was presented at the 5th INTERTIC Conference on Innovation and Competition in Venice, November 2011, at the Telecom ParisTech Conference on the Economics of Information and Communication Technologies in Paris, September 2011, at the 7th International Conference on Standardization and Innovation in Information Technologies in Berlin, September 2011, at the sixth 6th Annual Conference of the EPIP Association: Fine-Tuning IPR Debates and at the 10th ZEW Conference on the Economics of Information and Communication Technologies in Mannheim, June 2012.

The essay *Patent Pools and Patent Inflation* is coauthored by Justus Baron and was presented at the 4th INTERTIC Conference on Competition in High Tech Markets, Innovation, Networks and Multi-sided Markets in Milan, October 2010, at the Conference on ICT and Economic Growth, Strategy in ICT Markets in Munich 2010 and at the 4th ZEW Conference on the Economics of Innovation and Patenting in Mannheim, May 2011. The essay is further accepted for presentation at the European Association for Research in Industrial Economics (EARIE) Conference which will be held in Rome, September 2012.

The essay *Attributes and Dynamic Development Phases of ICT Standards Consortia* was presented at the IADIS International Conference, Telecommunications, Networks and Systems in Freiburg, August 2010.

The essay *Joint Innovation in ICT Standards: How Consortia Drive the Volume of Patent Filings* is coauthored by Justus Baron and Yann Ménière and was presented at the 2nd Asia Pacific Innovation Conference in Singapore, 2011, at the 7th International Conference on Standardization and Innovation in Information Technology SIIT in Berlin 2011, at the 6th Annual Conference of the EPIP Association: Fine-Tuning IPR Debates in Brussels 2011, at the Conference on the Economics of Information and Communication Technologies in Paris 2011 and at the 4th ICTNET Conference – ICT, R&D, Intangibles and ICT Diffusion in London, April 2012.

The essay *Cooperate to Declare, Firms’ cooperatives activities as driving factors for patent declaration on technology standards* is coauthored by Knut Blind and was presented at the DRUID-DIME Academy Winter Conference on Economics and Management of Innovation, Technology and Organizations in Aalborg, January 2011, at the International EMAEE Conference (European Meeting on Applied Evolutionary Economics) in Pisa, March 2011 and at the 7th International Conference on Standardization and Innovation in Information Technology SIIT in Berlin, September 2011.

The essay *Standard Essential Patents to Boost Financial Returns* is coauthored by Knut Blind and Peter Neuhäusler and was presented at the 6th EPIP Conference Fine-tuning IPR Debates in Brussels, September 2011.

Summary

Information and communication technology (ICT) markets are subject to short product lifecycles and a rapid technology evolution. Competition takes place on several market levels where firms compete on products, on services and on platforms. ICT products are often interdependent and in some cases indispensably work together. E.g. applications are dependent on the underlying operating system which is again designed for computers that rely on the functioning of their computer chips. Firms thus compete on different market levels pursuing different business models to sponsor their proprietary technologies and to maintain market share for their products and services. However, interoperability of products is a crucial factor for market success and firms evermore have to coordinate their innovation activities with other, often competing market participants.

Technology standards specify a common language for technologies to communicate and interact. This ensures compatibility and functionality of complex technology systems. Standards evolve in markets where returns increase when a large number of firms rely on the same technology (Arthur, 1988). In markets where network effects are dominant, consumers not only benefit from the consumption of a product but also from the number of other users of the same product. As to Katz and Shapiro (1985) network effects are the primary reason for the existence of compatibility standards. The success of a standard thus always depends on the installed base of consumers (David and Greenstein, 1990). A strand of literature discusses several effects of network externalities which are subject to standards. Bandwagon effects in early technology cycles can yield lock-in. Competing standard solutions may further create technological uncertainty which often results in waiting games, penguin effects and stranding on unsuccessful specifications (Farrell and Saloner, 1985, 1986; Besen and Farrell, 1994; Choi, 1997; Clements, 2004).

In the field of ICT, standard setting is no longer a sheer specification of compatibility standards, but in fact a joint development of sophisticated technologies. Thus, standards often frame a large number of innovative technologies (GSM, UMTS, WiFi, DVD, Blue-Ray, MPEG, etc.). GSM and UMTS ensure communication of mobile phones and smart phones. The Wi-Fi standard provides wireless connection to local internet hosts. CD, DVD or Blue-Ray guarantee that decoders or players read discs to watch movies on TV or computer screens and the MP3 standard allows listening to high quality music in compressed data formats on multiple devices. The increasing need for interoperability comes along with a rising sophistication of technology standards. In this context, standard setting is much more

demanding in terms of R&D. Most consumers are not aware that these standards may incorporate hundreds of patents from multiple companies (Simcoe, 2007).

Market accepted "standards" may be developed by a single firm, while "standard agreements" are results of market coordination and consensus decisions (David and Greenstein, 1990). Standards are described as de facto standards when they are subject to proprietary technologies sponsored by a single firm or industry alliance. In comparison, standards are described as de jure standards when they are specified by formal standard setting organizations (SSOs). SSOs are voluntary and non-profit organizations which coordinate the specification of commonly accepted standards. These organizations are inclusive and attempt to gather all markets participants to reach consensus on technology specifications (Bekkers et al., 2011). While de facto standards may also compete, de jure standards seek to only foster one market accepted technology to ensure sustainable compatibility (Farrell et al., 2007). Farrell and Saloner (1988) model coordination benefits when standard solutions are set by committees instead of markets and show that SSOs increase a standard's value even though negotiation may take longer. Especially in recent years SSOs increasingly gained importance. In markets with complex technologies, firms rely on stable and interoperable solutions that require coordination of all market participants (Lemley, 2002). SSO's outcomes are market accepted standards that determine technology trajectories for future generations. Standards may thus influence the value of a whole technology (Rysman and Simcoe, 2008). Firms that provide proprietary technologies are increasingly joining SSOs to value their often patented technology by having it approved as part of an industry-wide standard. Competition also takes place within SSOs, since technology selection in SSOs can be crucial for a firm's future market position (Bekkers et al., 2002). Although the need for interoperability is not recent, the last two decades have seen standard setting in ICT evolve from mere coordination on common specifications to the joint development of complex technology platforms. New generations of standards tend to embody more components and functionalities. Consequently, the number of patents claimed on ICT standards has been increasing since the early nineties (Simcoe, 2007).

Even though SSOs seek to align interests of all interested stakeholders, coordination also takes place outside SSOs. Market participants may coordinate in rather loose ad hoc meetings (Kerstan et al., 2012) or in more explicit alliances. Firms join informal industry alliances to better influence and control technology development within standard setting. Members of these coalitions are often likeminded peers with the common interest to support and sponsor a certain technology (Weiss and Sibru, 1990; Axelrod et al., 1995). These consortia may help standard setting participants to improve their positions in negotiation for technology selection (Leiponen, 2008, Rosenkopf et al., 2001). Lerner and Tirole (2006) make the case of forum shopping where firms choose the appropriate standard setting venue for including their proprietary technology. The forum choice especially depends on the value of the technology and on expected revenue incomes. However, Blind and Gauch (2008) show that standards consortia and formal SSOs rather co-exist than compete.

While the complexity of standardized technologies is growing, technology providers which participate in standard setting, increasingly pursue very different business models (Simcoe et al., 2009). This may upsurge the cost of coordination or even lead to coordination failures. Especially when firms have commercial stakes in standards, vested interests may delay standard setting processes or even yield a war of attrition (Farrell and Saloner, 1988; Farrell and Simcoe, 2012). Conflicts and discrepancies in SSOs are often connected to a firm's preference of its own patented technology solution. Patents are essential to a standard when any adoption or implementation would necessarily infringe the patent claims. Even though some patents only contribute minor innovations to a standard, holders of essential patents can hold-up the use of a whole technology (Lemley and Shapiro, 2006; Farrell et al., 2007). In recent years famous litigation cases (Qualcomm v. Broadcom; Infineon v. Rambus; IP COM v. Nokia; Apple v. Samsung; etc.) raised attention to often complex legal questions concerning standard setting and the role of essential IPR.

Farrell and Simcoe (2012) have shown that IP rules may decrease firms' vested interests. In practice, bylaws of SSOs provide a legal framework for the general treatment of patents that are relevant for standardization. SSOs often mandatorily require firms participating in standardization to disclose any patent that might turn out to be essential for the standard in question. Furthermore holders of such patents have to submit a declaration whether they accept to commit on fair, reasonable and non-discriminatory licensing terms (FRAND). If a firm discloses a patent and refuses to commit on such licensing terms, the SSO will usually set the standard excluding the protected technology (Lemley and Shapiro, 2006).

Even though standardization may be accompanied by complex licensing agreements, the rules for licensing essential patents are far from conclusive and can be subject to complex discussions or even legal and political investigations.[1] Nevertheless, FRAND commitments are commonly seen as an important instrument to curb anticompetitive and abusive behavior. Antitrust authorities have referred to FRAND commitments as a remedy to the potential competitive risks of standardization (Layne-Farrar et al., 2007; Farrell et al., 2007; Schmalensee, 2009).

In conclusion, firms in ICT standardization are confronted with particularly two major challenges. First, coordination is much more demanding and often results in cooperation of competing firms jointly developing complex and sophisticated technologies. Second, standardized technologies in ICT are in many cases protected by patents. Standard essential patents are subject to a new and different legal framework which goes beyond the rights of regular patent law. Both challenges influence incentives to develop and specify ICT standards, incentives to invest in R&D or incentives to file patents. The six essays of this dissertation build upon existing literature findings and theoretical implications to shed light on the interaction of essential patents and standard dynamics. The essays furthermore investigate different coordination mechanisms around standardization and measure the effect on firms' R&D investments and patenting behavior.

Essential patents may increase incentives for firms to invest in standards, since future licensing revenue pays back earlier investments. However, vested interest may delay standardization or yield lock-in of outdated standards. SSOs coordinate the transition of technology generations. Standard makers confronted with technological change can often choose between replacing old by new standards and upgrading existing standards. The first essay *Standard Dynamics and Essential Patents* investigates how this trade-off is affected by the introduction of essential patents on standard components. Using a database of over 3,500 different ICT standards, the essay shows that essential patents reduce the likelihood of standard replacement, but increase the rate at which standards are upgraded. The increase in the number of upgrades may reflect an increase of firms' investment in improving existing standards. More frequent upgrades can only partly explain the effect of the delayed rate of

[1] On January 31st, 2012 the European Commission announced to open a formal investigation on Samsung's filed injunctions on standard essential patents. Samsung made injunctions against a number of competitors, among others Apple Inc. The Commission now turns the antitrust lens on Samsung to analyze whether these injunctions themselves are in breach of competition law. In particular it has to be investigated if Samsung has failed to honor its irrevocable commitment to license any standard essential patent under fair, reasonable and non-discriminatory (FRAND) terms. It has to be examined if Samsung's behavior is an abuse of a dominant position prohibited by Article 102 of the Treaty on the Functioning of the EU (TFEU).

replacement when essential patents are declared. Other explanations for this effect could be frictions and vested interests among standard setting firms.

Patent pools are one of the most important mechanisms to coordinate complex licensing of standard essential patents. Pools combine IPR to be licensed under a single contract. This may increase transparency, reduce transaction costs, avoid costly infringement litigation and furthermore may even reduce royalty rates by eliminating wasteful multiple marginalization. The second essay *Patent Pools and Patent Inflation* investigates patenting around technology standards when patent pools exist. Data from a rich sample of firms active in ICT standardization is used to empirically test patent behavior around pool formation in a time span of 1992-2009. The essay makes use of the information on the general clearance of patent pools in 1997-1999 to conduct a quasi-experimental test on firms' reaction to pool creation. Results indicate that firms show an immediate positive response to a pool creation in years before 1999 and in comparison show positive anticipating reactions if a pool is launched after 1999. These findings suggest that legal certainty in periods after the pool clearance leads to anticipating effects, while situations of legal uncertainty triggers a prompt effect after pool launch. Furthermore tests provide evidence for a patent shift within the timing of standardization when pools exist. While this evidence indicates a positive effect of patent pools on the incentives to file and declare essential patents, the overall effect of pools on the inflation of essential patents around standards seems to be limited.

The third essay *Attributes and Dynamic Development Phases of ICT Standards Consortia* investigates the evolution of standards consortia in the field of ICT. The essay provides a broad and comprehensive picture of standards consortia and their dynamic development in the past ten years. Analyses show that consortia have distinct characteristics which help to explain and justify their existence in the standard setting context. Observing consortia evolution over the last 10 years identifies relationships between formation, termination and merger of consortia with respect to market and technology development. Results of a consortia performance analysis reveals that the probability of consortia success is especially connected to the scope and focus on markets and technology and further depends on structures that determine coordination among members.

The fourth essay *Joint Innovation in ICT Standards: How Consortia Drive the Volume of Patent Filings* investigates the effect of R&D investments into standards when firms join standards consortia accompanying formal standardization. The essay aims to assess how such consortia influence the volume of R&D investments around standards, and whether this is efficient. The essay shows that the effect depends on the strength of firms' incentives to develop the standard. Consortium membership triggers a higher number of R&D investments when insufficient rewards for essential patents induce underinvestment in the standard. This effect is necessarily pro-efficient. In situations where excessive rewards induce patent races, consortium membership only moderately increases or even reduces R&D investments.

The fifth essay *Cooperate to Declare* investigates direct ties of firms that co-declare essential patents for the same standards and measures different types of consortia participation. The essay empirically tests whether participation in standards consortia increases a firm's ability to introduce patented proposals to formal standards. Results indicate that memberships in technically related standards consortia help firms to influence standardization by channels of partner control and mutual trust. Thus firms find it easier to introduce patented components into formal standards when they are consortia members. However, consortia connections in technically unrelated standards consortia show no significant effects. The empirical analysis further provides evidence that consortia size positively influences the likelihood of member firms to introduce patents into standards.

The sixth essay *Essential Patents to Boost Financial Returns* measures whether the value of standards increases firms' return on investments. In particular the influence of declaring a patent to a standard on financial performance of firms active in ICT standard setting is tested. Results indicate a curvilinear (inverse U-shaped) relationship of patent declarations on firms' return on assets (ROA). This effect lasts for one year, while the incremental effect is higher for patents declared to standards consortia when comparing declarations to formal SSOs. The optimal number of patent declarations is further measured and shows a higher optimal level of financial return for declaring patents to formal standards. The curvilinear relationship suggests firms to balance their patent portfolio by introducing a share of patents into standards and by holding a share of patents on standard constructive technologies.

Results of the six essays show that essential patents constitute a special case for the dynamics of innovation. Essential patents influence the generational change of standards and contribute to standard improvements. The coordination of licensing essential patents in a patent pool alters incentives to patent in terms of timing and volume. Consortia are subject to R&D coordination and strategic partnering to influence the outcome of standardization. Participation in consortia indicates to affect standard specific patent behavior and the ability integrate essential patents in standards. Essential patents further influence the value of a standard and thus affect the structure of financial returns.

Zusammenfassung

Informations-und Kommunikationstechnologie (IKT) Märkte sind gekennzeichnet durch kurze Produktlebenszyklen und eine schnelle Technologieentwicklung. Dabei konkurrieren Firmen auf mehreren Marktebenen über ihre Produkte, Dienstleistungen und auf Plattformen. IKT-Produkte sind oft technisch voneinander abhängig oder funktionieren unabdingbar zusammen. Beispielsweise sind Anwendungen abhängig von dem zugrunde liegenden Betriebssystem, welches wiederum für Computer entwickelt wurde, die auf Computer-Chips aufbauen. Unternehmen können auf verschiedenen Ebenen im Markt unterschiedliche Geschäftsmodelle verfolgen, um ihre proprietären Technologien zu fördern und Marktanteile für ihre Produkte und Dienstleistungen zu sichern. Ein entscheidender Faktor für den Markterfolg ist die Interoperabilität von Produkten. Daher müssen Unternehmen ihre Innovationsaktivitäten mit anderen, oft konkurrierenden Marktteilnehmern koordinieren, um wettbewerbsfähig zu bleiben.

Technologie-Standards spezifizieren eine gemeinsame Sprache, damit Technologien kommunizieren und interagieren können. Standards sorgen damit für Kompatibilität und ermöglichen das Funktionieren komplexer IT-Systeme. Standards sind besonders wichtig für Märkte, in denen Erträge steigen, wenn eine große Anzahl von Unternehmen die gleiche Technologie unterstützt (Arthur, 1988). In Märkten, in denen Netzwerkeffekte dominieren, profitieren Verbraucher nicht nur von dem Konsum eines Produktes, sondern auch von der Anzahl anderer Nutzer des gleichen Produktes. Für Katz und Shapiro (1985) sind Netzwerk-Effekte der Hauptgrund für die Existenz von Kompatibilitäts-Standards. Der Erfolg eines Standards ist somit immer abhängig von der so gennannte “installed base“ von Verbrauchern (David und Greenstein, 1990). Ein wesentlicher Literaturstrang befasst sich mit den verschiedenen Wirkungen von Netzwerk-Externalitäten, die in Verbindung mit Standards stehen. Bandwagon-Effekte in frühen Technologie-Zyklen können zu Lock-in Situationen führen. Weiterhin können konkurrierende Standards technologische Unsicherheit erzeugen, die Anreiz zu Warte-Spielen oder Pinguin-Effekten geben, wie auch zu Strandung auf erfolglosen Standards führen können (Farrell und Saloner, 1985, 1986; Besen und Farrell, 1994; Choi, 1997; Clements, 2004).

Im Bereich der IKT spezifizieren Standards eine große Anzahl von innovativen Technologien (GSM, UMTS, WLAN, DVD, Blue-Ray, MPEG, etc.). GSM und UMTS sorgen für die Kommunikation von Mobiltelefonen und Smartphones. Der Wi-Fi-Standard

ermöglicht die drahtlose Verbindung zu mobilen Endgeraeten. CD, DVD oder Blue-Ray sorgen dafür, dass Decoder Discs lesen, um Filme auf TV- und Computerbildschirmen sehen zu können. Der MP3-Standard ermöglicht das Hören von Musik in komprimierten Datenformaten auf unterschiedlichen Geräten. Der steigende Bedarf an Interoperabilität geht einher mit einer steigenden Komplexität von Technologie-Standards. In diesem Zusammenhang hat sich die Entwicklung von Standards in den letzten Jahren als wesentlich anspruchsvoller in Bezug auf Forschung und Entwicklung (F&E) erwiesen. Die meisten Verbraucher sind sich nicht bewusst, dass diese Standards Hunderte von Patenten aus einer Vielzahl an Unternehmen (Simcoe, 2007) integrieren.

Im Markt akzeptierte "Standards" werden von einer einzelnen Firma entwickelt, während "Standard-Vereinbarungen" das Ergebnis von Markt Koordination und Konsens Entscheidungen sind (David und Greenstein, 1990). Standards werden als de-facto-Standards bezeichnet, wenn proprietäre Technologien von einer einzigen Firma oder Industrie-Allianz etabliert werden. Im Vergleich werden Standards als de-jure-Standards beschrieben, wenn sie durch formale Standard-Organisationen (SSO) spezifiziert sind. SSOs sind freiwillige Non-Profit-Organisationen, die die Spezifikation von gemeinsamen Standards koordinieren. Diese Organisationen versuchen alle Marktteilnehmer einzubeziehen, um einen Konsens über Technologie-Spezifikationen zu erreichen (Shapiro, 2001). Während de-facto-Standards auch konkurrieren können, werden de-jure-Standards spezifiziert, um lediglich eine vom Markt akzeptierte Technologie nachhaltig zu etablieren (Farrell et al., 2007). Farrell und Saloner (1988) modellieren Koordinationsvorteile, wenn Standards in SSOs statt in Märkte etabliert werden und zeigen, dass SSOs den Wert eines Standards erhöhen, auch wenn Verhandlungen in SSOs die Standardisierung verlängern können. Besonders in den letzten Jahren haben SSOs zunehmend an Bedeutung gewonnen. In Märkten mit komplexen Technologien, müssen Unternehmen auf stabile und interoperable Lösungen vertrauen, was die Koordination aller Marktteilnehmer erfordert (Lemley, 2002). SSOs spezifizieren Standards, die die Technologie Felder für zukünftige Generationen bestimmen. Standards können damit Einfluss auf den Wert einer ganzen Technologie haben (Rysman und Simcoe, 2008). Firmen, die proprietäre Technologien anbieten, treten zunehmend SSOs bei, um ihre oft patentierten Technologien in branchenweit akzeptierte Standards einfließen zu lassen. Der Wettbewerb findet somit auch innerhalb von SSOs statt, da die Auswahl von Technologien in SSOs die zukünftige Marktposition von Unternehmen entscheidend beeinflussen kann (Bekkers et al., 2002). Obwohl die Notwendigkeit der Interoperabilität nicht neu ist, haben die letzten zwei Jahrzehnte der IKT-Standardisierung gezeigt, dass sich das Spezifizieren von Standards von einer anfänglichen Koordination zu einer gemeinsamen Entwicklung von komplexen Technologie-Plattformen ausgeweitet hat. Neue Generationen von Standards neigen dazu, mehr Komponenten und Funktionalitäten zu integrieren. Folglich ist die Zahl der wesentlichen Patente, die auf IKT-Standards beansprucht werden, seit den frühen neunziger Jahren gestiegen (Simcoe, 2007).

Auch wenn SSOs versuchen die Interessen aller Marktteilnehmer zu vertreten, findet Koordination auch außerhalb der formellen Standardisierung statt. Dabei können sich Firmen bei sporadischen Treffen (Kerstan et al., 2012), oder in eher verbindlichen Allianzen koordinieren. Im Rahmen der IKT Standardisierung treten Firmen zunehmend informellen Industrie Allianzen oder Konsortien bei, die den formellen SSOs zuarbeiten. Dabei sollen besonders der Einfluss und die Kontrolle über die Entwicklung von Standard Spezifikationen erhöht werden. In Standard Konsortien treffen sich Firmen die ein gemeinsames Interesse an der Unterstützung und Weiterentwicklung bestimmter Technologien haben (Axelrod et al., 1995; Weiss und Sibru, 1990). Ziel ist es die Verhandlungspositionen, bei der Auswahl von Technologie Komponenten in der formellen Standardisierung, zu stärken. (Leiponen, 2008; Rosenkopf et al., 2001). Lerner und Tirole (2006) beschreiben so genannte „forum shopping“ Aktivitäten, bei denen Firmen wählen, in welches Standardisierungs-Forum sie ihre proprietäre Technologie einführen. Diese Wahl hängt von dem Wert der Technologie, sowie von den erwarteten Einnahmen ab. Blind und Gauch (2008) zeigen jedoch, dass Standard Konsortien und formelle SSOs eher koexistieren und weniger konkurrieren.

Während die Komplexität der standardisierten Technologien wächst, ist die Anzahl der sich beteiligenden Technologie-Anbieter ebenfalls angestiegen. Diese verfolgen oft sehr unterschiedliche Geschäftsmodelle (Simcoe et al., 2009). Dies kann die Kosten von Koordination steigern oder sogar zu Koordinierungsausfällen führen. Vor allem, wenn Unternehmen kommerzielle Anteile an Standards haben, können Interessenunterschiede Standardsetzungsverfahren verzögern oder sogar zu einem Zermürbungskrieg führen (Farrell und Saloner, 1988; Farrell und Simcoe, 2012). Konflikte und Unstimmigkeiten in SSOs sind oft damit verbunden, dass Unternehmen ihre eigenen patentierten technologischen Lösungen präferieren. Patente sind wesentlich für einen Standard, wenn eine Implementierung bzw. Durchführung notwendigerweise Patentansprüche verletzt. Auch wenn Patente nur für einen kleinen Teil des Standards verantwortlich sind, können die Inhaber von wesentlichen Patenten mit so genannten Hold-up Strategien den Einsatz einer ganzen Technologie blockieren (Lemley und Shapiro, 2006;. Farrell et al., 2007). Besonders in den letzten Jahren hat der unabdingliche Charakter von wesentlichen Patenten zu vielen Rechtsstreitigkeiten geführt

(Qualcomm v. Broadcom, Infineon v. Rambus; IP-COM v. Nokia, Apple v. Samsung, etc.). Dies hat die Aufmerksamkeit auf oft komplexe rechtlichen Fragen gelenkt, die sich mit Standardisierung und den grundlegenden Rechten des geistigen Eigentums befassen.

Farrell und Simcoe (2012) haben gezeigt, dass ein geeignetes IP-Regelwerk das eigeninteressierte Verhalten von Firmen verringern kann. In der Praxis formulieren SSOs Satzungen, um einen rechtlichen Rahmen zu schaffen, der den allgemeinen Umgang mit Patenten, die für die Standardisierung wesentlich sind, regelt. Dabei fordern SSOs ihre Mitglieder dazu auf, Patente, die sich möglicherweise als für die betreffenden Standards wesentlich erweisen, offen zu legen. Darüber hinaus müssen Inhaber dieser Patente eine Erklärung unterschreiben, dass diese Patente zu fairen, angemessenen und nicht diskriminierenden Bedingungen lizensiert werden (FRAND). Wenn eine Firma ein Patent offenbart und sich weigert, entsprechende Lizenzbedingungen zu unterzeichnen, wird die SSO in der Regel den Standard unter Ausschluss der geschützten Technologie spezifizieren (Lemley und Shapiro, 2006). Obwohl die Standardisierung oft in Zusammenhang mit komplexen Lizenzvereinbarungen steht, sind die Regeln für die Lizenzierung wesentlicher Patente nicht immer eindeutig. Dies führt nicht selten zu komplexen Diskussionen oder in Härtefällen sogar zu rechtlichen und politischen Untersuchungen.[2] Dennoch werden FRAND Verpflichtungen häufig als ein wichtiges Instrument gesehen, um wettbewerbswidrigem Verhalten Einhalt zu gebieten. Kartellbehörden bezeichnen FRAND Verpflichtungen als Heilmittel, um den Risiken potenzieller Wettbewerbsvorteile in der Standardisierung entgegenzutreten (Layne-Farrar et al., 2007; Farrell et al., 2007; Schmalensee, 2009).

Zusammenfassend lässt sich hervorheben, dass Unternehmen in der IKT-Standardisierung mit zwei entscheidenden Herausforderungen konfrontiert werden. Zum einen entwickelt sich die Koordinierung zwischen den Firmen als wesentlich anspruchsvoller und führt nicht selten zu einer Zusammenarbeit von konkurrierenden Marktteilnehmern, die gemeinschaftlich komplexe und anspruchsvolle Technologien entwickeln müssen. Zum anderen sind diese Technologien in vielen Fällen durch Patente geschützt. Standard wesentliche Patente sind Gegenstand eines neuen und anderen gesetzlichen Rahmens, der

[2] Am 31. Januar 2012 kündigte die Europäische Kommission an, ein förmliches Prüfungsverfahren über Unterlassungsklagen von Samsung auf Standard wesentliche Patente zu eröffnen. Samsung hat in diesem Zusammenhang einstweilige Verfügungen gegen eine Reihe von Konkurrenten, unter anderem Apple, eingeklagt. Die Kommission untersucht nun den Fall darauf, ob die Anordnungen von Samsung selbst eine Verletzung des Wettbewerbsrechts darstellt. Insbesondere soll untersucht werden, ob Samsung gegen die unwiderrufliche Verpflichtung, jedes wesentliche Patent unter fairen, zumutbaren und diskriminierungsfreien (FRAND) Bedingungen zu lizenzieren, verstoßen hat. Es ist zu prüfen, ob das Verhalten von Samsung einen Missbrauch einer marktbeherrschenden Stellung durch Artikel 102 des Vertrags über die Arbeitsweise der EU (AEUV) darstellt.

über die Regeln des geltenden Patentrechts hinausgeht. Diese Herausforderungen können die Anreize zur Entwicklung von IKT-Standards, sowie das Investieren in F&E oder das Anmelden von Patenten beeinflussen. Die sechs Aufsätze der Dissertation bauen auf bestehenden Literatur Befunden und theoretischen Implikationen auf. Das Ziel der Arbeit ist es, die Standard Dynamiken sowie Standard Generationswechsel in Interaktion mit wesentlichen Patenten zu analysieren. Weiterhin werden verschiedene Koordinations-Mechanismen rund um die Standardisierung betrachtet und der Einfluss auf Patentierung und F&E-Investitionen analysiert.

Wesentliche Patente können Anreize generieren, in Standards zu investieren, da zukünftige Lizenzeinnahmen Rückflüsse aus vorherigen Investitionen erzeugen. Jedoch kann erhöhtes Eigeninteresse Standardisierung verzögern oder zu einem Lock-in Effekt auf veraltete Standards beitragen. Die Rolle von SSOs ist es, den Übergang von Technologie-Generationen zu koordinieren. Teilnehmer der Standardisierung sind immer mit einem technologischen Wandel konfrontiert. In der Standardisierung wird somit regelmäßig zwischen dem Ersatz alter durch neue Standards und der Modernisierung bestehender Standards entschieden. Der erste Aufsatz *Essential Patents and Standard Dynamics* untersucht, wie diese Entscheidung durch die Einführung wesentliche Patente auf Standards beeinflusst wird. Mit einer Datenbank von über 3.500 verschiedenen IKT-Standards zeigt der Aufsatz, dass wesentliche Patente die Wahrscheinlichkeit für den Ersatz alter Standards reduzieren, jedoch die Geschwindigkeit, mit der Standards aktualisiert werden, erhöhen. Der Anstieg der Aktualisierung von Standard Versionen kann auf einen Anstieg der Investitionen von Unternehmen in die Verbesserung bestehender Standards zurückgeführt werden. Eine erhöhte Aktualisierung des Standards kann jedoch nur zum Teil die niedrigere Rate der Standard-Ersetzung erklären wenn wesentliche Patente den Standard betreffen. Andere Gründe für diesen Effekt könnten Konflikte und Eigeninteressen sein, die auf Grund von Standard wesentlichen Patenten entstehen.

Patent-Pools sind eine der wichtigsten Mechanismen, um die komplexe Lizenzierung von wesentlichen Patenten zu koordinieren. Pools kombinieren Patente, die unter einem einzigen Vertrag lizenziert werden. Dies kann die Transparenz erhöhen, die Transaktionskosten verringern, kostspielige Verletzungsklagen vermeiden und darüber hinaus, durch den Wegfall mehrerer Marginalisierungen, Vergütungssätze in Form von Lizenzen reduzieren. Der zweite Aufsatz *Patent Pools and Patent Inflation* untersucht das Patentierungsverhalten für Technologie-Standards, bei denen es Patent-Pools gibt. Es werden Daten von Unternehmen, die in der IKT-Standardisierung aktiv sind, verwendet, um das

Patent Verhalten rund um die Bildung von Patent-Pools zwischen 1992-2010 zu analysieren. Der Aufsatz nutzt dabei Informationen über die allgemein rechtliche Freigabe von Patent-Pools im Zeitraum 1997-1999, um in einen quasi experimentellen Test, die Reaktionen von Firmen auf das Entstehen von Patent Pools zu messen. Die Ergebnisse zeigen, dass Unternehmen eine direkte und positive Reaktion auf eine Pool-Entstehung aufzeigen, wenn der Pool vor 1999 gegründet wurde. Im Gegensatz dazu antizipieren Firmen die Entstehung eines Pools für die Jahre nach 1999. Diese Ergebnisse legen nahe, dass die rechtliche Sicherheit in den Jahren nach der Pool-Freigabe zu antizipierenden Effekten führt, während in Situationen juristischer Unsicherheit ein Patent-Pool einen prompten und direkten Effekt hat. Außerdem haben Tests den Nachweis erbracht, dass sich die Patentierung für Standards, die einen Pool haben in frühere Perioden verschiebt.

Der dritte Aufsatz *Attributes and Dynamic Development Phases of ICT Standards Consortia* untersucht die Entwicklung von Standard Konsortien im Bereich IKT. Der Aufsatz zeigt ein breites und umfassendes Bild der Standard Konsortien und untersucht ihre dynamische Entwicklung in den vergangenen zehn Jahren. Analysen zeigen, dass Konsortien spezifische Merkmale haben, die ihr Bestehen in der Standardisierungslandschaft rechtfertigen. Zusätzlich wurde die Evolution von Konsortien in den letzten Jahren beobachtet. Die Analyse zeigt Zusammenhänge zwischen der Bildung, Auflösung und Fusion von Konsortien mit Markt-und Technologieentwicklungen auf. Ergebnisse einer Performance-Analyse von Konsortien zeigen, dass die Wahrscheinlichkeit eines erfolgreichen Konsortiums vor allem auf Strukturen, die die Koordination zwischen den Mitgliedern bestimmen, zurück zu führen ist.

Der vierte Aufsatz *Joint Innovation in ICT Standards: How Consortia Drive the Volume of Patent Filings* untersucht den Einfluss von F&E-Investitionen in die Standardisierung, wenn Firmen Standard Konsortien beitreten. Der Aufsatz versucht aufzuzeigen, wie Konsortien das Volumen der F&E-Investitionen beeinflussen und ob dies effizient ist. Der Aufsatz zeigt, dass die Wirkung von der Stärke der Anreize von Unternehmen, den Standard zu entwickeln, abhängt. Konsortien Mitgliedschaft erzeugt höhere F&E-Investitionen, wenn ein zu niedriger Ertrag für wesentliche Patente eine Unterfinanzierung von Standards bewirkt. Diese Wirkung ist zwangsläufig pro-effizient. In Situationen, in denen ein zu hoher Ertrag aus wesentlichen Patenten erzeugt werden kann, haben Konsortien einen moderat steigenden oder sogar reduzierenden Einfluss auf F&E-Investitionen.

Der fünfte Aufsatz *Cooperate to Declare* analysiert die direkte Verbindungen von Unternehmen, die beide wesentliche Patente für einen Standard besitzen, und misst den Einfluss einer Ko-Mitgliedschaft in technisch verwandten und technisch weniger verwandten Standard Konsortien. Der Aufsatz überprüft empirisch, ob die Teilnahme an Konsortien die Fähigkeit eines Unternehmens erhöht, patentierte Komponenten in formale Standards zu integrieren. Die Ergebnisse zeigen, dass Mitgliedschaften in technisch verwandten Konsortien einen positiven Einfluss auf die Fähigkeit eines Unternehmens haben, patentierte Komponenten in formale Standards zu integrieren. Konsortien, die technisch weniger verwandt sind, zeigen keinen signifikanten Effekt. Die empirische Analyse zeigt außerdem, dass die Größe eines Konsortiums den Einfluss eines Unternehmens auf die formelle Standardisierung erhöht.

Der sechste Aufsatz *Essential Patents to Boost Financial Returns* untersucht, ob der Wert eines Standards den Return on Investment eines Unternehmens erhöht. Insbesondere wird untersucht, ob die Deklaration eines wesentlichen Patents Einfluss auf die finanzielle Performance von Unternehmen hat. Die Ergebnisse zeigen, dass das Verhältnis von Patent-Anmeldungen auf den 'Return on Assets (ROA) von Unternehmen krummlinig (umgekehrt U-förmig) ist. Dieser Effekt hält für ein Jahr und ist stärker für Deklarationen wesentlicher Patente aus Standard Konsortien. Des Weiteren wird das optimale Niveau von wesentlichen Patenten gemessen. Ergebnisse zeigen ein höheres Optimum für Deklarationen in formellen Standards. Die krummlinige (umgekehrt U förmige) Beziehung legt nahe, dass Unternehmen ihr Patent-Portfolio diversifizieren sollten um einen Teil der Patente in die Standardisierung eizuführen und einen anderen Teil in Technologien und Produkte zu integrieren, die außerhalb des Standards liegen.

Die Ergebnisse der sechs Aufsätze zeigen, dass wesentlichen Patenten eine besondere Rolle in der Dynamik von Innovationen zukommt. Wesentliche Patente beeinflussen den Generationswechsel von Standards und tragen zu Standard-Verbesserungen bei. Die Koordinierung der Lizenzierung von wesentlichen Patenten in einem Patent-Pool, ändert die Anreize zu Patententieren in Bezug auf Zeitpunkt und Volumen. Konsortien unterstützen F&E-Koordination und strategische Partnerschaften, die das Ergebnis der Standardisierung beeinflussen können. Somit wird gezeigt, dass Unterschiedliche Koordinierungsmechanismen im Kontext der Standardisierung, Standard-spezifisches Patent Verhalten beeinflusst. Wesentliche Patente beeinflussen außerdem den Wert eines Standards und damit die Struktur der finanziellen Erträge.

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Contents

Essential Patents and Standard Dynamics

Abstract

Information and Communication Technology (ICT) standards need to keep up with technological progress, while providing a stable basis for investment building upon the standard. Standard makers confronted with technological change can often choose between replacing old by new standards and upgrading existing standards. Studying the case of formal Standard Development Organizations (SDO), we investigate how this trade-off is affected by patents on standard components. Using a database of over 3,500 different ICT standards, we find that essential patents reduce the likelihood of standard replacement, but increase the rate at which standards are upgraded. We argue that the increase in the number of upgrades reflects an increase of firms' investment in improving existing standards. More frequent upgrades can only partly explain the effect of patents on the rate of replacement. Other explanations for this effect could be frictions and vested interests among standard setting firms.

Contents

1. Introduction

Technological standards include an increasing number of standard-essential patented technologies (Bekkers et al., 2012). A patent is called essential if it is necessarily infringed by any implementation of the standard. Recent contributions show that the inclusion of patented technology into a standard increases the value of the patent (Rysman and Simcoe, 2008). This increased value is an incentive for companies to adjust their patent filing strategies to ongoing standardization (Berger et al., 2012), and to build up strategic alliances in order to influence the selection process in standardization (Leiponen, 2008). The positioning of the firm even has a stronger impact on the inclusion of patented technology into a standard than the technological merit of the patent itself (Bekkers et al., 2011).

While these advances have improved our understanding of the incentives and strategies of firms contributing patented technologies to a standard, we know little about the consequences of essential patents for standardization and standard users. Essential patents can discourage standard adoption, because standard adopters fear to be held up by owners of essential patents and to be faced with exorbitant requests for royalties (Lemley and Shapiro, 2006). There is also the concern that a high number of patents leads to patent thickets (Shapiro, 2001) which hamper and slow down standardization processes. Standard setting involving proprietary technologies is often subject to tensions and diverging interest between participating firms (Garud et al., 2002). Vested interests in standardization due to increasing commercial stakes reduce the speed at which new standards are developed (Simcoe, 2012). Nevertheless, it is important to also see the potential benefits of essential patents for standardization. Once their proprietary technology included, firms have a private interest in improving the standard to protect it from being replaced by rival technologies. Holders of essential patents thus become platform leaders for the standard (Cusumano and Gawer, 2002), and have an incentive to sponsor standard adoption (Katz and Shapiro, 1986) and to promote coordinated technological change (Bresnahan and Greenstein, 1999, Cusumano and Gawer, 2002). As a result, essential patents may actually accelerate the technological progress of existing standards and encourage their implementation.

It is the aim of this article to have a more comprehensive understanding of the effect of patents on the evolution of standards after their release. Standards need to respond continuously to technological innovation, as outdated standards can become an impediment to technological progress. In order to integrate new technology, standard setters can often choose between replacement and upgrade of the existing standard. While a standard upgrade only incrementally improves upon an existing standard, standard replacement indicates a more radical change in the underlying technology. On the one hand, in presence of fundamental innovation, standard replacement may be necessary in order to fully integrate the advances in the state of the art. On the other hand, standard replacement can induce loss of backward compatibility and impose higher implementation costs upon standard users compared to standard upgrades. Based upon these insights, we investigate the frequency of upgrade and replacement of standards including essential patents, as compared to other standards.

We rely upon a comprehensive database of ICT standards released from 1988 to 2008. This dataset includes detailed information for over 3,500 *de jure* standards issued by formal standardization bodies. We match the standards in our sample to a comprehensive database of patents declared to be essential and furthermore inform for each standard class the speed of technological progress, as measured by the number of patent files in the related technological field.

Essential patents tend to concentrate on highly valuable, technology-intensive standards (Rysman and Simcoe, 2008). In order to deal with this bias, we construct an appropriate control sample based upon the characteristics of the standard and the technological field. Second, we estimate the hazard rate of standard replacement over time, controlling for relevant technological events. The results show that essential patents reduce the likelihood of standard replacement, but increase the likelihood of upgrade. While standard upgrades temporarily reduce the risk of standard replacement, the effect of essential patents on standard lifetime cannot be fully explained by more frequent upgrades. This finding provides support to the hypothesis that essential patents lock in existing ICT standards and hamper discontinuous change. In contradiction with widespread concerns regarding the effect of patent thickets on standardization, the effect of including essential patents is independent of the number of patents.

Our findings have several managerial implications. For potential standard adopters, essential patents can signal that the standards will be regularly improved and are less at risk of an early replacement. Essential patents could thus reduce technological uncertainty, increase standard related investments and encourage standard adoption. This positive effect of essential patents on standard adoption could counterweigh the well-known negative effects associated with the risk of patent holdup. For patent holders, this is an argument for transparent disclosure of essential patents, weighing against the profitability of “patent ambush” strategies and other incentives for late patent disclosure (Ganglmair and Tarantino, 2012). For standardizing firms, our findings have ambiguous implications on the costs and benefits of selecting patented technology. On the one hand, inclusion of patented technology provides the standard with sponsors who have incentives to invest in standard improvements. On the other hand, the inclusion of essential patents may give rise to vested interest and compromise future changes of the standard.

2. Analytical Framework

2.1 Inertia and momentum in the innovation of network technologies

Advanced ICT technologies often build upon thousands of complementary technological ideas that are individually invented, but brought to the market in a discrete number of "generations".[1] If a new, incompatible generation is brought to the market, users must decide whether or not to incur the switching cost in order to benefit from the newer technology. The value of the new technology to the users however crucially depends upon how many other users decide to switch. Markets where adoption decisions are made independently can therefore be subject to important coordination failures, such as lock-in of outdated technologies, or stranding of adopters of a new technology that fails to attract further users (Farrell and Saloner, 1986).

Adopters of a new technology require that the technology will be kept in place for a sufficient time to justify the costs of adoption. These adoption costs are sunk, and some users will not take the risk of adopting a new technology when there is uncertainty about future technological progress (Balcer and Lippman, 1984). However, if a substantial number of users switch to the new technology, users of the old technology are stranded and suffer from loss of network effects (Farrell and Saloner, 1985). It is therefore crucial for a provider of a new network technology that he can guarantee technological stability over some time. Too frequent innovations in the network are socially detrimental. Nevertheless, network technologies also exhibit a tendency to lock-in situations and excessive inertia. Once markets widely adopt a technology; switching costs and the risks of lock-in increase (Arthur, 1989). This lock-in can be the result of the installed base of the whole technology, but also of specific network ties resulting from the adoption rate of specific components (Suarez, 2005). New technologies may thus be introduced at a too low frequency, and the users and

[1] Generations of mobile phone standards are good examples for this process. Since the release of its first specifications in 1990, the GSM standard has continued evolving in order to integrate new functionalities, for instance related to mobile internet connection. Nevertheless, in order to obtain more significant increases especially in data transmission rates, UMTS, a new standard building upon a very different coding technology, had to be developed (Bekkers, 2001, Bekkers and Martinelli, 2012)

implementers of the technology incur the opportunity cost of not using the best technology available.

Lock-in of installed technologies does however not necessarily prohibit technological progress. An installed dominant design can be subject to substantial and sustained incremental progress (Abernathy and Utterback, 1978). This incremental progress follows trajectories defined by the technological paradigms of the underlying technological basis (Dosi, 1982). In contrast with these continuous technological changes along a given trajectory, a discontinuous technological change is the shifting to a superior trajectory. Christensen and Bower (1996) show that established market leaders tend to lose their leadership position when they face a discontinuous technology change. Christensen et al. (1998) provide evidence that in the case of continuous progress of a dominant design or standard, firms may retain their market positions throughout the successive technological generations. Technological incumbents thus have incentives to promote and favor continuous technological progress and to prevent discontinuous changes (West and Dedrick, 2000). The lock-in of a dominant design may however be socially detrimental, if it permanently prevents shifting to a different, more promising technological trajectory.

The socially optimal rate of discontinuous technological change strikes a balance between the discrete costs of developing and adopting new technologies on the one hand, and the continuous opportunity cost of using an outdated technology or moving along an inferior technological trajectory on the other hand. Uncoordinated deployment and adoption of new network technologies can deviate from this socially optimal rate in both directions, yielding either excessive inertia or excessive momentum (Farrell and Saloner, 1985). Liebowitz and Margolis (1995) argue that excessive inertia or momentum can be avoided if technology is proprietary. Katz and Shapiro (1986) show that the owner of a proprietary technology has an incentive to sponsor adoption costs, thereby contributing to the efficiency of standard adoption processes. Clements (2005) however finds that the incentives of an owner of a proprietary technology to have a new standard adopted deviate from what would be socially optimal and can induce excessive inertia or momentum.

2.2 Formal standardization as coordination device

Most inefficiencies in the rate of discontinuous technological change in network technologies result from the lack of coordination between the users of the technology. Often, these inefficiencies can be overcome if users can communicate and coordinate adoption decisions (Weitzel et al., 2006). In practice, coordination on adoption decisions in network technologies takes place inside more or less formal standard bodies. Participation in this collaborative standard development is a crucial factor for the success of companies in technology intensive industries (Fleming and Waguespack, 2008). Coordination on standards ensures compatibility and substantially reduces the risk for the developers and adopters of new technology (Tassey, 2000, Aggarwal et al., 2011). The different generations of technology are embedded in different generations of standards. The issuance and adoption of a new standard thus determines the common adoption of thousands of complementary technological inventions resulting in a new technological platform[2]. This process can take place more or less frequently, and the technological progress incorporated in a new standard can be more or less important.

The economic literature has addressed the issue of inertia and momentum in standard replacement mainly for the case of uncoordinated adoption decisions[3]. Timing is however a crucial problem also for formal standardization. Formal standardization results in better coordination on the best technology, but comes at the cost of decreased speed (Farrell and Saloner, 1988). Formal standard setting bodies face an important tension between responding to an advancing technological frontier and fixing a stable technological basis for creating compatible products and investing in applications and implementation (Egyedi and Hejnen 2005, Blind and Egyedi, 2008). Technological change exerts a constant pressure on standard setting bodies to revise existing standards. Consistently, an empirical analysis of factors influencing the lifetime of national ICT standards (Blind, 2007) has revealed that standard survival time decreases with the speed of innovation, as measured by patent files in ICT in the respective country.

While standard bodies coordinate on adoption decisions, both advances in the technological frontier resulting in opportunities for new standard generations and the development of improvements and implementations of existing standards are subject to independent investment decisions. Coordinated adoption decisions may be insufficient to prevent excessive inertia or excessive momentum, if there is no coordination on the complementary investment. Investment in R&D for new standards or applications of existing standards is subject to competition, complex strategic alliances (Leiponen, 2008) and potential coordination failures (Baron et al., 2011). The incentives of firms to invest in R&D and to develop applications are shaped by the extent to which technology holders can use patents to appropriate important parts of the value generated by the standard.

[2] For recent case studies of the interplay between standardization and innovation, see Bekkers and Martinelli (2012) and Fontana et al. (2009).

[3] Farrell and Saloner (1985, 1986), Katz and Shapiro, (1992), De Bijl and Goyal (1995), Kristiansen (1998)

2.3 The role of essential patents

Essential patents play an important role in standardization, as they provide incentives for firms to develop technologies for standards and to contribute to the effort of standardization. Standardization entails a costly private investment into a public good (Kindleberger, 1983). Due to this externality, standard makers underinvest in developing and improving standards. The prospect to include their proprietary technology into technological standards is an important incentive for firms to increase their investment in standardization (Rysman and Simcoe, 2008). Patent holders also have a stronger private interest to invest in improvements of existing standards if they can recoup the costs through licensing fees. Standards are a good illustration of the argument raised by Kitch (1977) that Intellectual Property Rights are important for innovation not only as a reward for successful innovators, but also to ensure incentives in continuous investment in improving the protected technology. Empirical findings show that patents reduce uncertainty to incur investments that are complementary to a specific technological choice (McGrath and Nerkar, 2004, Arora et al 2008). However, there is so far no evidence for such effects of patents that are essential to standards. The incentive for owners of essential patents to regularly upgrade a standard is expected to be particularly strong when the technological evolution in the sector generates pressure for standard replacement. Holders of essential patents have an incentive to develop and advocate continuous marginal improvements that avoid challenges from incompatible rivaling technologies. West and Dedrick (2000) and Dedrick (2003) show that IPRs are an important tool for allowing the owner of a platform to control a coherent evolution of the platform architecture. If the inclusion of essential patents signals that the standard will be regularly improved, but faces less risk of replacement, essential patents could also be a valuable commitment device that encourages standard implementation and reduces welfare losses from under-investment in standard adoption.

In spite of these virtues, essential patents have also drawbacks for standardization. For instance, patents on formal standards can generate conflicts among standard makers regarding the shares of proprietary technology covered by the standard. Evidence for this concern can for instance be found in the survey which is part of the "EU Study on The Interplay of IPR and Standards". Surveyed practitioners see consensus reaching and the speed of standardization processes to be the most negatively affected fields when essential IPRs are introduced to a standard (Blind et al., 2011). Essential patents can lead to a time-consuming « war of attrition » in building consensus on a new standard (Farrell and Simcoe, 2012; Simcoe 2012). Practitioners report cases in which holders of patented technology "*would only* *agree to a certain standard if they are allowed to integrate their technology, which makes the standardization process more complex and time-consuming and sometimes even induces errors on products*"[4]. Conflicts between holders of technology are even more likely to delay standard replacement than the development of a completely new standard. As formal standard development is, at least in principle, a consensus decision, owners of components of the existing standard can oppose to any standard replacement unless they are fully compensated by sponsors of the new standard.

If holders of standard essential technology exercise a high degree of control over a standard, they may on purpose "kill off" the incumbent technology by introducing new versions which are not backward compatible (Iizuka, 2007). For the case of network externalities Waldman (1993) and Choi (1994) show that firms' incentives to introduce incompatible new products are too high compared to what is socially optimal. These strategies of planned obsolescence are especially beneficial in monopoly situations such as the case of holders of essential patents (Choi, 1994). However, in the case of formal standardization, the rules of standard setting organizations require consensus decision making. While consensus decision making allows single players to oppose to changes and thus to delay or prevent releases of new standards, even dominant firms would not have the means to enforce planned obsolescence against the interests of other participants.

From the academic literature and practitioner statements, we thus draw the following hypotheses: first, essential patents allow some degree of internalization of the costs of standard improvements and therefore provide incentives for patent holders to invest in standard upgrades. These incentives are particularly strong if investing in standard upgrades is a way of reducing the risk of obsolescence and replacement by a different standard.

> **Hypothesis 1:** *The inclusion of essential patents induces incentives to invest in continuous technological progress, which results in more frequent standard upgrades.*

Second, the continuous upgrade of standards delays standard obsolescence. Furthermore, holders of essential patents have an incentive to oppose standard replacement and exclusion of their proprietary technological components from the standard. Both factors concur, and essential patents are expected to delay standard replacement.

[4] The interview with Dr. Ivstan Sebestyen held in April 13th 2010 was conducted in the context of a fact finding."EU study on the Interplay of IPR and Standards". Ivstan Sebestyen has been involved in the worldwide multimedia standardization work for over 20 years including telecommunication standardization experience in CCITT, ITU-T, ISO/IEC, ETSI and DIN and ITU-T and still picture coding (JPEG, JBIG).

> **Hypothesis 2**: *The inclusion of essential patents increases the persistence of existing standards and reduces the risk of standard replacement and discontinuous technological change.*

We will test these hypotheses empirically using comparative and econometric analysis.

3. Empirical Methodology

3.1 Identifying standard upgrades and replacements

We analyze the rate of standard upgrade and replacement using a comprehensive database of international ICT standards drawn from PERINORM. PERINORM is the world's biggest standard database with bibliographic information on formal standards and is regularly updated by the SDOs DIN, BSI and AFNOR. We include all ICT standards (ICS classes 33 and 35) issued by the main formal international SDOs (ITU-R, ITU-T, IEEE, ISO, IEC, JTC1). We restrict the analysis to *de jure* standards issued from 1988 to 2008, and we observe these standards until 2010. We start in 1988, because the *International Telecommunication Regulations* issued in 1988 constitute an important policy change, leading to changes in the way standards are released. Draft standards, amendments and errata documents as well as technical reports and other documents produced by SDOs that are not standards are screened out using the document codes in the name of the document. This yields a sample of 7,625 standards. For the econometric analysis, we furthermore restrict the sample to technological fields where there is a potential for essential patents (fields in which at least one standard includes essential patents) and exclude standards with missing explanatory variables. This sample comprises 3,551 standards, 4,671 standard versions and 36,179 standard-year observations. 367 standards and 1,709 standard versions included in this sample have been withdrawn during the observation period.

For every standard version, the database gives precise dates of release and withdrawal. SDOs regularly revise their standards to keep up with technological progress. During the revision, „*a majority of the members of the TC* (Technical Committee) *decides whether the standard should be confirmed, revised or withdrawn*"[5]. We can observe withdrawal of standard versions in PERINORM, and identify new versions of the same standard using PERINORM information on standard history. To give an example, the MPEG2 Video standard version ISO/IEC 13818.2(1996) was withdrawn in 2000 and replaced by

[5] http://www.iso.org/iso/standards_development/processes_and_procedures/stages_description.htm

ISO/IEC 13818.2(2000)[6]. This new version consolidates several corrigenda and amendments made to the standard since the release of the first version in 1996. New encoders or decoders produced according to the new standard are fully compatible with media or devices produced according to the previous version. We consider that in such a case where a standard version is replaced by a more recent version, the standard is revised and simply upgraded. These upgrades reflect continuous technological change along the technological trajectory defined by the standard and the embodied technological basis.

If a standard version is withdrawn without a direct successor, we consider that the standard is replaced. In practice a standard is generally not withdrawn immediately when a new generation of standards is released. For example, several generations of mobile phone standards (GSM and UMTS) and audio and video coding standards (MPEG2 and MPEG4) currently coexist. Nevertheless, evolution and deployment of new generations eventually lead to the earlier standard being withdrawn. The SDOs point to technological progress of as a main reason for withdrawing standards: *"Several factors combine to render a standard out of date: technological evolution, new methods and materials, new quality and safety requirements[7]"*. Earlier research (Blind, 2007) and our own empirical analysis confirm the direct link between standard withdrawal and related technological innovation. We therefore use the withdrawal of a standard version without direct successor to indicate standard replacement, a discontinuous technical change that renders the standard obsolete.

We can thus differentiate between standard upgrade and standard replacement and calculate the survival rate of standards and standard versions. The survival time of standard versions is hereby defined as the time from version release to version withdrawal, and the survival time of standards is the time elapsed between release of the first standard version and standard replacement. We investigate the effects of our explanatory variables on these rates using duration analysis.

In the case of our example, the standard ISO/IEC 13818.2 is part of a group of standards that are closely related. Indeed, this standard defines the video coding technology of MPEG2, which also includes other components dealing e.g. with audio coding. These connections between standards lead us to worry that the survival rates of the different observations in the sample are not determined independently, and that failure to account for

[6] MPEG2 is a widely used coding technology for video and audio content. For an overview of the second edition, see http://webstore.iec.ch/preview/info_isoiec13818-2%7Bed2.0%7Den.pdf

[7] http://www.iso.org/iso/standards_development/processes_and_procedures/how_are_standards_developed.

this could overstate the significance of the results. In order to account for this, we define clusters of standards that can be identified as belonging to a common family of standards[8].

3.2 Explanatory variables

We match the standards in our sample to a database of declared essential patents. Declarations of essential patents have been downloaded from the websites of the SDOs in March 2010. The declaration of patent essentiality is made by holders of the patents, and no external validation of this essentiality claims is made. There is furthermore no guarantee that all essential patents are accurately declared. The existing literature has nevertheless found that declared essential patents are a reasonable proxy for essential patents, and that the date of declaration proxies the date of inclusion into a standard (Rysman and Simcoe, 2008). In the following we will speak of essential patents, empirically approximated by our database of patent declarations. We identified more than 8,000 patent declarations for 700 formal standards included in our sample. In order to analyze the effect of essential patents on the rates of standard upgrades and replacements, we can then compare the respective survival rates of standards and standard versions including essential patents with standards in the remainder of the sample. This comparison is however subject to several potential biases. Essential patents could indicate that a standard has a stronger focus on innovative technology, and is thus subject to faster changes in the state of the art. On the other hand, patent holders may prefer declaring essential patents on standards with a long expected lifetime. Finally, declarations of essential patents could also signal the importance, technological complexity or commercial relevance of a technological standard. All these factors are likely to have an impact upon the survival rate of standards and standard versions.

We therefore make use of a broad range of technological indicators including the issuing SDO, the ICS (International Classification of Standards), the breadth of the technological scope (approximated through the number of ICS classifications, which we will refer to as "*ICS width*"), the number of pages, standard modifications, and references to prior standards (*backward references*). We also count accreditations of the standard that have taken place before the standard release at the body in our sample (*prior accreditations*). This happens when the standard has not been first issued by one of the SDOs we observe (for example if a national standard is accredited on international level). These standard characteristics are time-invariant, and are therefore particularly suitable for the construction of

[8] We identify clusters using the number until the dots in the case of ISO, IEC, and JTC1, until the slash for ITU-T and ITU-R, and using only the numbers and not the letters in case of IEEE (e.g. IEEE802.11n is identified as belonging to IEEE802.11)

a control group of standards whose evolution over time can be compared with standards including essential patents.

However, this sampling approach is not effective to control for time-variant factors and to analyze the interplay between essential patents and standardization dynamics. In a second step we will therefore propose a multivariate panel analysis, where explanatory variables are allowed to vary over time. In the majority of cases, the patent declaration database informs the date of declaration, so that we can match each of these essential patents to its relevant standard at any time from the year of declaration.

We approximate the evolution of the state of the art using information drawn from essential patents. Building upon Baron et al. (2011), we use the technological classification of declared essential patents to match patent and standard classes in the field of ICT. We can thus identify how many patents are filed in fields that are potentially relevant for the standards in the different ICS classes. Thus we can inform for each standard class on a relatively disaggregate level the speed at which the state of the art evolves (in the following, we refer to this variable as "*innovation intensity*"). Blind (2007) has shown that the replacement rate of national ICT standards increases with the number of ICT patent files in the respective country. In our data, we can identify innovation rates that are more closely related to specific standards. The yearly patent files in the related field indicate the flow of standard-related inventions. Following Hall et al. (2000) and Bessen (2009)[9], we accumulate these yearly flow data to a standard-related knowledge stock which depreciates at 15% per year. This knowledge stock approximates the "*technology gap*" or distance of the standard to the technological frontier. We assume that a new standard release fully integrates the advances in the state of the art, so that the technology gap is set back to zero.

It is also important to control for standardization activities related to the standard that are likely to have an impact on the probability of standard replacement. We build a variable indicating changes to referenced standards upon which the standard is built (*change of referenced standard*). Changes upstream in the technological architecture are a decisive factor of changes of depending downstream standards. For the same reason, we include references from other standards (*forward references*) and accreditations by other SDOs (*ulterior accreditations*). As these downstream standards need to be replaced when the standard itself is replaced, forward references and accreditations increase the social cost of standard

[9] Park and Park (2006) provide a list of industries and estimate the depreciation rate of related patents. ICT standards of our sample can be categorized to the industry code 17: Electrical machinery and apparatus n.e.c. (ca. 14%) as well as the industry code 18: Radio, TV and communication equipment and apparatus (ca. 16%).

replacement. These variables are likely to capture up to some extent downstream investment building upon the standard. A full list of variable definitions is provided in Appendix 1.

3.3 Sampling

It is the objective of our analysis to compare standards including essential patents with other standards. However, essential patents are not randomly distributed over the standards in ICT. Many of the factors affecting the likelihood of including essential patents are also likely to have an impact on the duration until standard upgrade and replacement.

We therefore build an appropriate control group in order to be able to present meaningful descriptive statistics. First, we eliminate standards issued before 1988. We then carry through a propensity score matching based upon a broad range of observable fixed standard characteristics. The determinants of the inclusion of essential patents can be classified into three groups: first, several technological variables can be used as indicators of complexity or value. For instance, the number of standard pages is an indicator of the size of the standard, and the technological complexity of the issues that it addresses. Being referenced by other standards in the first years of standard life is an indicator of the relevance of the standard for further technological applications. We use a reference window of four years, by analogy to the common practice of citation windows as indicators of patent significance (Trajtenberg, 1990). Second, technological classes of standards capture whether a standard is in an innovative and patent-intensive field, or rather in less innovative fields, where essential patents are less likely to occur. Third, the issuing SDO has a statistically significant impact upon the likelihood that the standard includes essential patents. This could be due to more or less stringent rules regarding the declaration of IPR, but it could also reflect the fact that standardizing firms target patent-friendlier standard bodies as a forum for a standards project when they own proprietary technology that they wish to have included (Chiao et al., 2007). Appendix 1 presents the results of the regressions through which the propensity scores were calculated, and depicts the repartition of the propensity scores over standards including essential patents and other standards.

Building upon this propensity analysis, we eliminate the observations that have a lower propensity score than the treated observation (standard including essential patents) with the lowest propensity score. We then group the remaining observations into six strata of equal size[10]. Appendix 1 provides details of the calculation of propensity scores and gives an overview how standards are distributed over the different strata. The propensity scores increase with ascending strata numbers. The share of standards including patents increases from strata to strata, reflecting that the model is somehow successful in identifying the factors explaining inclusion of essential patents.

4. Comparative Analysis

In this section, we will present results of a comparative statistical analysis. We first compare the survival rates of standard versions including essential patents with other standard versions. Figure 2a shows the Kaplan-Meier estimates of the likelihood that a standard version has not been withdrawn by a certain time (indicated in years after release). Survival rates of standard versions including essential patents decrease more rapidly than those of other standard versions (Figure 3a). This figure does however not indicate whether the observed difference is a causal effect of essential patents, or whether essential patents are more likely to be declared for standard versions that would have had lower survival rates anyway. For instance, we could expect that patents are more likely to be declared on more important standards or on standards that are more responsive to technological change. Figure 2b corroborates this concern. Comparing the survival estimates of the different strata (strata 1 with the lowest likelihood of essential patents, strata 6 with the highest), we observe that standards a priori most likely to include essential patents are upgraded more often.

[10] According to Caliendo and Kopeinig (2008), five strata are often enough to remove the bias from the data. As our propensity score is very skewed, five strata are not enough to equalize all important variables among control and treated within the strata, but more than six strata would leave us with very small numbers of treated standards in the lower strata

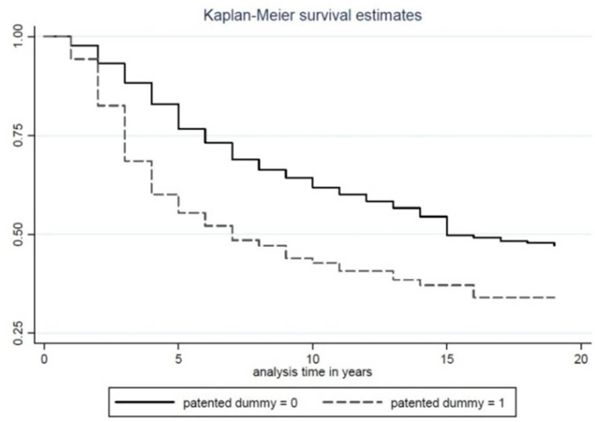

Figure 2a: Survival estimates of standard versions, including and not including patents

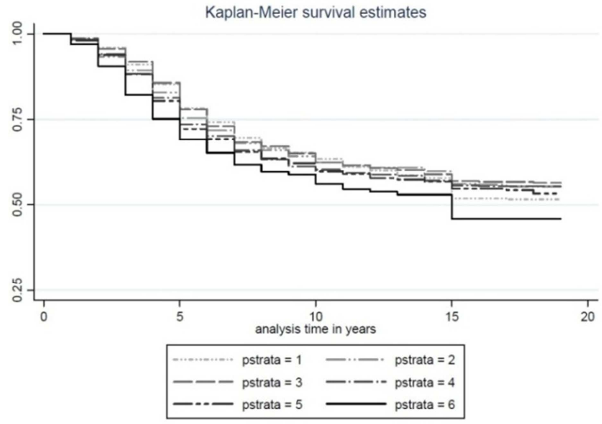

Figure 2b: Survival estimates of standard versions, by strata

In order to control for this selection effect, we have to make the comparisons within the strata. Table 1 displays results of a log-rank test of equality of survivor functions of standard versions. We observe the withdrawal of 391 standard versions including essential patents. If essential patents had no effect on standard version survival, we would expect only 225 versions to be withdrawn during the observation period. Carrying through the analysis by strata of propensity scores even exacerbates the difference between the observed and expected standard version survival rates[11]. Significant differences are observed within all the strata, except for strata 1 and 2, where numbers of standards including essential patents are very low.

Version Upgrade		Stratified by SDO and ICS	Stratified by 6 PSM strata	Within Strata 1	Within Strata 2	Within Strata 3	Within Strata 4	Within Strata 5	Within Strata 6
	Events								
Patented	Obs: *Exp:*	391 *225.50*	350 *192.20*	3 *3.20*	14 *9.55*	47 *17.16*	57 *21.25*	79 *39.07*	150 *101,98*
Non-patented	Obs: *Exp:*	5147 *5312.50*	2131 *2288.80*	421 *420.80*	473 *477.45*	392 *421.84*	349 *384.75*	250 *289.93*	246 *294,02*
Chi2 Pr>chi2		140,75 0,0000	167.29 0.0000	0.01 0.9076	2.29 0.1304	58.30 0.0000	67.73 0.0000	48.91 0.0000	32.70 0.0000

Table 1: Log-rank tests of equality of version survival functions Standards including and not including patents, by strata, within strata

We have discussed that standard versions can be withdrawn in cases of either standard upgrade or standard replacement. We will therefore compare the survival rates of standards. The survival time of a standard is defined as the time elapsed between release of the first version and withdrawal of the last version of the standard (standard replacement).

[11] Some observations are excluded because of missing values. Notice also that we excluded all standards with a propensity score that was lower than the lowest score of a standard including patents.

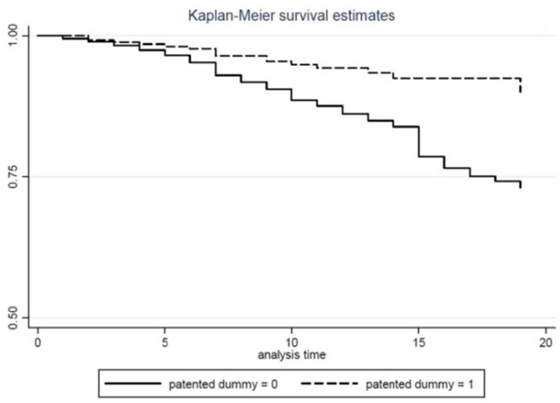

Figure 3a: Survival estimates of standards, including and not including patents

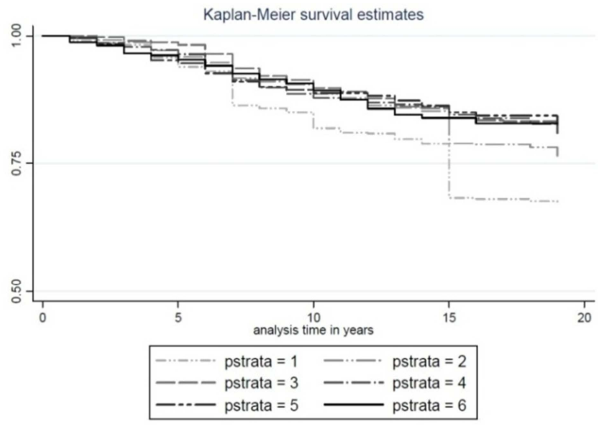

Figure 3b: Survival estimates of standards, by strata

We can see on Figure 3a that the survival estimates of standards including patents decrease slower than what can be observed for other standards. On figure 3b, we see the survival estimates by strata. Standards that are – based upon their observable characteristics – least likely to include essential patents (Strata 1 and 2) have significantly lower survival estimates. Patents are thus more likely to be declared on standards with a longer expected lifetime. To account for this selection effect, we once again carry through the comparison by strata. We observe 22 replacements of standards including essential patents. Had these standards the same survival functions as other standards, we would expect 67 standard replacements. If we carry out the comparisons by strata, we remove the selection bias based upon observables. The number of expected replacements decreases to 42, which is still much higher than the observed 21. There is thus strong evidence for inequality of survivor functions. Differences are statistically significant within strata 5 or 6. The numbers of standards including patents are probably too small in the other strata to yield reliable results.

Standard Replacement		Stratified by SDO and ICS	Stratified by 6 PSM strata	Within Strata 1	Within Strata 2	Within Strata 3	Within Strata 4	Within Strata 5	Within Strata 6
	Events								
Patented	Obs: *Exp:*	22 *66.92*	21 *41.89*	2 *1.17*	0 *2.61*	2 *3.25*	5 *4.73*	3 *9.93*	9 *20.21*
Non-patented	Obs: *Exp:*	1864 *1819.08*	714 *693.11*	201 *201.83*	150 *147.39*	108 *106.75*	99 *99.27*	85 *78.07*	71 *59,79*
Chi2 Pr>chi2		32.87 0.0000	12.41 0.0004	0.61 0.4349	2.67 0.1021	0.49 0.4818	0.02 0.8985	5.48 0.0193	8.34 0.0039

Table 2: Log-rank tests of equality of standard survival functions Standards including and not including patents, by strata, within strata

The comparative analysis thus indicates that standard versions including essential patents have a shorter expected lifetime, while standards including essential patents have a longer expected lifetime than comparable standards. These findings are consistent with our two hypotheses: essential patents induce more frequent standard upgrades, while reducing the likelihood of standard replacement.

Standards including essential patents have significantly higher survival rates in all SDOs except IEC. The number of IEC standards including essential patents is very low, and only two IEC standards including essential patents have been withdrawn in the observation period. Also the difference regarding standard versions does not seem to depend upon the identity of the issuing SDO. The survival rate of standard versions including essential patents is significantly lower for all standard bodies with a large number of standards including essential patents. There are no significant differences only in the groups of standards issued by ITU-R and ISO.

4.1 Robustness analysis

The stratified analysis removes the bias based upon observable standard characteristics. We might worry that the remaining, unobservable explanatory factors of patent declaration could also have an influence on standard upgrades and replacements. Our matching of standards based upon the technological class or the issuing SDO, while ruling out that these observable factors affect the comparability of standards, could actually have increased the difference between standards in terms of unobservable characteristics. If standards in patent-intensive technologies and issued by patent-friendly SDOs nevertheless do not include any essential patents, they are likely to be different in some other, unobservable respect from standards actually including patents. For instance, we risk comparing important standards with less important standards. If our control variables are unable to control for these factors, it might be preferable to compare standards including essential patents with other standards that do not include essential patents because of observable characteristics, such as the technological field or the issuing SDO.

Based upon this reasoning, we can construct three different control groups. The first group includes the standards in the same technological field (ICS) as standards including essential patents (list in Appendix 2), but issued by SDOs having few declarations of patents (ITU-R, ISO and IEC, see Appendix 2). The second group includes standards in ICS with few patents, but issued by SDOs issuing many standards including patents (ITU-T, JTC1 and IEEE). The third group consists of standards in patent-intensive ICS issued by SDOs with many essential patents. The latter group is over-represented in the upper strata of the comparative analysis, but might be a bad control group based upon unobservable standard importance or commercial relevance. No control group is perfect. But each control group is different from the standards including essential patents for a different reason, and having several control groups allows us analyzing whether our control variables account for the unobserved biases (Rosenbaum, 1987).

Comparing survival estimates between the group of standards including patents and the three control groups, we find very significant differences not only between our standards of interest and the controls, but also among control groups. If however we stratify by the technological indicators used in the propensity score estimation (including the share of IT and Telecom standards and the years of standard release) statistically significant differences among control groups disappear (see Appendix 2). This indicates that these variables can account for the relevant bias in the data (Rosenbaum, 1987). Even accounting for the technological characteristics of standards, differences between standards including essential patents and the controls remain strongly significant[12].

5. Multivariate Panel Analysis

5.1 Estimation

The comparative analysis has revealed that standards including essential patents are less likely to be replaced, but more frequently upgraded. We will next proceed to an econometric analysis. This research framework allows us analyzing the effects of essential patents on standard upgrades and standard replacement, as well as the interactions between the rates of standard upgrades and standard replacements. First, on the version level, we estimate the risk of the version to be withdrawn (model 1). Analysis time in this setting is time elapsed since version release, and the estimated failure of the observation is withdrawal of the standard version. The withdrawal of a standard version can be explained either by standard upgrade or standard replacement. We can then differentiate between the effects of essential patents on the competing risks of standard upgrade and standard replacement (model 2). The two events exclude each other, and we speak of competing risks. SDOs face a choice between upgrade and replacement. We will analyze separately this choice using a logit model (model 3):

[12] Applying the analysis to standard upgrade, we find that the bias is X-adjustable between the samples of standards issued by the same SDOs (in patent-intensive or other technological fields). Other SDOs upgrade their standards less often, even accounting for technological characteristics. This leaves us with two valid control groups, displaying very significant differences with the standards including patents (Appendix 3, Table 13).

conditional upon a version being replaced, we analyze how essential patents affect the likelihood of standard replacement rather than upgrade.

The effects of patents on standard replacement can then be studied on the standard level (model 4). In contrast to the previous analysis, the unit of observation is the standard, and observation time is from the release of the first until withdrawal of the last version. In model 5, we take into account releases of the different versions as events affecting the survival rate of the standard. It is possible to analyze the risk of standard replacement using two different ways of controlling for upgrades: first, we introduce a variable counting the number of upgrades. Second, we include a variable indicating the time elapsed since the last upgrade. As the time elapsed since first release of the standard is used for the baseline hazard, this version age variable indicates the effect of failure to upgrade on the risk of standard replacement. The comparison between Models 4 and 5 allows estimating whether controlling for upgrades captures the effect of essential patents on standard replacement.

The effect of the variables is tested using a Cox model, a semi-parametric survival analysis. In the Cox model, the likelihood of withdrawal (hazard) is estimated year by year, conditional upon the fact that the version or standard has not already been withdrawn. The estimated hazard is a multiplicative of a baseline hazard $h_0(t)$, varying over time, and the covariates multiplied by constant coefficients:

$$h\ (t|x_{j,t}) = h_0(t) \times \exp(x_{j,t}\beta_x)$$

$h_0(t)$ and covariates $x_{j,t}$ are allowed to vary over time, but estimated coefficients β_x are constant over the time of observation. The Cox model therefore rests upon the Proportional Hazard (ph) assumption that the real effect of the covariates is independent of the observation time. We are unwilling to make this assumption for several factors expected to have important and not necessarily linear effects on the timing of standard withdrawal. This is the case for the issuing SDO, the technological field, and the period of standard release. In order to control for these factors, we use stratified survival analysis. In stratified survival analysis, the observed individuals j are classified into strata j. The baseline hazard rate is allowed to vary between the strata, but the effect of the explanatory variables is jointly estimated in all strata. We stratify jointly by SDO, ICS class and cohorts of standards released before and after 2001.

$$h\ (t, i, x_{j,t}) = h_0(t|i) \times \exp(x_{j,t}\beta_x)$$

The remainder of the variables is included as covariates $x_{j,t}$ in the Cox model. We test for the functional form of the variables using the residuals of a stratified null model. It results that the count of forward and backward references has non-linear effects on withdrawal rates, and we transform these variables in log. For the remaining variables, we see no indication of non-linear effects. We then estimate Cox models including all variables and interaction terms between variables and observation time. Insignificant interaction terms and variables are progressively dropped. Finally we test the ph hypothesis for all the chosen models. Even including interaction terms, these tests reject the ph hypothesis unless we further stratify the sample. We therefore stratify standards by ranges of standard size (number of pages), and standard versions by their position in the series of successive versions (e.g. first version, second version, and so on).

The effect of patents can be estimated in various ways. First, we test for the effect of including essential patents or not. This is done via a dummy variable which is one if at least one essential patent has been declared ("Patented"). Second, we count the number of patents declared over time, and include this count as a second explanatory variable ("Patents_cumulative"). The results are presented in Table 3[13]. We report hazard rates, which can be obtained from the estimated coefficients as $hr_1 = \exp(\beta_1)$. The hazard rate of *patented* can then be interpreted as the factor by which the hazard of version withdraw or replacement is multiplied if a standard includes essential patents, all other variables being held constant:

$$hr_{patented} = \frac{h_0(t|i) \times \exp(x_{j,t}\beta_x + \beta_{patented})}{h_0(t|i) \times \exp(x_{j,t}\beta_x)}$$

[13] The number of subjects at risk reported by the competing risk model is twice the number of standard versions, as each version faces two different risks. In the logit model, SDO and technology fixed effects are controlled for using dummy variables (coefficients not reported)

	Version survival		Replacement vs Upgrade	Standard survival	
Variable name	Model 1 Cox Regression	Model 2 Competing risk Cox	Model 3 Logit	Model 4 Cox regression	Model 5 Cox regression
Patented	1.41036*** z: 3.62		-1.26969*** z: -2.61	0.39669** z: -2.22	0.43528** z: -1.99
Patented* Upgrade		3.70638*** z: 6.60			
Patented*Re-placement		0.02290*** z:-5.85			
Patented* Upgrade_age		0.92696* z: -1.85			
Patented*Re-placement_age		1.34151*** z: 3.69			
Patents cumulative	1.00207 z: 1.33	1.00214 z: 1.34	-0.02486 z:-0.73	0.98842 z: -0.70	0.98697 z: -0.78
Technology gap	0.48055* z: -1.83	0.52004* z: -1.67	-0.12399 z: -0.68	0.89398 z: -0.51	0.63356 z: -0.98
Technology gap_age	1.10171* z: 1.84	1.09155* z: 1.69		1.04837** z: 2.03	1.00752 z: 0.14
Innovation Intensity	3.03448 z: 1.33	2.87475 z: 1.28	1.34117* z: 1.82	0.16776 z:-1.50	0.41715 z: -0.65
Innovation Intensity_age	0.98418 z: -0.12	0.99139 z: -0.07		1.69143*** z: 3.10	1.81033*** z: 3.21
log(Backward references)	0.90803*** z: -3.08	0.90924*** z: -3.00	-0.04919 z: -0.62	0.85831* z:-1.89	0.86837* z:-1.76
Change of refe-renced standard	1.01430 z: 0.27	1.01369 z: 0.26	0.20009*** z: 3.26	1.58315*** z: 7.45	1.61017*** z: 8.00
Change of referenced standard_age	1.06194*** z: 4.88	1.06241*** z: 5.01			
log(Forward references)	1.06194*** z: 5.31	1.21710*** z: 5.50	-0.50629*** z:-5.46	0.79521** z:-2.20	0.77905** -2.29
Ulterior accreditations			0.13872 z: 1.54	1.18583*** z: 3.14	1.16642*** z: 3.14
accreditations_ age			-0.02306** z: -2.44	0.97708*** z:-2.92	0.98025** -2.38
Number of pages			-0.00163** z:-1.99		
ICS width			0. 89885* z: 1.85		
Year	0.96885*** z: -2.99	0.96985*** z: -2.93	-0.00743 z: -0.32	1.04108 z: 1.31	1.04724 z: 1.53
Version Age			0.18618** z: 2.01		2.44156*** z: 4.29
Version Age_Sq					0.97290*** -2.85
Version number			-0.02016 z: -0.18		6.64184** 2.38
Version number_Sq					0.71194** -2.01
Subjects	4671	9342	Cons: 10.064	3551	3551
Failures	1709	1709	Obs: 1399	367	367
chi2	217.91	372.84	267.00	119.28	155.61

Log-likelihood	-5343.9173	-6422.0711	R2:0.3152	-1014.5515	-1005.7632
Proportional Hazard test	Chi2: 16.35 Pr:0.1285	Chi2: 13.76 Pr:0.4681		Chi2: 12.92 Pr:0.3751	Chi2: 19.20 Pr:0.2585

Table 3: Results of the multivariate panel analysis. Results of Models 1,2, 4 and 5 display hazard rates. Models 1 and 2 are stratified by SDO, ICS, cohort and version number, Models 4 and 5 by SDO, ICS, cohort and standard size range.

5.2 Results

The econometric results confirm our hypotheses and descriptive findings. First, we confirm Hypothesis 1: the inclusion of essential patents reduces the survival rate of standard versions, meaning that standards with patents are upgraded more frequently (model 1). This effect is significant and sizeable: the inclusion of essential patents increases the rate at which standard versions are replaced by more than 40%. We then analyze the survival rate of standard versions distinguishing between the two competing risks of standard upgrade and replacement. We find that essential patents have very different effects on the two different risks: the inclusion of essential patents strongly increases the likelihood of upgrade, but strongly reduces the risk of standard replacement (model 2). Both of these effects however decrease with the age of the standard version. We then directly model the choice between upgrade and replacement (model 3). Conditional upon a standard version being withdrawn, the inclusion of essential patents significantly increases the likelihood of the version being replaced by a new version of the same standard.

Essential patents lead to withdrawing standard versions more often, but also increasing the likelihood of choosing standard upgrade rather than replacement. The resulting net effect on the survival rate of standards is unclear. We therefore estimate the effect of essential patents on the hazard of standard replacement and confirm Hypothesis 2: Essential patents reduce the likelihood of standard replacement (model 4). This effect as well is significant and sizeable: holding constant other variables, the inclusion of essential patents reduces the rate of standard replacement by 60 %. As discussed, one potential explanation for this finding is that more frequent upgrades delay the obsolescence of standards and therefore reduce the risk of standard replacement. Models 1 and 2 have confirmed that the inclusion of essential patents increases the rate of standard upgrades. Model 5 furthermore confirms that a standard upgrade temporarily reduces the risk of standard replacement. This can be seen from the fact that the risk of standard replacement increases with version age[14], while controlling for the baseline age effect. However, controlling for standard upgrades only slightly reduces the magnitude and significance of the effect of essential patents on standard replacement (model 5).

[14] The effect of version age is non linear, but the risk of standard replacement strictly increases with version age over the first 16 years of the version lifetime. The longest observed version lifetime in the sample is 19 years.

5.3 Discussion

The results show that essential patents increase the rate of standard upgrades, but reduce the rate of standard replacement. The inclusion of patented technology into a standard provides the holder of essential patents with incentives to regularly invest in further improvements of the standard. Arguably, one main incentive for the holder of essential patents to invest in improving the standard is to prevent standard replacement by keeping the standard up to date. However, this mechanism only accounts for a small part of the observable effect of essential patents on the rate of standard replacement.

These findings indicate that essential patents contribute to reduce the rate of standard replacement also through other mechanisms. Earlier findings (Simcoe, 2012) show that higher commercial stakes in standardization slow down the development of new standards. This effect is arguably much stronger for the replacement of existing standards. We argue that essential patents on a standard raise the standardizing firms' resistance to radical changes of the standard excluding patented technological components. This argument corroborates suspicions that essential patents increase inertia of technological standards. In contradiction with widespread concerns about the negative effects of patent thickets, we do however not find any evidence that the evolution of standards is affected by the number of essential patents. Indeed, the only significant effect is the difference between standards including at least one patent, and those not including any essential patents.

There are also other, complementary explanations for the effects of essential patents on the rate of standard replacement. As has been argued by Liebowitz and Margolis (1995) and Katz and Shapiro (1986), holders of proprietary standard components have an incentive to sponsor standard adoption and complementary investments. If the installed base of a standard and the value of complementary assets increase, the social costs of switching to a new standard also increase. We do not directly observe standard adoption. However, we have proxies for technological investment building upon the standard. If the technology building upon a standard is standardized itself, the more recent standard references the standard it builds upon. Using forward references as a proxy, we find that downstream investment building upon a standard reduces the risk of standard replacement. For instance references by ulterior standards strongly increase the likelihood of choosing standard upgrade rather than standard replacement. This finding corroborates our hypothesis that standard upgrades generate less problems of backward compatibility. If the number of applications building upon a standard increases, the cost of backward incompatibility increases, making standard replacement increasingly unattractive.

The analysis of the other control variables reveals that our model is able to capture key aspects of our analytical framework. We already confirmed in the comparative analysis that our control variables capture a significant part of the heterogeneity between standards. The panel analysis now also reveals that our variables capture well the time-varying effects on standard evolution. The likelihood of standard replacement is strongly associated with the "*technology gap*", the weighted stock of patents filed in the broader field over the years since the last standard release. The technological gap has no effect on very early standard replacement, but its effect strongly increases over standard age, and the average sample effect is positive and significant. This indicates that standard replacement indeed responds to progress in the field of science and technology. We also find that strong related technological progress ("*innovation intensity*") induces standardizing bodies to choose standard replacement rather than upgrade. This finding could indicate that standard upgrades are a less effective means of catching up with the technological frontier. The latter argument is important, as we have seen that essential patents induce a substitution of standard upgrades for standard replacement.

We also find strong evidence for significant interdependence of standards. Backward references to other standards strongly reduce the risk of standard replacement. This indicates that a standard building upon a more comprehensive architecture of other standards is less at risk of being replaced. If a referenced standard is replaced or upgraded ("*Change of referenced standard*"), there is however a very strong pressure to upgrade or replace the referencing standard as well.

6. Conclusion

We have presented empirical evidence that essential patents reduce the likelihood of standard replacement. This finding could indicate that essential patents lead to frictions in standardization, for instance because owners of essential patents oppose to changes in the standard that exclude their patents from the standard. We also discussed extensively the hypothesis that essential patents lead to more frequent upgrades of the standard, which would in turn delay standard obsolescence. While the inclusion of essential patents indeed increases the rate of standard upgrades, this effect alone is not sufficient to explain why standards including essential patents are less likely to be replaced. We further show that the effect of essential patents, even controlling for the rate of standard upgrade, is positively connected to a longer existence of standards.

Nevertheless, we would not argue based upon the presented evidence that essential patents lead to an inefficient lock-in of outdated standards. Indeed, essential patents seem to have a positive effect on the rate of standard upgrades. We have argued that these standard upgrades do not entail replacement of standard components, explaining why essential patents could induce standardizing firms to substitute standard upgrades for standard replacements. Essential patents do however not only induce standardizing firms to substitute standard upgrades for replacements, but also to overall increase the rate at which they revise standards (the sum of upgrades and replacements increases). The latter part of the finding can be explained by the fact that essential patents provide incentives for at least some standardizing firms to regularly invest into the standard in order to increase its value and associated royalty revenue, and to shield the standard from technological rivalry and replacement.

These findings have important implications for management and policy. For standard adopters, we argue that essential patents reduce the technological uncertainty associated with the adoption of a new standard. Users of a standard including essential patent benefit from increasing technological capacities through continuous improvements building upon a stable technological basis. Patents may thus signal the commitment of standard setting firms to continuously advance the standard. Furthermore, essential patents reduce the risk of standard replacement, thereby avoiding the loss of sunk investment in standard implementation. These beneficial effects should be weighed against the managerial risks arising from uncertainty about future levels of royalties.

For standard makers, the effects of essential patents can be controversially discussed based upon the presented evidence. Essential patents induce more frequent standard upgrades, but also inhibit standard replacement. On the one hand, standard upgrades do not seem to be as efficient as standard replacements in catching up to the technological frontier. Selecting patented technology can therefore inefficiently bind standard makers to a given technological trajectory, even when superior alternatives are available. On the other hand, standards referenced by other standards are also more likely to be upgraded rather than replaced. This could indicate that standard replacement entails significant social costs, including for adjustment of downstream applications and technologies building upon the standard. Essential patents, by substituting standard upgrades for replacements, could therefore reduce the cost of standard momentum for applications building upon the standard. The inclusion of essential patents thus reduces technological uncertainty and encourages users of the technology to incur costly and risky investments in standard implementation and complementary technology. These investments concur to the commercial and technological success of the standard.

Based upon this new analytical framework, we find a new justification for the argument that sponsorship of standards by a technology owner can act as an encouragement of standard adoption, and increase socially efficient investment building upon evolving standards. These effects of essential patents on the technological evolution of standards deserve more attention by policy makers currently working on a refinement of public rules for the treatment of patents in standardization in various legislations.

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Appendix 1

Patented_dummy	Indicates that a standard observation includes essential patents	Time invariant
Patented	Indicates a standard has received at least one patent declaration by this year	Time-variant
Patented_upgrade	Interaction term between patented and event-type upgrade	Time invariant
Patented_replacement	Interaction term between patented and event-type replacement	Time invariant
Patents_cumulative	Cumulative count of patents declared over time	Time-variant
Innovation intensity	Number of patents filed per year in the technological field, normalized by year; indicates strong innovative activity	Time-variant
Technology gap	Cumulative count of patent intensity scores since standard release, discount factor 15%; indicates distance of the standard to the technological frontier	Time-variant
Backward references	Number of standards referenced by the standard	Time-invariant*
Change of referenced	Counts the number of referenced standards that are replaced or upgraded per year	Time-variant
Forward references	Cumulative count of the references made to the standard by ulterior standards in the PERINORM database	Time-variant
Referencesafter4	Number of references received during the first four years after first standard release	Time invariant
atleastonereference	Referencesafter4 is bigger than 0	Time invariant
Ulterior accreditations	Cumulative count of the number of accreditations by other SDOs after release of the standard at the sample SDO	Time-variant
Prior accreditations	Count of the accreditations by other SDOs before the release of the standard at the sample SDO	Time-invariant*
National Standard	Indicates that the standard was not first developed at the sample SDO (Prior accreditations is higher than 0)	Time-invariant*
Number of pages	The number of pages of the standard	Time-invariant*
ICS width	The number of ICS classes in which the standard is classified	Time-invariant*
Year	Calendar Year	Time-variant
*	Number pages, backward references, ICS width and prior accreditations can change with a new version	

Table 4: Definition of variables

Appendix 2

Calculation of the propensity score

Probit regression				Number of observations:	6531	
				LR chi2(55):	646,62	
				Prob >chi2:	0,0000	
Log Likelihood:	-992,116			Pseudo R2:	0,2458	
Variable	Coef.	Std. Error	Z	Pr>|z|	95% Confidence Interval	
number_pages	0,00257	0.00030	8,46	0,000	0,0019	0,0032
at_least_one_reference	0,27398	0.07319	3,74	0,000	0.1305	0.4174
references_after_4years	0.00406	0.00321	1,26	0,206	-0.0022	0,0103
nationalstandard	-0.57748	0,26795	-2.16	0.031	-1.1027	-0.0523
prior_accreditations	0.41569	0,18716	2.22	0.026	0.0489	0.7825
ics_width	0.26732	0,20240	1,32	0,187	-0.1294	0.6640
It	-0.15721	0.21168	-0.74	0.458	-0.5721	0.2576
Telecom	0.64812	0,19895	3.26	0.001	0,2581	1.0381
Ieee	1.64179	0,38053	4.31	0.000	0.8959	2.3876
Iso	0,92272	0,40467	2.28	0.023	0.1296	1.7159
jtc1	1.30466	0.37165	3.51	0.000	0.5762	2.0331
itu-t	1.83084	0.35116	5.21	0.000	1.1426	2.5191
Constant	-3.80847	0.51554	-7.39	0.000	-4.8189	-2.7980
Year dummies and ICS-class dummies not reported						
There are observations with identical propensity scores.						

Table 5: Probit regression model used for calculating the propensity scores

Pstrata	patented_dummy		Total
	0	1	
1	734	7	741
2	730	11	741
3	719	21	740
4	707	34	741
5	662	78	740
6	562	180	742
Total	4.114	331	4.445

Table 6: Standards with and without essential patents, by strata

Appendix 3

Sensitivity analysis to unobserved biases using multiple control groups

SDO	Number of Standards in ICT from 1988 to 2008	% of these standards including patents	Classified as SDO with patents
ISO	1169	2,10 %	No
IEC	1348	0,59 %	No
JTC1	1704	5,81 %	Yes
ITU-T	3874	6,43 %	Yes
ITU-R	1217	0,41 %	No
IEEE	477	8,59 %	Yes

Table 7: SDOs classified as with or without patents

ICS "with" patents			**ICS "without" patents**		
ICS	Standards	% patents	ICS	Standards	% patents
33040	1792	6,25	33020	659	0,30
33160	589	10,88	33030	62	0,00
35040	473	17,55	33050	138	2,89
35110	409	11,25	33060	970	0,93
35180	98	10,20	33070	53	0,00
Others	65	25,76	33080	510	4,90
			33100	193	0,00
			33120	234	0,00
			33140	19	5,20
			33170	516	2,52
			33200	51	1,96
			35020	57	0,00
			35060	229	2,18
			35080	257	0,80
			35140	74	2,70
			35160	97	3,10
			35200	309	5,82
			35240	1606	4,73
			37040	16	0,00
			37060	21	0,00
			Others	1419	0,85

Table 8: ICS classes classified as with or without patents

Standard replacement		Test without strata	Test without strata, controls	Test with strata	Test with strata, controls
	Events				
Treated	Obs: *Exp:*	20 *49,46*		20 *54.91*	
Control 1	Obs: *Exp:*	50 *56,88*	50 *58,74*	50 *59.37*	50 *61,11*
Control 2	Obs: *Exp:*	674 *549,00*	674 *565,65*	674 *626.80*	674 *652,41*
Control 3	Obs: *Exp:*	270 *358,66*	270 *369,61*	270 *272.93*	270 *280,48*
Chi2 Pr>chi2		69,29 0,0000	49.16 0,0000	30.16 0,0000	3,91 0,1419

Table 9: Log rank test of equality of standard survival with multiple control groups

Standard upgrade		Test without strata	Test without strata, controls	Test without strata, 2 controls	Test with strata	Test with strata, controls	Test with strata, 2 controls
	Events						
Treated	Obs: *Exp:*	267 153,69			267 171,03		
Control 1	Obs: *Exp:*	41 94,77	41 89,35		41 88,78	41 81,43	
Control 2	Obs: *Exp:*	1064 992,61	1064 936,02	1064 960,53	1064 1064,75	1064 1023,19	1064 1045,69
Control 3	Obs: *Exp:*	838 972,93	838 917,63	838 941,47	838 889,44	838 838,38	838 856,31
Chi2 Pr>chi2		146,29 0,0000	53,07 0,0000	23,67 0,0000	101,77 0,0000	27,82 0,0000	1,09 0,2962

Table 10: Log rank test of equality of version survival with multiple control groups

Patent Pools and Patent Inflation

An empirical analysis of contemporary patent pools

Abstract

Patent pools combine patents to be licensed out under a single contract. This may increase transparency, reduce transaction costs, avoid costly infringement litigation and reduce royalty rates. For this reason, an increasing number of patent pools have been created for patents that are essential to technological standards. Little is known however on the effects of patent pools on the incentives to file and declare essential patents. We investigate how patenting around technological standards and the number of patents declared essential has been affected by the increasing number of patent pools since 1997. Using data from a comprehensive sample of ICT standards released between 1992 and 2009, we show that periods around pool creation are characterized by exceptionally high levels of patenting and high declaration rates. In the case of standards released after 1999, when the possibility of pool creation was already established, patenting peaks prior to pool creation, and takes place earlier than for comparable standards. These findings are consistent with the theoretical analysis of the effects of expected pool creation on patenting incentives. In the case of earlier standards, patenting peaks immediately after pool creation, highlighting a reaction to the exogenous policy change establishing a more permissive approach towards pools. While this evidence indicates a positive effect of patent pools on the incentives to file and declare essential patents, the overall effect of pools on the inflation of essential patents around standards seems to have been limited.

Contents

1. Introduction

Over the last ten years, the increasing number of patents declared essential to technological standards has attracted wide attention in the academic literature and among policy makers. A patent is called essential for a standard when it is necessarily infringed by any implementation of the standard. Obtaining such a blocking power over a standard may increase the commercial value of a patent for its holder (Rysman and Simcoe, 2009, Bekkers et al., 2002). Standardization thus generates additional incentives for firms to file more patents (Layne-Farrar, 2008, Bekkers et al., 2012), or to adjust their patent files to ongoing standardization (Berger et al., 2012). The increasing number of patents around standardization thereby evolves to become a challenge for standard development and implementation (Shapiro, 2001).

In order to deal with these challenges, standardizing firms have come up with mechanisms to coordinate their strategies with respect to Intellectual Property Rights (IPRs). Patent pools are the most important of these mechanisms (Shapiro, 2001). Pools combine IPR to be licensed under a single contract. This increases transparency, reduces coordination costs and avoids costly infringement litigation. As long as pools only include patents that are complementary and necessary for implementing a standard, they furthermore reduce royalty rates for users of the standard by eliminating wasteful multiple marginalization (Lerner & Tirole, 2004). Based upon these arguments, patent pools are generally believed to increase *ex post* economic efficiency, and antitrust guidelines have adopted a permissive policy stance towards patent pools including only complementary patents.

The effect of patent pools on the incentives to innovate is however subject to debate. Simcoe (2005) argues that the spreading practice to create patent pools for technological standards is one of the driving factors of the increasing number of essential patents. This claim is supported both by the theoretical literature, predicting a positive effect of pools on innovation incentives, as well as by practitioner reports (Peters, 2012) and case studies evidencing the importance of opportunistic patenting in view of patent pools (Nagaoka et al., 2009, Baron and Delcamp, 2012). Recent empirical research (Lampe and Moser, 2012; Joshi and Nerkar, 2011) however suggests that patent pool creation was followed by a decline in related patenting. These findings however only describe a decline in follow-on innovation, once a number of existing patents were bundled into a pool (the *ex post* innovation effects).

The effect of patent pools on the incentives to file patents to be included into this pool (the *ex ante* innovation effects) have so far not been subject to a thorough empirical analysis.

We will investigate *ex ante* effects of patent pools on innovation and evaluate whether policy changes facilitating the creation of more than 50 ICT patent pools have increased incentives to file standard-essential patents. We collect data on 60,000 declarations of essential patents to more than 700 ICT standards. We will describe the growth in the number of patent declarations over the past twenty years, and discuss to what extent the increasing number of patent pools is likely to have contributed to this evolution.

We then analyze on the standard and firm level whether the creation of the individual patent pools can be related to unusual peaks in the levels of patent declaration and patent files. We build up a comprehensive database of 7 million patents that are technologically close to declared essential patents, filed by over 150 companies contributing proprietary technology to the specific standard. We relate patenting and patent declarations to 700 standards and technical specification and 28 patent pools. We especially describe the baseline timing of patenting and declaration with respect to the development of technology standards. We can then analyze whether there is an unusual change in the extent of patenting before or after the launch of patent pools. We distinguish between expected and unexpected patent pools using the favorable business review of patent pools from 1997 to 1999 as an exogenous policy change. Firms investing in R&D related to standards released after this policy change were able to integrate the new policy environment in their expectations of the returns on essential patents. We will analyze how the timing of patenting and patent declaration around pools differs for pools created before and after policy change. Furthermore, we describe how the timing of patenting differs from standards related to a (foreseeable) patent pool with respect to other standards which are otherwise comparable but not subject to patent pools.

We find evidence for a positive effect of patent pools on patenting and the number of patent declarations. The effect of patent pools depends upon whether the pool creation was expected or came as a surprise to innovating firms. For instance, the periods before pool creation are characterized by high numbers of patent files in the subsample of standards released later than 1999. There is no such relationship in the sample of standards released earlier then 2000. Furthermore, we find that companies entering a patent pool increase their level of patenting with respect to companies contributing to the same standard, but staying outside the pool. The overall effect of patent pools on the number of essential patents seems however to be limited. The recent surge in the number of essential patents was mainly driven by standards for which pools were not an option.

2. Review of the Literature

The theoretical literature on patent pools generally predicts a positive effect on the incentives to invest in related R&D (Lerner and Tirole, 2004; Aoki and Schiff, 2007). Dequiedt and Versaevel (2012) analyze the dynamic incentives for R&D in view of a patent pool. In their model, patent pools increase innovation incentives, and especially induce patent races preceding the launch of the pool. Llanes and Trento (2009) analyze the impact of patent pools on follow up innovation. Patent pools efficiently reduce the royalty stacking problem, thus reducing the negative effect of patent protection on follow-up innovation.

Recent empirical advances however rather point to a negative effect of patent pools on innovation and patenting. In a study of the sewing machine patent pool in the 19th century, Lampe and Moser (2010) find that this pool had a positive effect on the number of subsequent patent files by insiders and outsiders. Nevertheless, the authors show that the effect on innovation is negative, as measured by indicators of real technical progress. There is thus apparently evidence of an increased patent propensity which does not translate into an increased innovation effort. In a more recent study of patent pools in the 1930s, Lampe and Moser (2012) find that most of these pools had a negative effect on subsequent patenting in the field. In the only existing study of the effects of contemporary ICT patent pools, Joshi and Nerkar (2011) find that the creation of the DVD patent pools was followed by a decline in patenting in related technical fields by pool licensors and licensees.

It is difficult to confront the empirical evidence with empirical predictions from the recent theoretical literature because of the heterogeneity of research settings. The expected effects depend upon whether the pools are allowed to include substitutable patents or not. Evidence on historical patent pools is thus only in a very limited sense applicable to contemporary patent pools.

The empirical papers measure the effects of patent pools upon measures of technological progress (Lampe and Moser, 2010) or patenting (Lampe and Moser, 2012; Joshi and Nerkar, 2011), while the theoretical papers typically focus upon related R&D efforts (Lerner and Tirole, 2004; Dequiedt and Versaevel, 2012; Llanes and Trento, 2009). Several of the empirical papers use patents to indicate R&D efforts or innovation. The number of patents however indicates innovation or R&D effort only under the condition that the pool has no effect on patent propensity and on the efficiency of R&D investment. Given the impact of patent pools on the return structure of patents, particularly the first assumption seems overly strong. Layne-Farrar and Lerner (2011) for instance highlight that holders of the most valuable patents often refrain from joining patent pools, because large numbers of insignificant patents included in pools water down the return on significant inventions. Evidence on effects of patent pools on patent counts should therefore only cautiously be interpreted as indicating an effect on innovation.

Furthermore, the empirical papers either measure the effects on patenting by pool members and licensees (Joshi and Nerkar, 2011), or on all firms in the field (Lampe and Moser, 2010, 2012). On theory side, some papers focus upon the incentives of potential pool members (Lerner and Tirole, 2004; Dequiedt and Versaevel, 2012), others concentrate on outside innovators using the technology licensed out through the pool as input (Llanes and Trento, 2009). While the comparison between pool members and outsiders is informative, it would be mistaken to interpret changes in the extent of patenting by members relative to outsiders as a measure of the overall effect of patent pools. Theoretical work clearly indicates that pool outsiders' innovation incentives are affected by patent pools (Llanes and Trento, 2009). Aoki and Nagaoka (2004) even stress that pool outsiders are the ones to benefit most from pool creation.[1] Furthermore, participation in a patent pool is endogenous to various factors that are likely to also have a direct influence on future R&D in the specific technology, such as vertical integration or R&D capacities.

Finally, most theoretical models consider the effects of expected pool creation, and even explicitly address effects on the level of innovation preceding the pool creation (Dequiedt and Versaevel, 2012). In contrast, all of the existing empirical work measures effects of patent pools in the time period following patent pool creation. This research setting requires that pool creation comes as a surprise to at least some firms. While arguably some pools have indeed been created in response to an exogenous policy change, it is implausible that significant effects on the incentives to file patents to be included into the pool can be measured with data from periods after pool creation. Indeed, contemporary ICT patent pools are restricted to include patents that are essential to precisely defined standards which are generally released several years before pool launch. An empirical researcher interested in the

[1] Lampe and Moser (2010) furthermore argue that pool outsiders reacted to the creation of a sewing machines patent pool by increased strategic patenting in order to counteract to the increased litigation capacity of pool members.

effects of contemporary patent pools on the incentives to file standard-essential patents needs to take into account the periods preceding the foreseeable creation of a patent pool, thereby testing empirical predictions of models of ex ante effects of pools, such as Lerner and Tirole (2004) and Dequiedt and Versaevel (2012).

3. Descriptive Analysis

3.1 Patent declarations and standards

The aim of our analysis is to assess whether patent pools have contributed to the increasing number of essential patents for technological standards. In a first step, we identify the totality of declarations[2] of essential patents made from 1992 to 2010 to the main formal standard setting organizations (SSO) which operate on an international level: ISO, IEC, JTC1 – a joint committee of ISO and IEC – CEN/CENELEC, ITU-T, ITU-R, ETSI, and IEEE[3]. We identify 64,000 declarations of essential patents made by 150 companies. Our measure is based upon a count of declarations, and not a count of essential patents. The number of declarations is higher than the number of patents, because we also include so-called blanket declarations (a generic declaration that a company owns essential patents without specifying the patent number), and we count patents declared essential to various standards as multiple declarations.

These declarations are related to more than 700 standards and technical specifications. The PERINORM[4] database provides detailed bibliographic information on formal standards such as standard version updates, standard amendments, the number of pages, the technical classification and the year of release.

3.2 The policy change

While there have been many patent pools in very different technological areas until World War II (Lampe and Moser, 2012), stricter enforcement of competition law impeded any pool creation from the end of World War II until the 1990s (Gilbert, 2004). In 1997 and 1999, the European and American antitrust authorities however authorized a new model of patent

[2] A patent declaration is a public statement by a patent holder declaring that his patent is essential to a specific standard. These declarations are made publicly available on the website of the SSO.
[3] These SSOs account for a large part of the essential patents identified by Bekkers et al. (2011). The sample is however restricted to formal SSOs operating with comparable rules on Intellectual Property Rights, thus excluding important SSOs and consortia, such as the IETF.
[4] PERINORM is the world's biggest database with bibliographic information on formal standards and is regularly updated by the SDOs DIN, BSI and AFNOR.

pooling for two important standards[5], including several important safeguards against anti-competitive abuses. This major policy change significantly altered the expectations of standardizing firms regarding the likelihood of successful patent pool creation.

Since this favorable business review, many other patent pools including very similar safeguards have been launched without meeting any resistance from antitrust authorities. *"The DOJ business review letters provide* ***a template*** *for patent pooling arrangements that should not run afoul of the antitrust laws. The letters embody a new thinking in economics and law and* ***contrast sharply*** *with early judicial opinions about the legality of patent pooling arrangements."* (Gilbert, 2004). It is thus reasonable to assume that companies working on a standard after the issuance of the business review letters had different expectations of the likelihood of pool creation than companies working on a standard before this policy change. These expectations in turn are likely to affect their patenting behavior. Simcoe (2005) notes that the policy change with respect to patent pools could be one of the explanatory factors of the increasing number of patents declared essential for technology standards.

3. 3 Patent pools and declarations of essential patents 1992 to 2010

We will first use our comprehensive database to describe the historical evolution of patent pools and the rate of patent declarations over the past 18 years. The most immediate effect of the policy change with respect to patent pools can be seen from figure 1: the rate at which new successful pool projects are created is steadily increasing. The increasing experience of companies with pools, the emergence of companies specializing in the administration of patent pools, initiatives by SSOs and standards consortia encouraging pool creation as well as the further clarification of the legal environment contributed to an increasing ease of pool creation.

Furthermore, we can compare the number of companies having joined the patent pool during the first four years after launch. We can see an increasing number of pools attracting a relatively large number of members. Nowadays, companies deciding upon the level of R&D investment for a future standard can integrate a non-negligible probability of successful pool creation into their calculations of the expected return on essential patents.

[5] MPEG2 and DVD, see the business review letters: http://www.justice.gov/atr/public/busreview/2485.pdf, http://www.justice.gov/atr/public/busreview/215742.pdf.

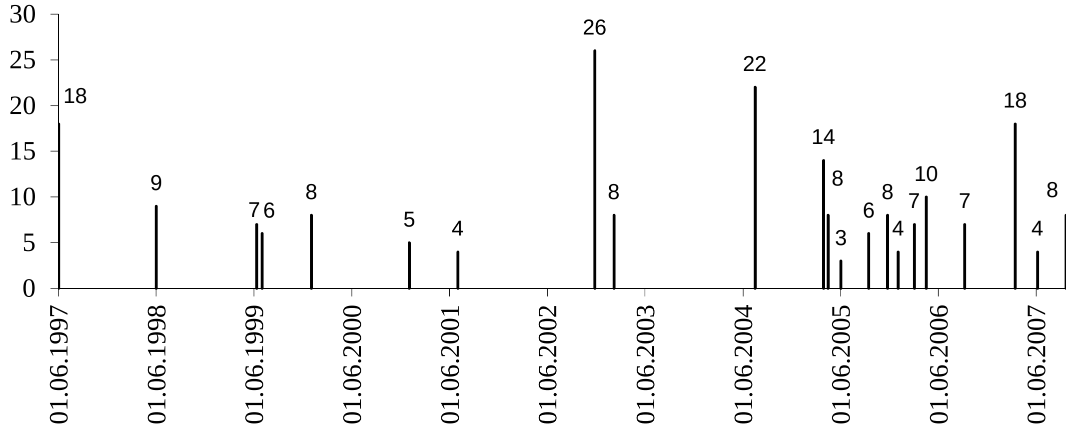

Figure 1 Pool creation and number of members after 4 years

In the following, we can use our declaration database, matched to individual standards, in order to analyze whether the increasingly widespread practice of pooling patents has affected the number of essential patents on new standards. First, our own data confirms a remarkable increase in the number of patent declarations beginning at the end of the 1990s (figure 2). These figures are however to a very large extent driven by declarations made to ETSI, and in particular related to 3G mobile communication standards (indeed, UMTS alone accounts for 11,000 declarations, 3GPP receives 15,000 declarations and AMR-WB 1,500 declarations). It can only be speculated to what extent the various attempts to create a large patent pool on 3G technology have fuelled this unprecedented level of patent declaration. It seems that the role of the (eventually failed) attempts to create important 3G patent pools have not been decisive for the huge number of essential patents on 3G standards[6]. Several of the most important holders of 3G patents have never aimed at joining a patent pool. Furthermore, patenting in this industry seems to be strongly driven by portfolio races between litigious rivals and by the presence of innovation specialists patenting aggressively, notably Qualcomm and InterDigital.

[6] As to practitioners and experts in the telecommunication industry only 8-9% of the GSM standard essential patents are pooled. Attempts by Sisvel and Via Licensing to form pools for LTE have yet not been successful even though there have been meetings to pool LTE patents since more than 2 years.

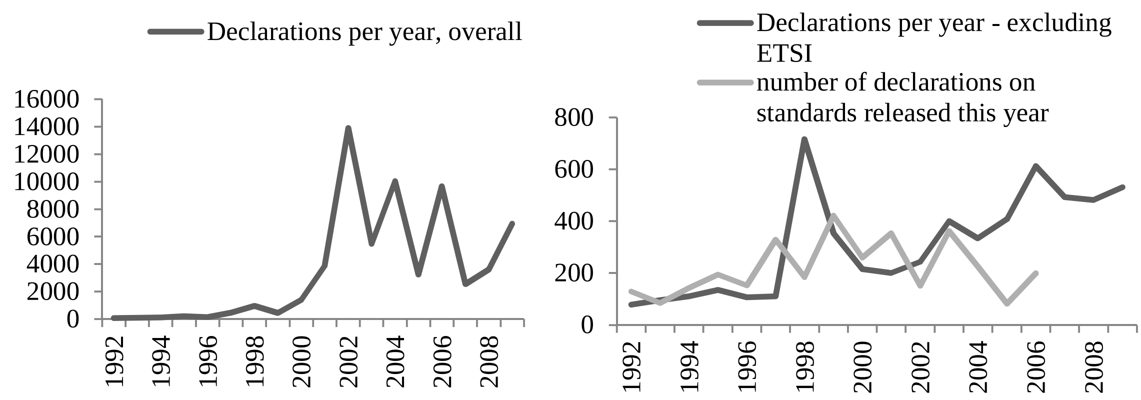

Figure 2 Declarations per year (whole sample left graph) Declarations per year and per year of release (excluding ETSI right graph)

Setting aside ETSI and the 3G mobile phone standards, we focus the analysis on ISO, IEC, ISO/IEC (JTC1), CENELEC, ITU and IEEE. These are standard bodies that, even though they account only for limited numbers of essential patents (compared to ETSI and IETF), are related to 24 out of the 48 pools in our database, including many of the most important ones. Concentrating on these standards, we can still see an increase in the number of declarations at the end of the 1990s (dark grey line in the right graph of Figure 2). The graph also exhibits a spike in the number of patent declarations in 1998. Possibly, this spike includes several declarations of essential patents made as an immediate reaction to the contemporaneous policy change. In order to analyze whether there was a lasting change in the levels of patenting related to new standards after this year, it is important to relate the number of declarations to the year of standard release. By comparing how many patent declarations standards receive in the first four years after release, we can see that standards issued after 1997 indeed include a higher number of essential patents, even though there is no obvious trend, and the numbers are in decline since 2003 (light grey line in the right graph of Figure 2)

We can go further in the analysis of these trends by comparing different types of standards in our sample. For instance, patent pools are a solution tailored to single large standards including many patents held by many different owners. In the following figure 3, we can however see that the increasing number of patent declarations on new standards is mainly driven by an increasing number of standards including patents.

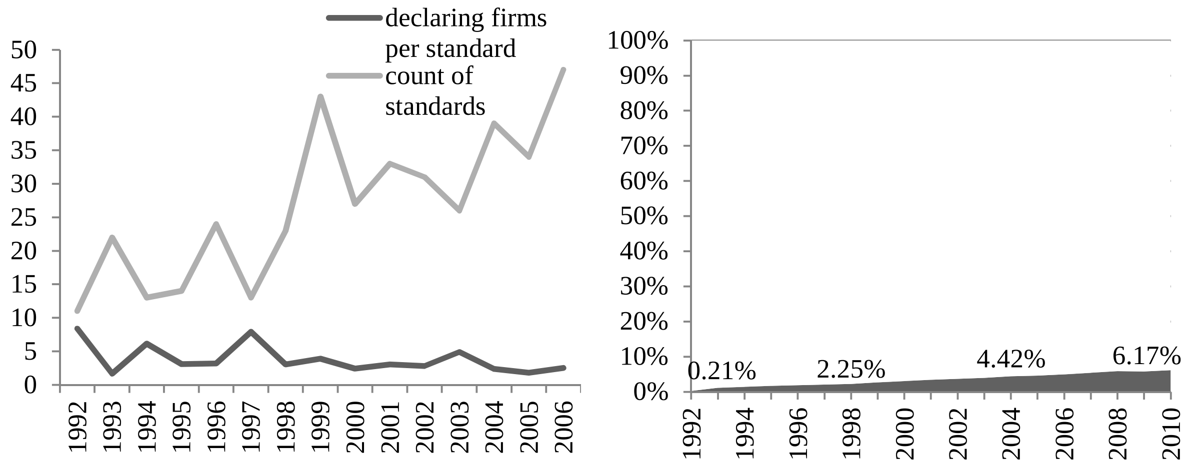

Figure 3 Number of declaring firms per standard and standards including essential patents released per year (excluding ETSI), the percentage of ICT standards with essential IPR (right graph)

The right graph reveals that an increasing share of the standards released by the SSOs in our sample receive at least one declaration of essential patents. At the same time, the average number of declaring firms per standard has decreased over this period.

This finding could indicate that the increasing number of patent declarations is driven by many small standards, for which pools are not really an option. We thus concentrate our analysis on standards including declarations by more than 4 firms. Analyzing this restricted sample, we find important numbers of patent declarations on standards released from 1997 to 2003, but no steady increase neither in the overall number of declarations on such standards, nor in the average number of declarations for each of these standards (figure 4).

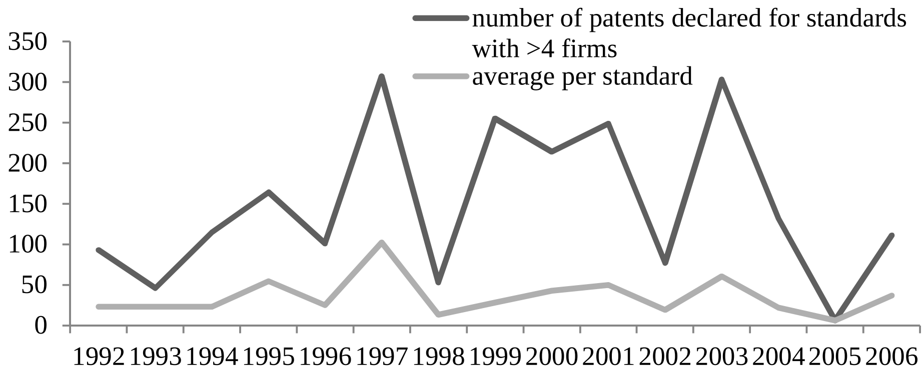

Figure 4 Number of patent declarations to standards receiving declarations from more than 4 firms, and average number of declarations for each of these standards (excluding ETSI)

The analysis of the trends in the number of patent declarations over the past twenty years indicates that the increasing number of patent declarations is on the one hand accountable to

3G mobile communication standards and on the other hand to a high number of standards including few essential patents. While this analysis suggests that patent pools have not been a main driver of the recent increase in the number of essential patents on standards, the analysis of the time trends does not allow concluding on the effect of patent pools on the incentives to file and declare essential patents. Indeed, the aggregate figures are affected not only by the policy change with respect to patent pools, but also by a strong variability in the rate of technological progress, by other policy changes with respect to disclosure obligations and reasonable royalty rates, and by a strong heterogeneity between standards released in different periods. In order to analyze the effect of patent pools on declarations and patenting, we will therefore proceed to an analysis on standard level, analyzing how patent pools affect the level and timing of patenting and declarations for each company and standard.

4. Patent Pools and Dynamics of Patenting

4.1 Methodological Approach

We will next analyze how the rate of patenting and declaring patents relevant for specific standards is affected by patent pools. The patents that are declared essential only constitute a share of the patents filed in view of technological standards. Indeed, very often rivaling firms develop competing technological solutions for the same problem of a standard. If only one of the proposed solutions is chosen for inclusion into the standard, the patents protecting the competing technologies are not essential patents, even though they have been filed as part of the technological development of the standard. In order to identify standard related patent files, we use the 7-digit IPC classification of the declared essential patents, and count the number of patents filed per year in the respective IPC classes. We use all ICT patents filed at the three major patent offices (USPTO, JPO and EPO) from 1992 to 2009 by the firms declaring at least one essential patent for the respective standard, using the PatStat database and the merging methods of Thoma et al. (2010). This merging yields 7 million patents filed by over 150 firms. To create our explained variable, we computed for each company-standard pair and year the number of priority patents filed in the relevant IPC classes for the standard of observation.[7]

[7] We further conduct tests of the technological position of standards as well as size measures to prove that our matching method reliably identifies standard-related patents. The method and the various tests have been presented at the Patent Statistics for Decision Makers Conference 2011 at the USPTO.

In a next step we identify 28 patent pools (including failed attempts to create a patent pool) and match these pools to the standards in our sample[8]. Matching pools with standards is straightforward, as pool administrators clearly display the technological standards that are covered by the patent pool license. The date of launch is defined as the date at which a patent pool administrator publishes a call for patents to gather holders of patents that are essential to a technological standard (Baron and Delcamp, 2012). Such a call, often made upon the initiative of a group of patent holders wishing to create a pool, seeks to identify and federate the remaining patent holders and to steer negotiations on licensing provisions. The call for patents thus indicates the time where the prospective pool creation becomes common knowledge. In the period preceding the call for patents, several companies can already negotiate on eventual pool creation, but at this stage there is still uncertainty on whether a patent pool will be launched. In addition to the launch of the pool, we identify the dates at which the companies joined the pools using internet archives and the history of news releases of the pool administrators (Baron and Delcamp, 2012).

We further create control variables such as a yearly count of all patent declarations on formal standards[9] and a patent count of all patents per year in the IPC classes “G” and “H”[10]. The latter two variables should account for technology shocks in the technical field and organizational changes in the SSOs. We also control for informal industry alliances arising around standardization. Consortia are matched to formal standards using liaison statements[11]. If an official liaison statement was not given, we conducted a more detailed analysis in order to identify the related standard. In total 21 different informal consortia could be related to 63 formal standards including essential patents.

All information is given in longitudinal data over 18 years. This broad database allows testing the impact of patent pools on the number and timing of patenting controlling for fixed effects of company-standard pairs, activities in standardization and exogenous technological shocks.

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[8] The list of pools, the date of pool launch and the match of relevant standards is provided in Appendix 1.

[9] We labeled each patent declared essential to each standard as one declaration. For example a patent declaration for two patents declared essential to two different standards is counted as four declarations. Empty or so-called blanket patent statements - i.e. statements of ownership of essential IPR that do not provide patent numbers - were also counted as one declaration.

[10] “G” and “H” IPCs are technologies that can be connected to information and communication technologies. In our database of standard essential patents 95% of all patents are classified in in both or at least one of these IPC.

[11] A liaison implies an accreditation and a cooperative standardization development between the formal and informal standards bodies.

4.2 The counterfactual

In order to analyze the effects of patent pools, we need to compare the empirically observed patenting and declaration rate with the counterfactual rate that would have been observed for the same standard, the same company and the same year in the absence of a pool. The existing empirical literature on patent pools compares the levels observed after pool creation with the levels before pool creation, or with the hypothetical values which would be observed if these rates had continued to follow a general trend pre-existing to pool creation (Lampe and Moser, 2012), or if the patenting of pool members had evolved in a manner similar to the patenting of other firms (Lampe and Moser, 2012; Joshi and Nerkar, 2011).

We opt for a similar approach, especially tailored to the analysis of patent pools related to technological standards. The development of the essential technology for a standard does not follow a general trend, nor do patent files and patent declarations for different standards increase or decrease at the same time. Rather, we will show that the patenting and declaration rates follow an inverted U-shape over the development of the specific standard: the number of patent files related to technological standards increases up to the year of standard release and eventually declines, while the number of declarations culminates three years later. We will control for this baseline timing of patenting and declaration with respect to standardization by including a full set of standard age dummies. We furthermore control for different levels of investment in different standards with company-standard pair fixed effects.

In order to accurately estimate the baseline timing for standards related to patent pools, we estimate the baseline timing only over the subsample of standards for which at least some firms license out their patents through pools. This approach is warranted, if the standards licensed out through patent pools substantially differ from other standards. For instance, we expect that patent pools are concentrated on standards including many patents by many different firms, and that the development of these standards is more complex. Nevertheless, the estimated baseline timing is not completely unaffected by the creation of patent pools, even though different standards are affected by pool creation at different moments.

In a first robustness check, we thus estimate the baseline timing over the whole sample of standards including at least one declared essential patent. This yields a baseline timing which is unaffected by patent pools, but which is more prone to heterogeneity among standards. We therefore conduct a second robustness check on a sample of standards which are similar to standards licensed out through pools based upon observable characteristics. As can be seen in appendix 3, standards related to pools are updated more often and are significantly larger in terms of pages. These standards are much more often developed in connection with informal consortia, and they receive declarations of essential patents from a much higher number of firms. All these differences reflect the higher technological complexity and more important commercial stakes involved in these standards. Using these observable standard characteristics, we can construct a control sample of standards of comparable technological complexity and commercial importance (a detailed account of the sampling method based upon a PSM analysis is provided in appendix 4).

4.3 Patent declarations and standard dynamics

We wish to analyze how the pooling of patents affects the rates at which companies file and declare essential patents. Therefore we compare the level and timing of patenting and patent declarations between standards related to a patent pool and standards licensed out individually. We furthermore distinguish between standards released before and after the policy change with respect to patent pools.

As discussed, we have constructed two counts of standard-related patents: patent declarations and patent files in standard relevant IPC classes. We first analyze the timing of patenting and declaration with respect to standard development. Figure 5 compares the timing of our two measures around a standard release. In standardization, the release of the first standard version represents an important event. The first standard version specifies the core technological components that determine imminent standardization. Even though standards are regularly updated and may consequently progress in their technological scope beyond release, the first version often specifies a technical trajectory for ongoing development phases.

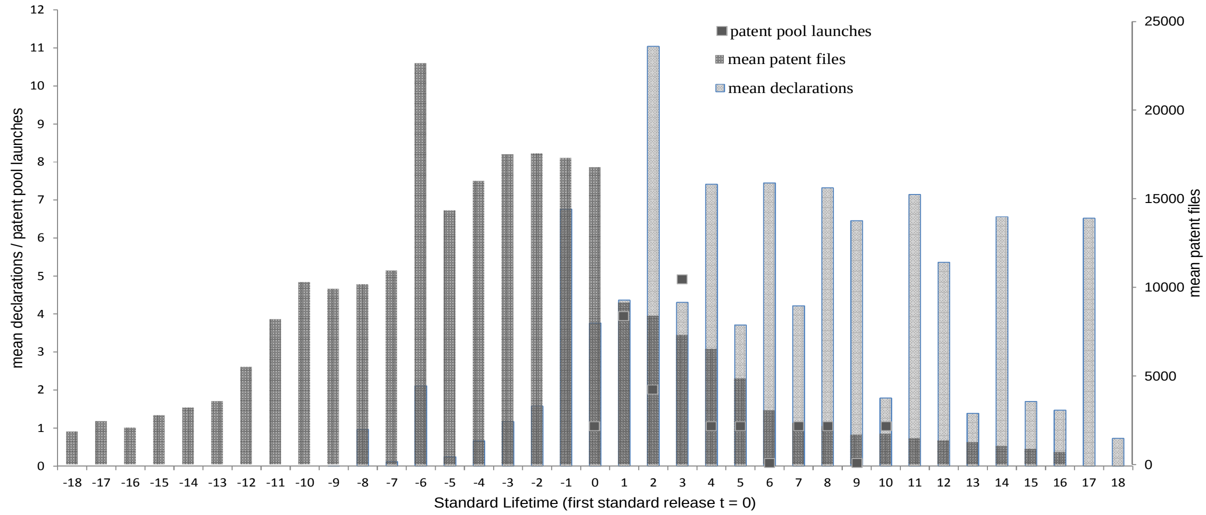

Figure 5 Patent files and Patent Declaration as to pool timing

The figure reveals the typical timing of patenting and patent declarations along the development of a technological standard. Most patents are filed during the four years preceding the first standard release, when the technological basis of the standard is under development. Most declarations are made after the first standard release. Furthermore the count of patent declarations is rather volatile and has a steeper peak around standard release compared to patent files. The graphical analysis shows that the patent count variable also measures some early R&D activities prior to standardization.

We next compare if firms' patent declaration timing differs when patents are pooled or not. In figure 6 we plot the mean patent declaration per firm over standard age. Both graphs show a peak of declaration around the year of standard release. This underlines our argument that the first version contains a major part of the standard's technology components. However, the figure also illustrates that standards related to pools exhibit an unusually high level of declarations in later periods. In comparison, standards without pools experience an almost steady decrease of patent declarations after release.

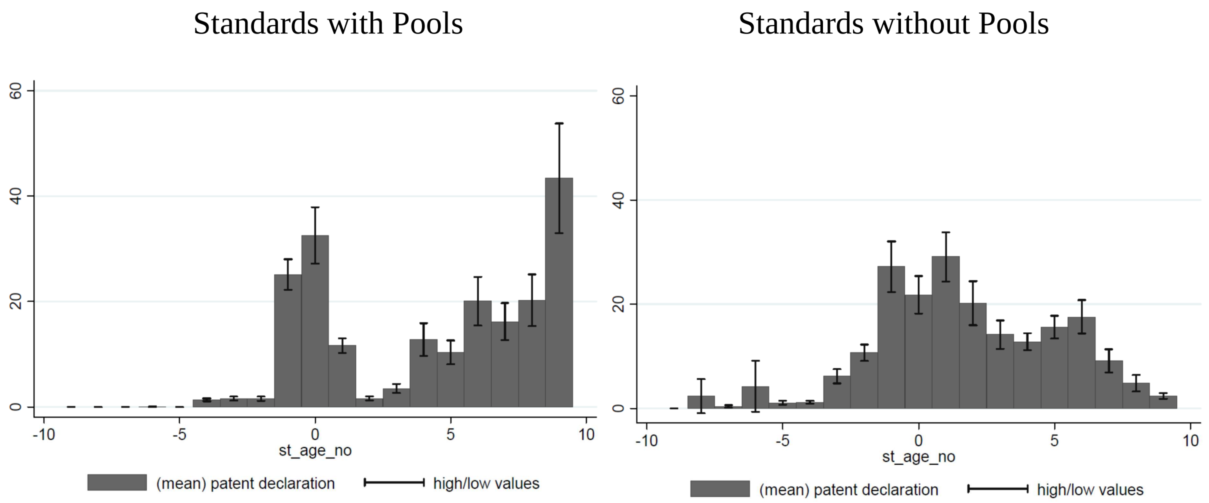

Figure 6 Patent declaration as to standardization timing if patents are pooled or not

In order to analyze whether the unusual peak in declarations well after standardization is related to pool creation, we turn to a panel data analysis. The unit of observation is a one year time span for each standard. We control for standard fixed effects, the baseline timing of declaration along standard development, for exogenous technology shocks and for standardization events (such as modifications or releases of new versions). We can then test whether the creation of a patent pool is related to an otherwise unexplained high level of patent declarations by introducing dummies for two-year periods around pool creation. We thus estimate the following poisson regression:

$$n_{S,Y} = \exp(\alpha_i PC_{S,Y+3} + \alpha_{ii} PC_{S,Y+1} + \alpha_{iii} PC_{S,Y-1} + \alpha_{iv} PC_{S,Y-3} + \theta S_S + \delta T_S + \eta S_{S,Y} + \zeta T_{S,Y} + \varepsilon_{S,Y})$$

Where $n_{S,Y}$ is the number of declarations per standard per year, $PC_{S,Y+3}$ to $PC_{S,Y-3}$ are dummy variables for the timing with respect to pool creation, S_S and T_S are time-invariant standard and technology characteristics, $S_{S,Y}$ and $T_{S,Y}$ are time variant standard and technology characteristics, and ε is an idiosyncratic error term. In the fixed effect specification, S_S and $T_S$are replaced by a standard fixed effect.

The full regression results can be consulted in appendix 2. The following figure 7 plots the estimated coefficients for the periods around pool creation. We can see that these periods exhibit significantly positive coefficients. The estimated coefficients are at the highest for the periods immediately preceding pool creation; and significantly decrease thereafter. This finding could indicate that preparations for pool creation trigger unusually high levels of the declaration rate well after standard release (indeed patent pools are usually launched several years after standard release). Alternatively, it could also indicate that patent pool creation is a reaction to periods of an unusual intensity of patent declarations.

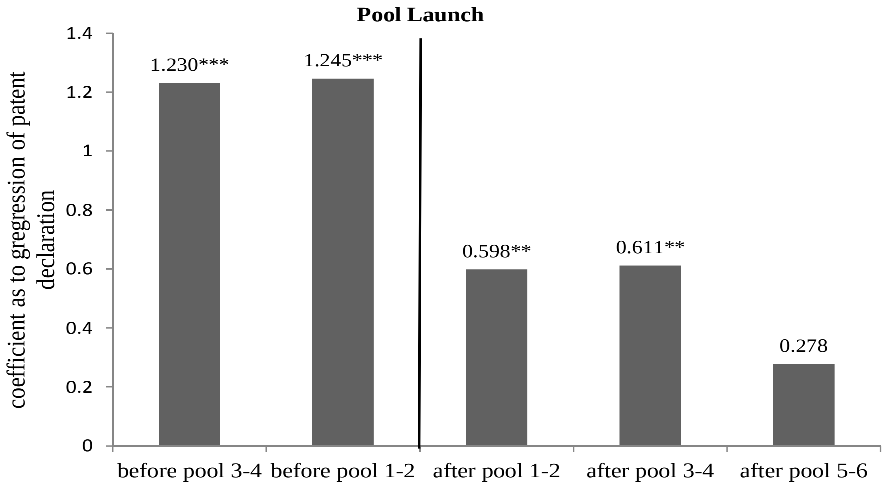

Figure 7 Coefficients on timing with respect to pool launch[12]

4.4 Patent pools and the timing of patenting

In a next step, we plot the evolution of our count of standard related patent files per firm standard pair over standard age. The timing of patenting refers to the date of patent publication. Again the two graphs in figure 8 illustrate that the timing of patenting differs when patent pools exist. Compared to the bell shaped distribution of patent files around the release of standards without pools, we observe an increase of patenting several years after the first release when the standard is related to a pool. Indeed most patent pools are formed several years after standard release. However, we have to be cautious in interpreting these shifts of patenting or patent declaration. On the one hand, we could argue that patent pool formation increases incentives to invest in R&D, leading to a peak in patent files that deviates from the normal timing of patenting around standard development. On the other hand, we could argue that patent pools are particularly formed for standards that are subject to ongoing technology development beyond standard release.

[12] ∗∗∗, ∗∗,and ∗ imply significance at the 99%, 95%, and 90% levels of confidence, respectively

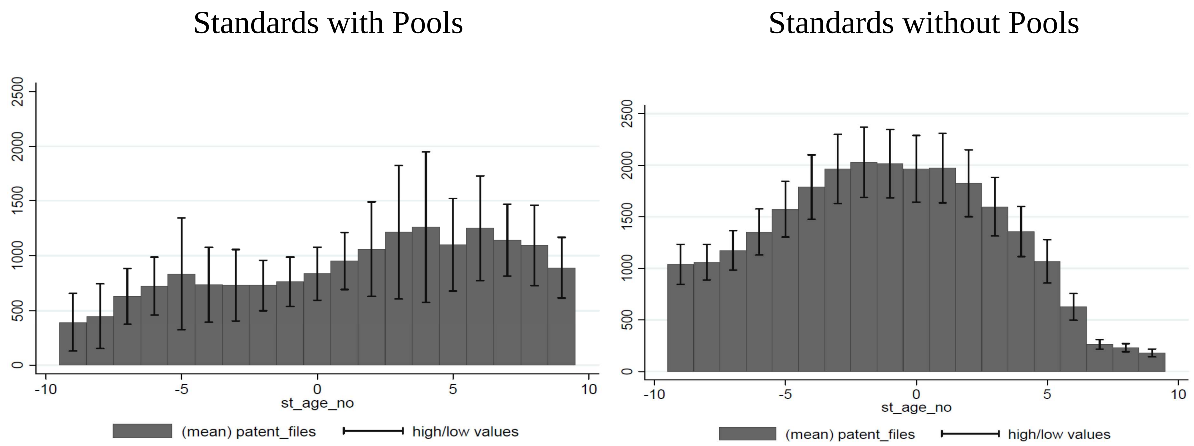

Figure 8 Patent files as to standardization timing if patents are pooled or not

Once again, we analyze whether the unusually high level of late patenting on standards related to patent pools can be connected to the timing of pool creation. We therefore graph patent files per company over time with respect to pool creation. We distinguish between pools for standards released before and after 1999.

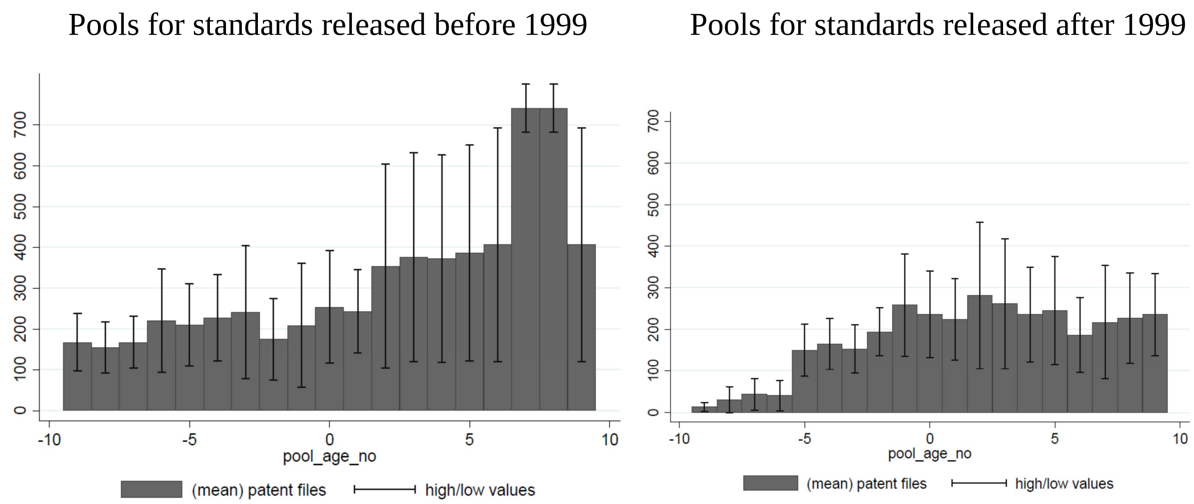

Figure 9 Patent files as to pool timing, standards released before and after 1999

Figure 9 illustrates patent files per firm as to pool timing for standards released before and after 1999. The graph for standards released after 1999 does not show clear evidence for a specific timing of patenting as to the creation of patent pools. We have discussed earlier that the business review of antitrust authorities ensured a legal certainty in periods after 1999. We have argued that for standards released after this date, the possibility of an eventual pool creation can be taken into account by the companies while investing in standard related R&D during the standard development phase. In comparison, for standards released before 1999, there is a strong peak in patent files well after the initial launch of a patent pool. These differences support our approach to distinguish between pools created for standards released before and after policy change. However, difference in the timing of patenting around pool creation between earlier and later standards could also be due to changes in the general dynamics of standardization, rather than the effects of a policy change on the expectations of pool creation. We therefore carry through a further analysis where we include a group of comparable control standards to account for generic changes in standard dynamics.

4.5 Patent pools and time shifts

We apply an additional analysis in order to examine the effects of expected pool creation. As we want to analyze the effect of a prospective pool launch on the overall timing of standard-related patenting, we need a counterfactual group of standards that are closely comparable with the analyzed standards in terms of technological complexity and commercial relevance, but are not licensed through a patent pool. As discussed, we have built up a control group of standards similar to standards related to pools based upon observable characteristics. These characteristics for instance account for the technological complexity and commercial stakes involved in the different standards (see appendix 4 for details).

We then compare the timing of patenting around standard development between the different groups of standards. We estimate the number of standard-related patent files by firm standard pair and year, controlling for fixed effects, persistent effects of transitory shocks, standard age dummies, and events affecting the standard and exogenous factors in the field. We test for the time-shifting effect of patent pools by including a linear standard age variable, which we interact with the dummy variable indicating that the standard is related to a pool. As in the previous analysis, we estimate this effect separately for standards issued before and after the policy shock[13] (results can be consulted in the appendix 5).

We estimate coefficients on the whole sample from 1992 to 2009. In order to avoid truncation of the observation period, we include for all standards only observations for the four years preceding and the four years following to standard release and restrict the sample to standards issued from 1995 to 2005 (results are robust to estimating the model over the full sample and the full observation period). We find that patent pools for standards released after

[13] As we are now interested in effects of patent pools on R&D investment made early in the standard life time, we decided to divide the sample at a later date. For instance, we cannot expect that the policy change from 1997 to 1999 led to an earlier start of R&D investment for standards released in 2000. We somehow arbitrarily chose the release date of 2002 as a separating line, but within reasonable bounds the results are not sensitive to the precise date separating the samples.

the policy change are connected with patenting taking place earlier in the standard life-time. We further conduct test of statistical differences for periods before and after the policy shock. The results reveal significant differences, ensuring that the time shift of patenting is specific to later standards.

4.6 Anticipation and reaction to pool creation

In order to confirm these descriptive findings, we apply econometric analysis to control for heterogeneity and isolate the pool timing effect. We use our panel of firm standard pairs over the timespan of 1992-2009. Thus we are able to make use of the baseline timing of standardization while testing for specific effects around the time when a pool is launched. All firms are observed over the whole period of time. Following our discussion of the importance of expectations, we distinguish between standards released before and after the policy change. We interact the pool dummies with a variable indicating whether the standard was released before or after 1999. We test the following specification:

$$
\begin{aligned}
st\ patents_{ijt} = \ & \exp\big(\alpha_1\ st\ patents_{ijt-1} + \beta_1\ before\ pool\ active_{jt\ PL-3/4} * \\
& years\ later\ 1999_{\ j} + \beta_2\ before\ pool\ active_{jt\ PL-1/2} * \\
& years\ later\ 1999_{\ j} + \beta_3\ after\ pool\ active_{jt\ PL+1/2} * \\
& years\ later\ 1999_{\ j} + \beta_4\ after\ pool\ active_{jt\ PL+3/4} * \\
& years\ later\ 1999_{\ j} + \beta_5\ before\ pool\ active_{jt\ PL-3/4} * \\
& years\ earlier\ 2000_{\ j} + \beta_6\ before\ pool\ active_{jt\ PL-1/2} * \\
& years\ earlier\ 2000_{\ j} + \beta_7\ after\ pool\ active_{jt\ PL+1/2} * \\
& years\ earlier\ 2000_{\ j} + \beta_8\ after\ pool\ active_{jt\ PL+3/4} * \\
& years\ earlier\ 2000_{\ j} + \beta_9\ CT\ patent\ count_t + \beta_{10} \\
& standard\ activity_{jt-1} + c_t + \varepsilon\big)
\end{aligned}
$$

Where we count st $patents_{ijt}$ filed by firm *i* that are relevant to standard *j* per year *t*, $before\ pool\ active_{jt\ PL+3/4}$ equals one 3 to 4 years before the pool launch *PL* for standard *j* in year *t*, $before\ pool\ active_{jt\ PL-1/2}$ equals one 1 to 2 years before the pool launch *PL* for standard *j* in year *t*, $after\ pool\ active_{jt\ PL+1/2}$ equals one 1 to 2 years after the pool launch *PL* for standard *j* in year *t*, $after\ pool\ active_{jt\ PL+3/4}$ equals one 3 to 4 years after the pool launch *PL* for standard *j* in year *t*, $years\ later\ 1999_{\ j}$ is a dummy variable that equals one if a standard *j* is released later than 1999, $years\ earlier\ 2000_{\ j}$ is a dummy variable that equals one if a standard *j* is released earlier then 2000, $CT\ patent\ count_t$ denotes all worldwide ICT patent files for each year *t*, $standard\ activity_{ijt-1}$ denotes version releases and amendments to standard *j* in year *t-1*, c_t are year dummies and ε is an idiosyncratic error term.

We restrict our standard firm pair panel to standards for which a pool has been created at some time, and further control for unobserved heterogeneity using fixed effects. Thus we rely on a sample of standards that is subject to a comparable pattern. Rather than accounting for pre-existing trends or supposing linear evolutions, we include a full set of standard age dummies to control for the bell shaped baseline pattern of patenting around standardization observed in the descriptive analysis. We furthermore control for particular events affecting the standard in question (including variables for standard upgrades) and for technological shocks in the wider technological field (including the overall number of ICT patents files in the categories G and H per year). We furthermore control for persistent effects including the lagged dependent variable as control variable. We use a poisson estimator with robust standard errors, and furthermore cluster standard errors by firms (clustering standard errors by standards instead does not alter the results). In models M1a-M1c we sequentially include our control variables of standard updates and lagged patent files to ensure independency from our main explanatory variables. In M2 we only use observations of member companies and thus reduce our sample from 242 to 93 group observations. In M3 we also include variables accounting for the timing of pool member entrance. This is due to the possibility that firms which are prospective pool members might react on both, the time when the pool is created and the time when they actually join the pool. All models show robust results for our main explanatory variables.

The results corroborate our methodology to distinguish between standards released before and after the policy change with respect to patent pools. Indeed, the link between patent pools and patenting is very different in the two different samples. For standards released earlier than 2000, we can observe that the creation of a patent pool is immediately followed by an unusually high level of patenting. This group of standards has been released at a time when the prospect of pool creation was still very uncertain. Pool creation became common practice after 1999, when these standards were already released. In comparison, we do not evidence any significant reaction to the creation of patent pools in the sample of standards issued later than 1999. However, our results indicate an anticipatory effect. Periods up to 4 years before pool launch have a significant positive effect for observations of contemporary pools later than 1999.

DV= patent_files	M1a	M1b	M1c	M2	M3
Variable	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)
3-4 y. before pool launch (later 1999)	0.122*** (0.027)	0.151*** (0.028)	0.149*** (0.027)	0.162*** (0.028)	0.145*** (0.033)
1-2 y. before pool launch (later 1999)	0.122*** (0.035)	0.136*** (0.029)	0.127*** (0.031)	0.114** (0.045)	0.152*** (0.037)
1-2 y. after pool launch (later 1999)	-0.006 (0.045)	0.043 (0.036)	0.027 (0.04)	0.122* (0.066)	0.050 (0.035)
3-4 y. after pool launch (later 1999)	-0.074* (0.044)	-0.076* (0.04)	-0.071* (0.041)	0.039 (0.064)	-0.056 (0.04)
3-4 y. before pool launch (earlier 2000)	0.071 (0.066)	0.078 (0.062)	0.090 (0.064)	0.024 (0.064)	0.188*** (0.056)
1-2 y. before pool launch (earlier 2000)	0.032 (0.083)	0.075 (0.062)	0.091 (0.063)	0.04 (0.068)	0.129* (0.068)
1-2 y. after pool launch (earlier 2000)	0.350*** (0.128)	0.330*** (0.12)	0.340*** (0.116)	0.468*** (0.109)	0.268*** (0.085)
3-4 y. after pool launch (earlier 2000)	0.159 (0.108)	-0.023 (0.056)	-0.019 (0.056)	0.055 (0.085)	-0.065* (0.037)
patent files in G and H [1]	0.011*** (0.002)	0.010*** (0.002)	0.010*** (0.002)	0.011*** (0.002)	0.010*** (0.002)
Lag1 patent files		0.076*** (0.011)	0.075*** (0.011)	0.071*** (0.012)	0.077*** (0.008)
Lag 1 standard upgrade			-0.022* (0.013)	-0.048*** (0.016)	-0.018 (0.013)
1-4 y. before pool entry (earlier 2000)					0.067 (0.047)
1-4 y. before pool entry (later 1999)					-0.065 (0.06)
1-2 y. after pool entry (earlier 2000)					0.175** (0.071)
3-4 y. after pool entry (earlier 2000)					0.232** (0.113)
1-2 y. after pool entry (later 1999)					-0.102* (0.059)
3-4 y. after pool entry (later 1999)					-0.028 (0.057)
Standard Year Dummies	Included	Included	Included	Included	Included
Observation	3,928	3,928	3,928	1,473	3,928
Groups	247	247	247	93	247
Log likelihood	-476,922	-446,830	-445,701	-190,429	-438,846

Note: All models are estimated using the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. $***$, $**$,and $*$ imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible.

Firms that declare patents to standards where a pool will be created may react to two events: first, the launch of the patent pool and second, the timing of joining the pool as a full member. In the last model we therefore also include the timing of joining a patent pool. In comparison to M1-M3 our last model differentiates the timing of two effects. The effects of the pool creation remain unchanged. In the timing of joining a pool firms show no reaction in periods before or after joining for periods later than 1999. In comparison, firms active in pools for standards released before 1999 show an incremental positive reaction immediately after joining the pool. This effect last for up to 4 years. However, for the latter sample of firm-standard pairs, the positive effect of pool creation is still slightly stronger compared to the effect of actually joining the pool.

4.7 Robustness

In our first models (M1-M3), we compared the observed rate of patenting with the baseline evolution of patenting over standard age estimated exclusively for standards which are licensed through patent pools. This makes sure that we work with a sample of comparable standards and reduces heterogeneity. However, the estimated baseline timing of patenting with respect to standard development is not unaffected by patent pools. In a first robustness check, we thus compare the timing of patenting for standards related to pools with the timing around standards where pools do not exists. We therefore make use of our whole sample of standards where at least one patent has been declared essential, consisting in 1,704 firm standard pairs. We estimate our third model (M1c) over the expanded sample (M4-1).

As discussed, standards where patent pools exist differ from other standards in technological characteristics and in the characteristics of the contributing firms. We gradually reduce our sample to better account for these differences. To account for differences in contributing firms, we identify firms which are technological outsiders with respect to other firms also contributing to the same standard. Indeed, firms may have a different patenting timing when they specialize on different technologies relevant for the standard. In order to limit this firm specific heterogeneity, we measure the technological difference between the essential patents declared by different firms using the overlap of IPC classes. In model M4-2, firms are dropped if their technological focus differs strongly from the average focus of other firms.

Another source of heterogeneity between firms is that different firms can be differently affected by specific technology or business cycles. Our sample covers 18 years during which markets and technology have changed in a volatile manner, with many technology-intensive firms disappearing during the internet crisis and new actors appearing. In order to obtain a sample of firms with a comparable overall evolution, we identify positive or negative shocks to the number of employees of firms (M4-3). We observe differences in one year periods, indicating mergers, acquisitions, restructuring etc. If this shock takes place after 2000, all observations after the shock are dropped for this firm, if the shock takes place earlier, we drop all previous observations. Firms with more than one shock are dropped altogether.

DV= patent_files	M4-1	M4-2	M4-3	M4-4	M4-5
Variable	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)
3-4 y. before pool launch (later 1999)	0.177*** (0.064)	0.177** (0.084)	0.159* (0.096)	0.057 (0.05)	0.166*** (0.045)
1-2 y. before pool launch (later 1999)	0.220*** (0.061)	0.209*** (0.076)	0.197** (0.092)	0.116* (0.065)	0.095** (0.046)
1-2 y. after pool launch (later 1999)	0.071 (0.052)	0.037 (0.061)	0.043 (0.078)	0.069 (0.074)	0.027 (0.041)
3-4 y. after pool launch (later 1999)	-0.186 (0.127)	-0.244** (0.119)	-0.233* (0.123)	-0.006 (0.087)	-0.061 (0.041)
3-4 y. before pool launch (earlier 2000)	-0.115** (0.055)	-0.084 (0.079)	-0.043 (0.067)	0.035 (0.077)	0.199*** (0.069)
1-2 y. before pool launch (earlier 2000)	-0.112* (0.067)	-0.047 (0.089)	-0.009 (0.085)	0.026 (0.1)	0.133 (0.081)
1-2 y. after pool launch (earlier 2000)	0.347* (0.184)	0.428** (0.185)	0.446*** (0.172)	0.452*** (0.148)	0.413*** (0.103)
3-4 y. after pool launch (earlier 2000)	-0.014 (0.055)	0.025 (0.074)	0.103 (0.102)	0.106* (0.063)	0.098 (0.104)
patent files in G and H [1]	0.009*** (0.001)	0.009*** (0.001)	0.008*** (0.001)	0.004*** (0.001)	0.008*** (0.001)
Lag 1 standard upgrade	-0.020 (0.013)	-0.031** (0.015)	-0.028** (0.011)	-0.042*** (0.01)	-0.033** (0.013)
Lag1 patent files	0.007*** (0.001)	0.006*** (0.001)	0.004*** (0.001)	0.007*** (0.001)	0.005*** (0.001)
Standard Age Dummy earlier 2000	0.001 (0.001)	0.001 (0.002)	0.002* (0.001)	0.005*** (0.002)	0.003* (0.001)
Sample restrictions	None	Tech outsider	Employee shock	PSM	Pool Exists
Standard Year Dummies	Included	Included	Included	Included	Included
Observation	27,147	19,560	13,197	6,675	2,521
Groups	1,704	1,227	972	482	171
Log likelihood[2]	- 25,596	- 13,682	- 7,310	- 2,185	-288

Note: All models are estimated using the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. ∗∗∗, ∗∗,and ∗ imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible. [2] values in thousand.

Heterogeneity among standards is also an important source of concern. We therefore make use of our database of comparable control standards (the sampling method is discussed in appendix 4). As to our sampling method, we exclude firm standard pairs that were not matched and estimate another model (M4-4). In our last model we again restrict our sample to standards where pools exists, retaining the restrictions with respect to technical outsiders and employee shocks. All models show robust results for both the anticipation effect before pool launch for standards released later than 1999, and the prompt reaction in periods after pool launch for standards released before 2000.

4.8 Discussion

We have highlighted unusually high levels of patent declaration and patenting around the time when a patent pool is launched. For instance, we have shown that standards related to a patent pool exhibit a peak in patent declarations well after standard release. The rate of patent declaration is especially high in the two years preceding pool launch. When changing our level of analysis to the firm standard level, we have furthermore shown that there is an unusually high level of standard related patenting in the periods around pool creation. In the case of standards released after the policy change with respect to patent pools, patenting takes place before pool creation, whereas in the case of standards released before the policy change, the unusually high level of patenting takes place in the periods immediately after the creation of a pool. Furthermore, companies increase their level of standard-related patenting after joining the pool. As compared with other standards, early standards related to a patent pool are characterized by a peak in patenting occurring several years after standard release. Later standards related to patent pools do not exhibit unusual peaks of late patenting and overall patenting takes place in earlier periods than for standards not related to a pool or for standards before the policy shock related to a pool.

In principle, finding a correlation between pool creation and periods of strong patenting and high rates of patent declaration is not necessarily evidence for a causal effect of patent pools. As patent pools are conceived a solution to the problems of large numbers of complementary patents, it is plausible that periods of unusually strong patenting or high declaration rates lead to launches of patent pools. This argumentation does however not explain why the creation of patent pools for standards released before the policy change is followed by an increase in patenting. In the case of these standards, pool creation can be considered as an unexpected response to a relatively exogenous policy change. While several companies initiated the project to create a pool before 1997, the favorable business review revealed new information on a more permissive policy stance. The direct increase in patenting as a reaction to pool creation, especially but not only by pool members, can therefore be interpreted as an immediate reaction to newly revealed information. The distinction between standards released before and after the policy change is indeed a crucial condition for interpreting our findings as evidence of causal effects of patent pools.

We have argued that the favorable business review of patent pools in 1997 and 1999 created a template for viable pool licensing schemes. Companies investing in R&D related to standards released after this policy change could take the creation of a possible patent pool into account. Due to the benefits of patent pools for holders of essential patents, the prospective creation of a patent pool is expected to induce companies to increase their efforts to obtain essential patents (Lerner and Tirole, 2004, Aoki and Schiff, 2008). Dequiedt and Versaevel (2012) expect that this induced effect takes place before the pool is actually created, and culminates in the periods immediately preceding the launch of the pool. This expectation is based upon the assumption that patent holders would prefer being among the founding members of a pool, rather than having to negotiate entry with incumbent members. This assumption finds empirical support in Baron and Delcamp (2012). Based upon this hypothesis, Dequiedt and Versaevel (2012) also predict that expected patent pool creation induces companies to overall anticipate their investment in related R&D. Our empirical findings are thus fully consistent with the predictions of the theoretical literature on the effects of prospective pool creation on ex-ante incentives to invest in related R&D and patenting.

It should however be stressed that our findings are limited by the fact that we do not directly observe firms' expectations with respect to future pool creation. We only observe actual pool creation on some standards, and assume that at least some firms expected pool creation for these standards with a higher likelihood than for other standards released at the same time. In future work, it should be analyzed whether our findings are robust if we explicitly model expectations as a function of observable standard characteristics in conjunction with learning about the conditions for successful pool creation.

5. Conclusion

In this article, we have analyzed whether the recent policy change with respect to patent pools has contributed to the increasing number of declarations of essential patents in ICT standardization. Indeed, we show that the policy change has altered expectations concerning the creation of a patent pool. We provide evidence that patent declaration as well as firm individual patenting show unusually high levels around the launch of a standard-related pool. There is an important difference between standards released before and after the policy change. While patenting is especially high before the pool is launched for the most recent standards, we find a direct effect right after pool creation for standards released before 1999. These findings indicate that companies were less able to anticipate pool formation before 1999, when patent pools were still subject to legal uncertainty. Today, patent pools are commonly accepted by antitrust authorities and several successful pools set an example for well-functioning mechanisms for pooling patents. Firms are thus able to include the possibility of a pool formation in their expectations of future returns on patents.

Our findings overall support the argument that patent pools have a positive effect on patenting. However, our analysis on the increasing number of patent declarations points out that patent pools have contributed very little to this increase. Most patent declarations are declared to standards that do not qualify for pooling patents. Still, policy makers should take into account that firms’ incentives to patent may change due to a pool creation.

However, our analytical framework does not allow us to conclude whether this incremental patenting reflects an increase in substantial innovation or opportunistic patenting. The theoretical proposition that an increase in the expected value of patents leads to more R&D investment rests upon the assumption that firms cannot easily adapt their patent propensity. Given the importance of strategic patenting in the field of ICT standards, we would not be confident to interpret increases in the number of patents as evidence of an increase in substantial innovation. Further empirical research using outside measures of technological progress is required to analyze this question.

Furthermore, our research has pointed out that innovation measures need to take into account the role of expectations. We have made the case that in order to analyze substantial effects on innovation, researchers should focus upon the R&D investment incurred preceding expected or at least foreseeable patent pool creation. Our information on expectations concerning pool creation is however limited to the policy change. A challenge for future research is to better measure firms’ expectations concerning pool creation, which may also depend upon pool experiences, market constellations, licensing strategies and implicit or explicit agreements between firms.

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Appendix

Appendix 1 Patent Pools Standard Match and Timing

Pool	Pool Launch	License Available	Standard
mp3	1992	1992	ISO/IEC11172-3
MPEG2	1997	during 1997	ISO/IEC13818-1/ITU-TH.220.0
DAB	1998	1998	ETS300401
G.729	1998	July 1999	G.729
G723.1	2000	from 2000	G.723.1
IEEE1394	2000	2000	IEEE1394
MPEG2AAC	2000	2000	ISO 13818-7 (MPEG2 AAC)
DVB-T	2001	during 2001	EN300744
MPEGAUDIO	2001	2001	ISO/IEC11172-3
MPEG4Audio	2002	2002	ISO/IEC14496-3
MPEG4Visual	2002	2002-11-25	ISO/IEC14496-2
MPEG4Systems	2003	2003-2-4	ISO/IEC 14496.1
AMR	2004	2004-2-24	AMR
AMR-WB+	2004	2004-10-4	AMR-WB+
AVC	2004	2004-7-15	ISO/IEC14496-10/ITUH.264
DRM	2005	2005-3-28	ETSI ES 201 980 V1.2.2 (2003-4); ETSI TS 101 968 V1.1.1 (2003-04); IEC 62272-1 Ed. 1
IEEE802.11	2005	2005-4-14	IEEE802.11/ISOIEC8802-11
UHFRFID	2005	2005	ISO/IEC18000-6
DVB-MHP	2006	2006-3-2	ETSI …
MPEG2Systems	2006	2006-4-16	ISO/IEC13818-1/ITU-TH.220.0
OCAP	2006	2007-6-5	.
NFC	2007	2007-6-5	ISO/IEC18092
VC1	2007	2007-3-14	.
G729.1	2008	2009-1-12	G.729.1
AGORA-C	2009	2009-8-5	ISO 17572-3
AMR-WB/G.722.2	2009	3Q 2009	G.722.2
CDMA-2000	2009	2009-6-10	CDMA Family: CDMA2000 1X, CDMA2000 1xEV-DO and Ultra Mobile Broadband (“UMB”)
G711.1	2009	beginning 2009	G.711.1

Appendix 2 Timing of patent declaration as to pool launch

DV = patent declaration Vaiable	Coef. (S.E.)
3-4 y. before pool launch	1.230*** (0.290)
1-2 y. before pool launch	1.245*** (0.276)
1-2 y. after pool launch	0.598** (0.300)
3-4 y. after pool launch	0.611** (0.293)
5-6 y. after pool launch	0.278 (0.332)
Version Release	0.090*** (0.140)
Amendment	0.220*** (0.042)
Standard Age	0.161*** (0.008)
Standard Age Square[1]	-0.001*** (0.001)
Standard Year Dummies	included
Observation	8,730
Groups	485
Log likelihood	-5,805

Notes: All models are estimated using the conditional fixed-effects poisson estimator, standard errors (reported in parentheses). ∗∗∗, ∗∗,and ∗ imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 100 to make effects visible.

Appendix 3 T-Test analysis t-tests of explanatory variables by standard with and without patent pools

Standard Updates						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	567	0.360	0.057	1.361	0.248	0.472
St. with Pool	17	3.647	0.818	3.372	1.914	5.381
t = -9.1848 Pr(|T| > |t|) = 0.0000						
Number Pages						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	567	89.280	7.504	178.681	74.541	104.019
St. with Pool	17	159.882	37.181	153.301	81.061	238.703
t = -1.6111 Pr(|T| > |t|) = 0.1077						
Accompanying Standards Consortia						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	568	0.132	0.022	0.526	0.089	0.175
St. with Pool	17	1.941	0.466	1.919	0.954	2.928
t = -12.0743 Pr(|T| > |t|) = 0.0000						
Declaring Companies						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95 %ConfInterval]	
St. without Pool	568	7.273	0.652	15.527	45.99	8.553
St. with Pool	17	55.882	18.521	76.366	16.61	95.146
t = -9.9426 Pr(|T| > |t|) = 0.0000						
NPE on Standard Dummy						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	568	0.276	0.019	0.448	0.240	0.313
St. with Pool	17	0.824	0.095	0.393	0.621	1.026
t = -4.9816 Pr(|T| > |t|) = 0.0000						
NPE Share (for Standards with NPEs)						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	157	0.296	0.019	.235	.259	0.334
St. with Pool	14	0.147	0.021	.077	.102	0.191
t = 2.3571 Pr(|T| > |t|) = 0.0196						
Gini Coefficient of Essential Patent Dispersion						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	511	0.175	0.010	0.228	0.155	0.195
St. with Pool	17	0.267	0.048	0.199	0.165	0.369
t = -1.6484 Pr(|T| > |t|) = 0.0999						

Appendix 4 PSM Sampling for comparable standards

Our goal is to identify a comparable sample of standards that are licened individually to match it with partly pooled licensed standards. Propensity score matching (PSM) is a widely used approach to estimate causal treatment effects. We therefore apply a logit based propensity score matching algorithm to identify a common support region for both samples. In a first step we search for variables that explain the occurrence of pool formation. It is important to only use variables that are unaffected by the treatment (Heckman et al., 1999). We therfore only employ variables that are measured before pool formation. In particular we only estimate variables until two years after standard release to ensure a uniform measure among standards. In the literature it is argued that choosing to many variables might excaberate the support problem (Bryson et al., 2002). When including non-significant variables to explain the treatment, the propensity score estimates will not be biased but increase in their variance. As to Heckman et al. (1998) we therfore include all explanatory variables in our estimation and only keep variables when they are statistically significant and when they increase the prediction rates. Proceeding that way we dismiss standard characteristics such as the number of pages, the number of declaring companies, the number of essential patents and the gini coefficient of patent distribution. All of these variables did not significantly explain a pool formation and did not increase our prediction results. In comparison we found significant results for the occurrence of NPEs on standards, the existance of collaborating standards consortia and the number of standards updates (table 4).

DV= Pool Exists	Coef.	(SE)	z
Standard Updates	0.099*	(0.055)	1.81
Standard Consortia	0.259**	(0.114)	2.28
NPE Share	-4.188*	(2.257)	-1.86
Constant	-0.882	(0.444)	-1.99
Observations		102	
Pseudo R		0.3038	
Log likelihood		-27.091	

Table 4 Probit Regression

As to our t-test results more than 82% of the standards where we find a patent pool have at least one NPE that has declared essential patents on that same standard. We believe this to be an objective restriction to identify a comparable sample of standards. As discussed earlier, NPEs are an indicator of licensing profits from essential patents. Our PSM estimation is thus restricted to standards where at least one NPE declares essential patents and where the release of the standard has at least been three years ago. Table 4 shows that standards with consortia, with more updates but a lower NPE share explain the formation of pools. The latter results shows that the occurrence of NPEs is positivley connected while a higher share is negativly connected. Our former conducted t-test proved these results.

Figure 10 shows results of our PSM graph of treated (strandards with pools) and untreated (individually licensed standards) goups. We apply the nearest neighbor matching method where we identify matching partners of treated and untreated standards. We use a matching with replacement, where we allow matching an untreated standard observation more than once. This method is especially efficient when we have very different propensity scores as evidence in figure 10. Matching high with low values would result in bad matches. We overcome this problem by allowing replacement which on the other hand increases the variance of the estimator (Smith and Todd, 2005).

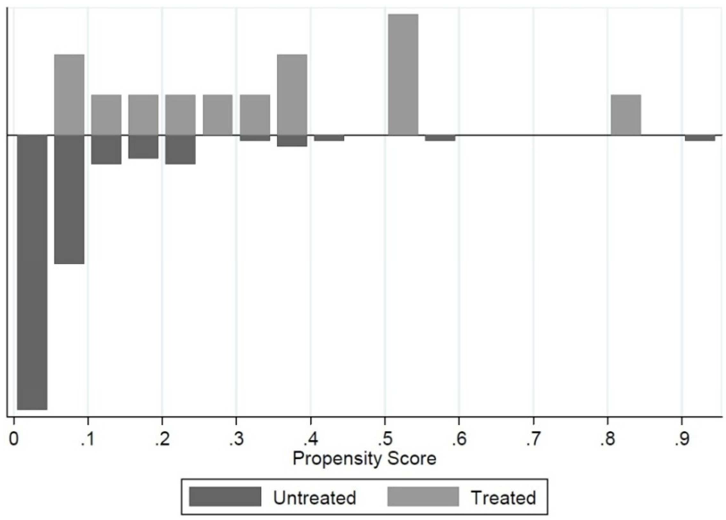

Figure 10 psm matching results

We also apply a maximum propensity score distance (caliper) but our neighbor matches remain the same. We conduct a sample statistic test after our propensity score matching. Table 5 shows that there is no remaining significant differences between characteristics of the standards in the two samples.

	Mean			% bias	% reduct	t-test	
Variable	Sample	Treated	Control		bias	t	p>t
Standard Updates	Unmatched	4.384	1.303	101		3.68	0.000
	Matched	4.384	7.230	-93.3	7.6	-1.59	0.124
Standard Consortia	Unmatched	2.231	0.404	113.5		5.03	0.000
	Matched	2.231	1.231	62.1	45.2	1.23	0.230
NPE Share	Unmatched	0.139	0.271	-85.3		-2.28	0.025
	Matched	0.139	0.127	7.4	91.4	0.47	0.642

Table 5 Sample statistics, matched and unmatched samples

Appendix 5 Time shift analysis

DV= patent files	M5	M5-1	M5-2
Variable	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)
standard age before 2002	-0.009***	0.004*	0.005**
	(0.001)	(0.002)	(0.002)
standard age * pool exists before 2002	-0.001***	-0.001	-0.001
	(0.001)	(0.001)	(0.001)
standard age after 2002	-0.006***	-0.006***	-0.005***
	(0.001)	(0.001)	(0.001)
standard age* pool exists after 2002	-0.004***	-0.003*	-0.003*
	(0.001)	(0.002)	(0.002)
patent files in G and H 1	0.011***	0.002	0.001
	(0.001)	(0.001)	(0.001)
Lag 1 standard Upgrade	-0.016	-0.006	-0.002
	(0.01)	(0.008)	(0.005)
Lag1 patent Files	0.001**	0.002***	0.001***
	(0.001)	(0.001)	(0.001)
Standard Year Dummies	Included	Included	Included
Added Restriction standard time and years	No restrictions	4 years bef. & aft. standard release	M5 restriction + 1995-2005
Observation	10,228	4,232	3,259
Groups	640	640	466
Log likelihood	-9,044,428	-2,107,350	-1,688,240

Note: All models are estimated using the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. ∗∗∗, ∗∗,and ∗ imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible.

Attributes and Dynamic Development Phases of ICT Standards Consortia

Abstract

Standards consortia are private industry alliances that serve a certain purpose and gather likeminded companies that share the same interest to sponsor and develop technologies for standardization. Compared to formal standard setting, participation in consortia is less bureaucratic, more efficient in reacting to market needs and allows, in respect to the tiered membership structures, a strategic influence of standard setting outcomes. Formal standardization is in contrast an often protracted process of development and negotiation. This paper tries to provide a broad and comprehensive picture of standards consortia and their dynamic development in the past ten years. Analyses show that consortia have distinct characteristics which help to explain and justify their presence in the standard setting context. The observation of consortia existence over time identifies relationships between the formation, termination and merger of consortia with respect to market and technology development. Furthermore the paper seeks to measure consortia performance with respect to organizational structures and market position. Therefore we test the likelihood of consortia termination. Results of a survival analysis reveal that the probability of consortia success is especially connected to structures that determine coordination among members. Additionally the scope and focus on technology and markets also influences if consortia remain in business over time.

Contents

1. Introduction

In the past years the complexity and speed of technological development has constantly been increasing. Especially in the field of information and communication technologies (ICT), markets show evidence of a higher variety of products and solutions in a more frequent manner (David, 1996). The need for technological standardization is growing (Blind et al., 2010), but the complexity and speed challenge companies in their coordination activities. Standard setting is a complex process, which is dependent on consensus agreements between often competing organizations. These processes can take several years. Especially formal standard bodies are sometimes not able to keep up with the market pace (Cargill, 2002). Since fast changing markets required more flexible solutions to set standards, the standardization landscape has changed over the past twenty years (Updegrove, 2008). Today not only formal standard developing organizations (SDOs), but also informal industry driven standard setting organizations such as consortia, produce widely adopted and important standard solutions. Other than formal organizations, which produce so called "de jure standards", informal consortia create and promote mostly "de facto standards" (Jakobs, 2004). For the latter we can further distinguish between a "de facto standard" developed by a single firm and a "consortia standard", where the standard is set by a group of firms (Bunduchi et al., 2008).

Formal standardization is often time consuming and can take several years, whereas informal consortia are more flexible and able to anticipate technological development and thus set the standard right in time (Cargill, 2002). Even though informal standard specifications are agreed on without a formal accreditation, they can still be widely accepted and of great importance or even follow up a certain formal standard (Blind et al., 2010). Yet, there is no common definition for a standards consortia and the consortia landscape has developed to be very heterogeneous in characteristics such as technical issues, structure, members, transparency or IP policies (Hawkins, 1999). Updegrove (2008) defines consortia as being "anything from a loose, unincorporated affiliation of companies, to an incorporated entity with offices, marketing, technical and administrative staff and a multi-million dollar budget". He distinguishes between *specification groups* which agree to promote an industry standard, *research consortia* with the main intent of creating and developing a technologic solution and *strategic consortia* which focus on the adoption of a technology or the formulization of a yet informal common practice (Updegrove, 1995).

In this article we consider standards consortia which meet the criteria set by the ISSS CEN Survey:

- *The organization must be international in outlook and scope, not simply an instrument of single-nation policy,*
- *must have an active and international membership,*
- *must not be set-up specifically as a single vendor, government, or proprietary technology advocacy group,*
- *must be of importance to the areas of standardization or its processes* (CEN/ISSS, 2009).

In Europe (Council of the European Union, 2000) and in the US (Center for Regulatory Effectiveness, 2000) standards consortia are recognized as being organizations that influence standard setting processes, but which are not officially recognized (Egyedi, 2001). So far there has not been much empirical work on the role of consortia. Earlier work mostly focuses on theoretical explanations for the existence of consortia (Cargill, Weiss 1992: Updegrove 1995; Axelrod et al., 1995; Hawkins, 1999; Bunduchi et al., 2008). More current research uses a case study approach and characterizes and compares the processes of informal consortia such as Updegrove (1995): *X Consortium and Open GIS Consortia*, Egyedi (2001): *W3C and ECMA*, Coulon (2004): *Symbian Alliance*, Anderson (2008): *ECMA, IETF, OASIS, OMG and W3C*, Koenig (2008): *FlexRay, Autosar and Jaspar*, Grotnes (2009): *Open Mobile Alliance (OMA).* A first comprehensive analysis on the evolution of standards consortia was done by Blind & Gauch (2008). They accessed a dataset of more than 250 consortia to map the change of consortia between 2000 & 2004 and found evidence for a complimentary relationship of formal and informal standard setting activities. Other empirical contributions rather focus on the effects of consortia in terms of coordination outcomes and efficiency (Leiponen, 2008; Delcamp and Leiponen; 2012; Baron et. al., 2012).

This paper presents a unique dataset of over 400 standards consortia. Consortia are analyzed by characteristics, attributes, membership, active markets and industries as well as by the dynamics of consortia evolution over the last 10 years. The article uses 14 editions of the ISSS CEN survey on ICT standards consortia. Further information was added exploiting the consortia database of Andrew Updegrove (http://www.consortiuminfo.org/). To retrieve historical membership information on consortia activity as well as memberships, the paper further makes use of the internet archive waybackmachine (http://archive.org).

2. Theoretical Considerations

In many literature sources, standards consortia are described as explicit alliances or groups, which are especially formed when the fast evolution of technology requires coordination mechanisms (Axelrod et al., 1995). Such alliances are further defined as groups of companies where the benefits of the collective activity arise from a commonly produced public good (Olson, 1971; Cargill and Weiß, 1992). Irrespective of the costs of producing the public good, the good is equally available to all members. However, members' benefits and incentives to invest may differ (Kindleberger, 1983). Groups emerge when a single firm is incapable of producing a certain good itself. Firms thus join groups when the collective activity is beneficial and exceeds the costs of membership. Incentives to join or leave the group are simply related to a cost-benefit analysis, though groups may scale costs to counteract defection (McGuire, 1972). The size of the group matters as a factor of effective coordination. As to Olson (1971), coordination failures such as "cheating" or "free-riding" diminish when the group is held respectively small. Furthermore, the costs of coordination increase with the size of the group. Groups are characterized as "exclusive" groups when the collective good increases by excluding others. In comparison "inclusive" groups are these, where it is more beneficial to include as many market participants as possible.

Group formation in standard setting postulates a special case of coordination and collective benefits. Standards are subject to network externalities since users of a standard obtain benefits not only from the technology itself but furthermore depend on the share of users in the market. Thus, the success of a standard always depends on the installed base of users (David and Greenstein 1990). When network externalities are significant, firms have to coordinate in product development processes. This coordination can be reached by standard-writing committees such as standard consortia (Weiss, Sibru, 1990). Besen and Johnson (1986) list several conditions for successful coordination in standard setting. In this sense, the consortia should gather a certain market share of the industry, the group should not be subject to antitrust objections and members should reduce the number of technological alternatives to reach consensus while further eliminating subjective disputes.

In conclusion, standards consortia are subject to network externalities, while also inhibiting coordination failures of a group. Oslen (1971) argued that small groups benefit from coordination efficiencies. In comparison Axelrod (1995) states that consortia are especially successful when they gather most market players. The latter argument is further connected to the installed base of a standard, which increases with the number of participants sponsoring the standard (David and Greenstein, (1990). To a certain extent standards consortia are inclusive, since a common standardization project is only reasonable when a sufficient number of market players participate. However, standards consortia pursue a particular approach to standardization compared to formal standard bodies. While formal standardization seeks consensus decisions and is open to all market participants, standards consortia are more closed in their membership rules. Membership fees, more regular meetings and a certain interest to influence technologies in early stages differentiate consortia from formal bodies. A consortium can thus be seen as an exclusive group of firms that are more committed to standardization or have a particular interest in a technology. However, consortia are inclusive to the limits of likeminded companies that share the same interests.

3. Methodology

This paper uses a broad approach to illustrate the dynamic landscape of ICT consortia over the past ten years. The research is based on the use of two data bases that have assembled more than 700 informal standards consortia since 1998. The CEN survey provides information on 435 informal ICT standardization consortia. These consortia have been selected based on transparent and objective selection criteria, which are stated above. The survey by Andrew Updegrove[1] provides information on 555 consortia, 276 of which are not covered by the CEN survey. Both data sources indicate the tiering of membership, the consortium scope, technical categories, industry sectors, IP policies and years of existence. The number and identification of consortium members (including 20,000 independent entities in more than 35,000 consortium memberships), was retrieved by an internet search using data from historic homepages from the internet archive waybackmachine (http://archive.org). To get a complete picture of the informal standard setting landscape, information from all databases were matched. However, to guarantee database compliance, time series analysis only uses information from fifteen editions of the ISSS CEN survey from 1998 until 2009. Furthermore, not all consortia could be classified in their respective attributes, since some consortia do not provide distinct information. Attributes such as industry sector, technical category, business spectrum and IP policy were only assessed from the CEN survey data. Finally, we build up a data panel over the time span of 1998-2009 to better assess organizational effects on consortia survival. We apply one year periods and use consortia termination as our event of failure.

[1] http://www.consortiuminfo.org/

4. Empirical Analysis

4.1 Consortia Characteristics and Attributes

In contrast to formal standard bodies where structures are fixed and default, the formation process of informal consortia allows a variety of organizational choices. The four charts in figure 1 give a vivid picture of informal ICT consortia characterized by member quantity, membership levels, business spectrum and industry sector. The two former attributes reveal information on specific member information such as quantity and member levels. The latter two charts illustrate the sector and the scope of involvement.

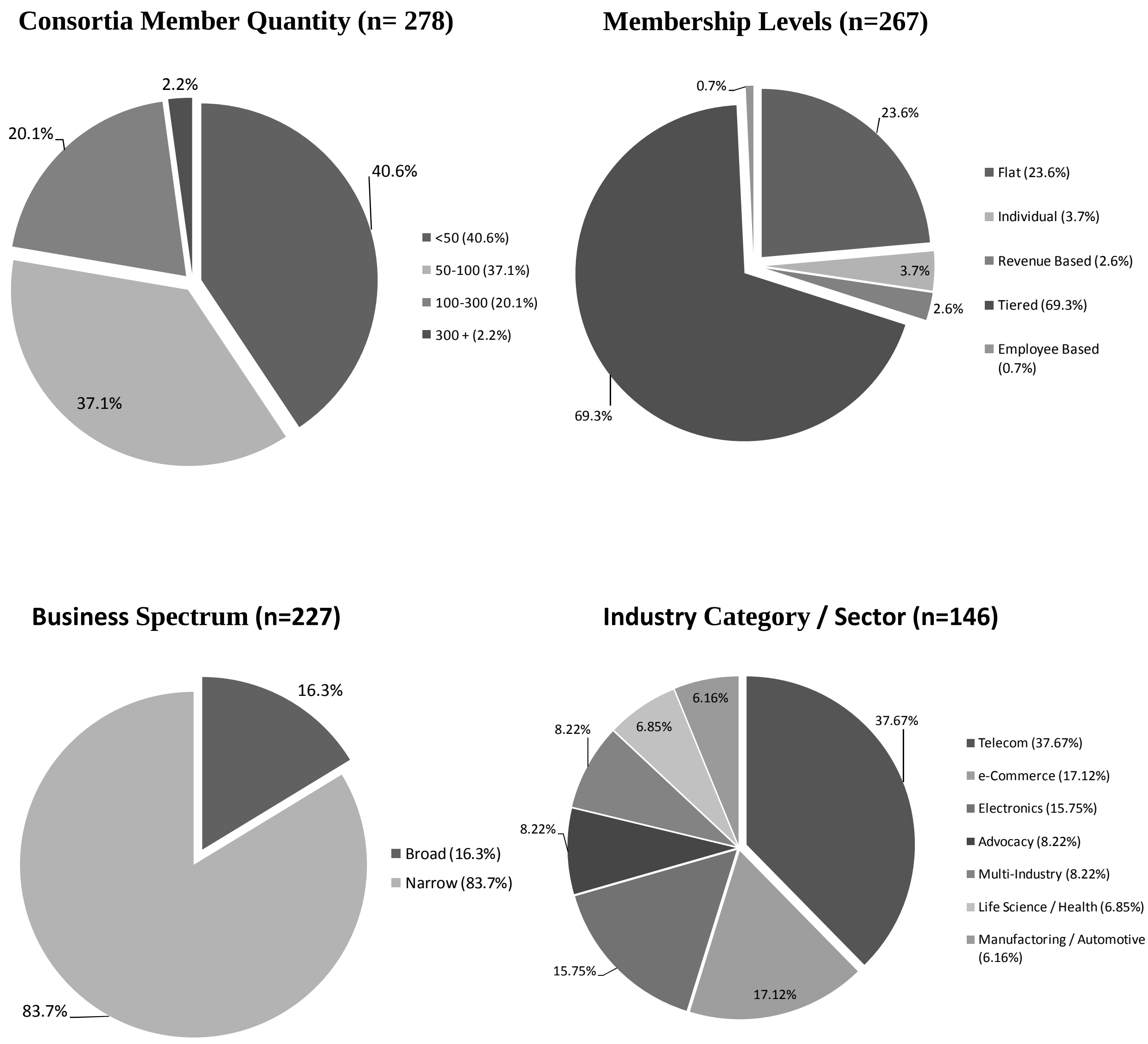

Figure 1 Characteristics and attributes of informal ICT standards consortia

Most consortia have a considerably low amount of members, since 77.7% have less than 100 participants, 20.1% have 100-300 members and only 2.2% list more than 300 members. To illustrate the scope of involvement in standard setting among consortia, the business spectrum was classified into broad and narrow. Only 16.3% of the consortia follow a broad spectrum of standardization, which is comparable to structures in formal standard bodies. The so called “one purpose consortia” usually pursue only one standard or specification and their business can therefore be classified as narrow (83.7%). These findings can be related to the quantity of memberships. The data shows that most narrow consortia tend to have a lower amount of members. A possible assumption is that this leads to more effective and flexible decision making processes within consortia. Both attributes are distinct characteristics to differentiate consortia from formal standard bodies, since the latter mostly follow a broad business spectrum and tend to have a higher number of members. The evaluation of the CEN survey further provides information on the primary and secondary industry sector where a particular consortium is active in. These findings indicate a very heterogeneous picture of the consortia landscape. In order to better frame these results, data was aggregated into seven categories. Over a third of the consortia produce standards for the telecommunication industry (37.67%). E-Commerce (17.2%) and electronics (15.75%) also make up one third of the consortia target industry. Less ICT related industries such as advocacy, life-science, manufacturing and multi-industry summarize the last third of consortia target industries. These results are in line with most researchers’ assumptions that especially ICT industries rely on more flexible and quick standard solutions developed by informal consortia.

The chart of membership levels illustrates the hierarchical structures of consortia. A flat membership structure can only be found in 23.6% of the regarded consortia. The findings indicate that informal standard setting is in many cases strategically dominated by market power and revenue of commercial entities and vendors. Organization types and shares per member level can be consulted in figure 2. The graph shows that 93.56% of the members are vendors and other commercial entities, whereas universities and colleges account for only 2.52%, governmental entities for 0.17% and consumer groups for a stake of 3.75%.

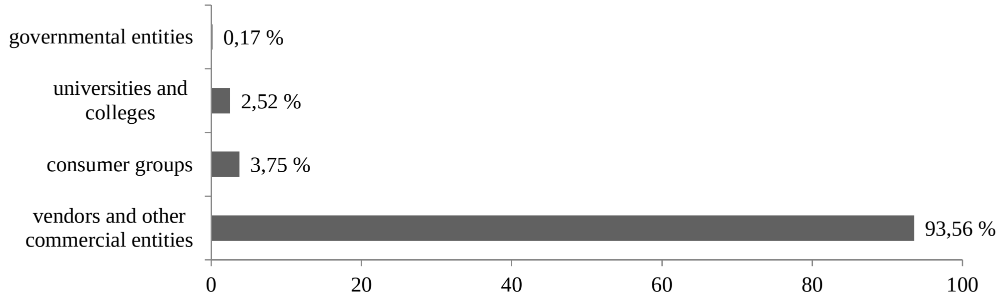

Figure 2 Consortia membership structure

As to the results of the survey, 69.3% of the standards consortia have tiered membership structures, where the member levels can in general be differentiated into *Leaders*, *Followers* and *Spectators*.

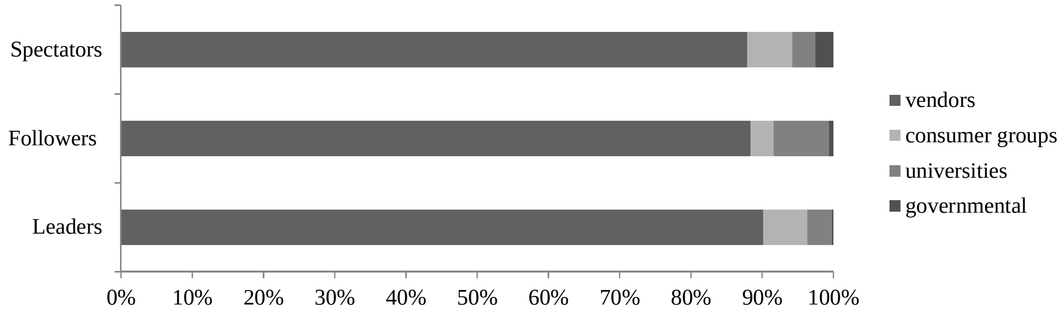

Figure 3 Consortia membership structure as to shares in tiered levels

Using this classification by Updegrove (2008) data analyses indicate that the *Leader* level is dominated by commercial entities, most universities can be found in the *Follower* and *Leader* level and governmental entities and consumer groups mostly choose the *Spectator* level (figure 3). However, all member levels are strongly dominated by vendors. In most cases membership fees are scaled, since *Leaders* usually pay higher dues. Thus they have more voting or veto power and are able to strategically influence the standard setting process. In consequence membership levels often reflect the balance of member power (Updegrove, 2008).

A very political and lately often discussed topic is the interplay of IPR and standards. In comparison to formal standard bodies, the IP policies of consortia are not always transparent and distinct. Thus only 95 consortia could be classified appropriately.

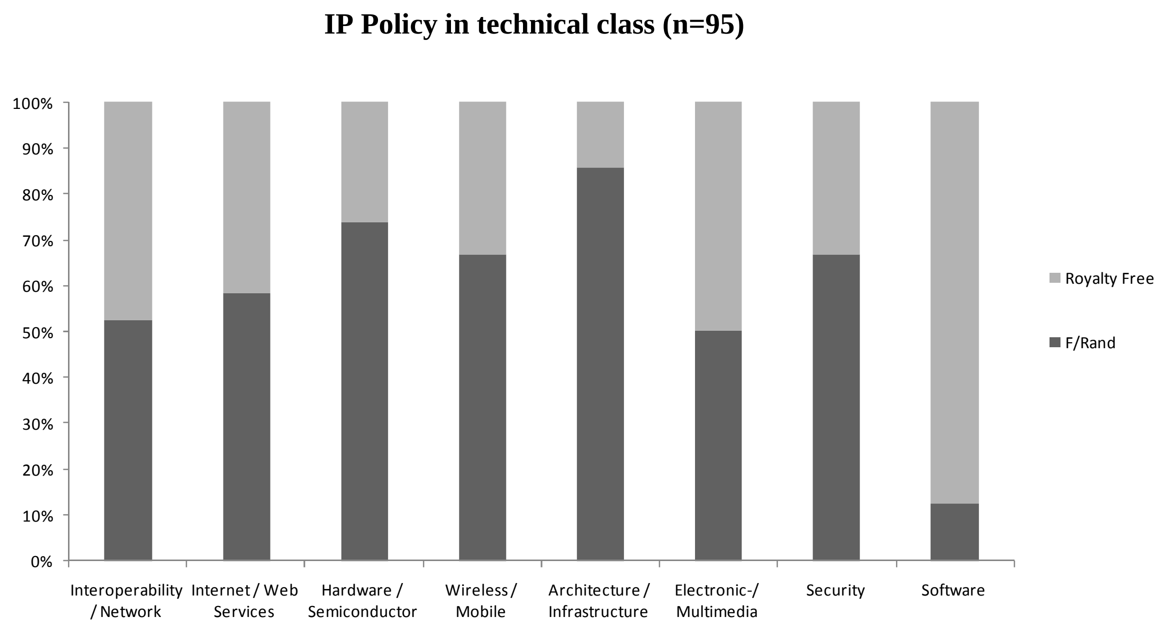

Figure 4 IP policy statements of consortia per technical class

The survey differentiates between royalty free and FRAND (Fair Reasonable and Non-Discriminatory) IP policies. Standard setting organizations often mandatorily require firms participating in standard setting to disclose any patent that might turn out to be essential for the standard in question. Furthermore holders of such patents have to submit a declaration on whether they accept to commit on fair, reasonable and non-discriminatory terms for licensing these patents (FRAND commitments). If a firm discloses a patent and refuses to commit on such licensing terms, the standard organization will usually set the standard excluding the protected technology. Even though standardization may be accompanied by complex licensing agreements, the rules for licensing of complementary patents essential for a common standard are often unclear and can be subject to complex discussions. Nevertheless, FRAND commitments are commonly seen as an important instrument to curb anticompetitive and abusive strategies. In situations of royalty free commitments firms may include patents into standards but commit upfront to not charge royalties (Layne-Farrar et al. 2007; Farrell et al. 2007).

As to the CEN survey 54.7% of the consortia follow a FRAND policy, whereas 43.3% of the consortia use royalty free IPR regulations. To better assess these results, consortia were also classified in their technical classes. Figure 4 illustrates the IP Rules of consortia per technology. The graph shows that IP policies differ between technologies and it thus seems presumable that the technical topic determines the pursued IPR rules. The high number of royalty free consortia in software is on the one hand due to several open source consortia which can be found within this class and can on the other hand be explained by the fact that IPR on software is restricted in several countries. Explanations of other technological classes are not always obvious and have to be assessed on a lower level of aggregation, since IPR rules differ between specific products and companies involved. However, one has to consider that F/RAND policies may also allow to license essential patents royalty free.

4.2 Consortia Development Phases

There are several articles that describe the development of standardization with respect to the formation and evolution of informal consortia (Hawkins, 1999; Cargill 2002; Jakobs, 2003; Updegrove 2008). However, there is yet no comprehensive quantitative approach to examine the survival of standards consortia over time. Using the CEN survey editions between 1998 and 2009 the data assembles a current list of ICT consortia for every year and even twice a year in 2001 and 2006. Figure 5 shows the quantity of consortia at the respective point of time, also indicating the fluctuation rate, which is the sum of new and terminating consortia. To consider consortia evolution with respect to the standardized technologies, figure 6 illustrates the consortia development assigned to the respective technology class.

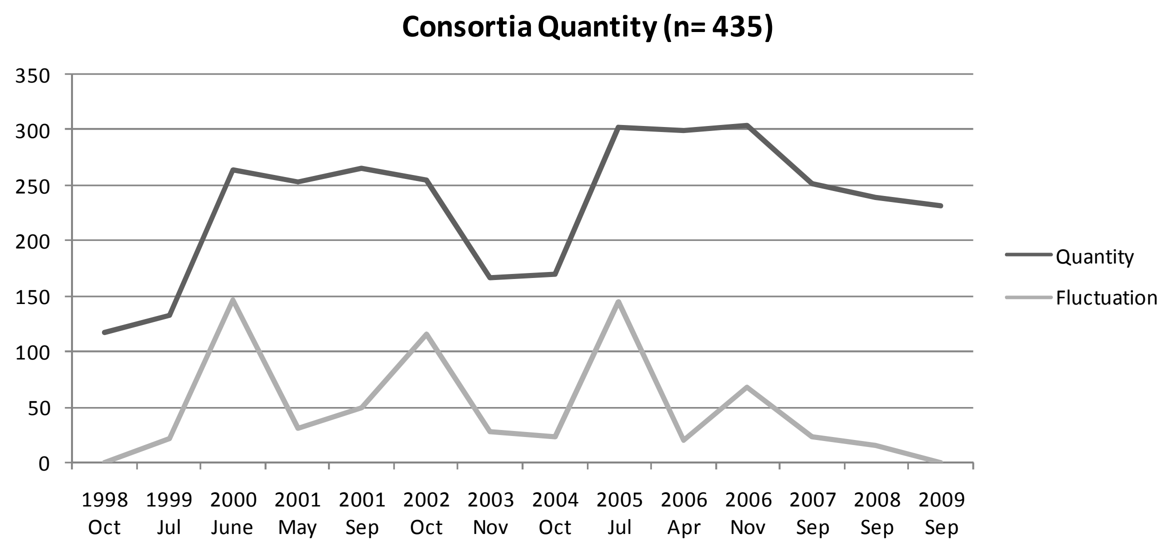

Figure 5 Evolution of ICT standards consortia 1998-2009

Since the mid-1990ies the increasing formation of consortia can be explained by the rise of the internet market, where the first peak of development is in June 2000, counting 123 new consortia compared to July 1999. This period is characterized by strong standard battles (Microsoft Explorer vs. Netscape Navigator) and the rise of future influential consortia in the internet infrastructure such as the Internet Engineering Task Force (IETF) or the World Wide

Web Consortium (W3C) (Cargill, 2002; Updegrove, 2008). Figure 6 shows that the class Internet / Web Services increased from a share of 14.47% in July 1999 to 20.16% in May 2001.

The next fluctuation peak can be found in 2002, where 107 consortia were terminated compared to May 2001. Taking a closer look at the technology class development, especially the percentage of Internet / Web Service consortia decreased from 20.44% in October 2002 to 16.67% in November 2003. Also Security and Wireless / Mobile decreased in their shares between 2-3%. A deeper look at the data also shows a consolidation process. Several consortia were not dissolved but merged with other consortia. The consortia amount remained stable in other technology classes and thus gained an increase of share.

Taking into account the burst of the “dot-com bubble” between 2000 and 2001 where the NASDAQ Composite had a historical decrease, these economic developments also led the consortia formation into a recession. The results are evidence for the close relation of market development and consortia formation. Thus the findings show how quickly consortia standard setting activities are able to react to economic developments and changing market needs.

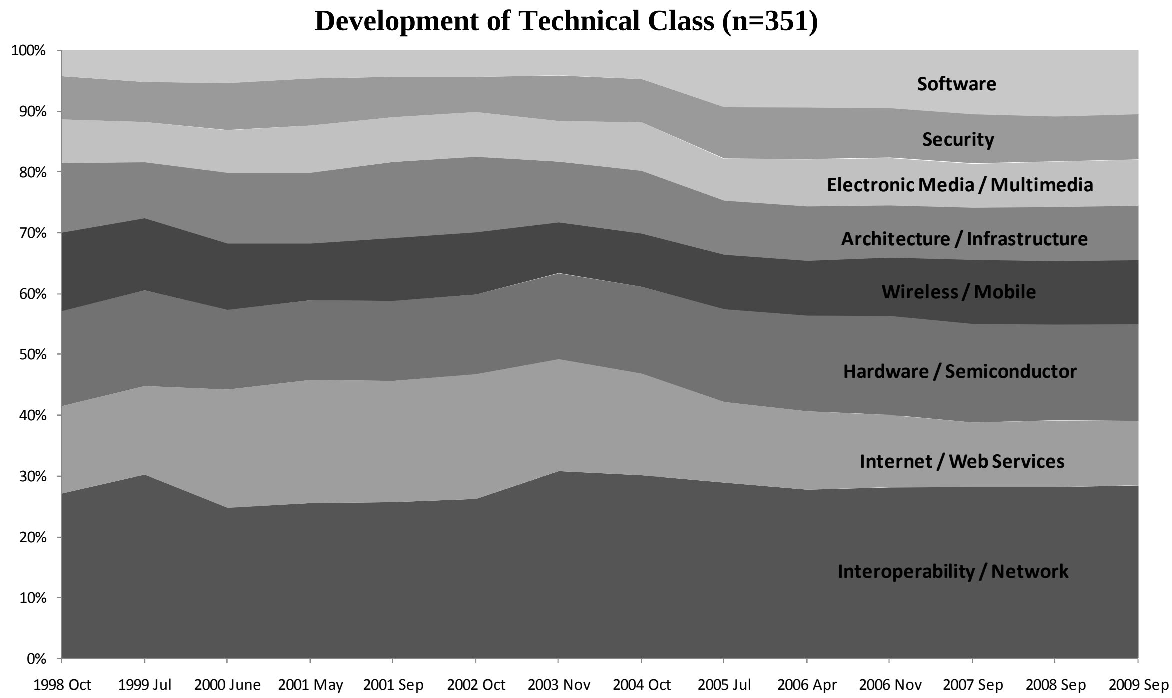

Figure 6 Consortia technology development 1998-2009

A significant period of consortia formation started in 2005. Between October 2004 and July 2005 the CEN Survey data identifies an amount of 133 new consortia. The technical class development shows that the share of software orientated consortia tripled within one year. This development was especially due to a new awareness of open standards in general and the rise of the open source consortia in particular. One third of the software consortia can be distinctly identified as open source projects. Except for Internet / Web Services a new formation of consortia in all technical classes has taken place. This gives evidence for an increasing broader appreciation of standard setting consortia.

Since the highest peak level in 2006, counting a quantity of 304 consortia, the formation of new consortia remained on a constantly low level in the years to come. In contrast between September 2006 and 2007 the second highest peak of consortia termination took place, as 50 consortia ended their business or merged with others. Again these findings can be linked to economic events, as the US subprime mortgage crises took place in 2007, which later triggered the worldwide financial crises starting in 2008. The findings are able to reflect the close connection of consortia development and industry performance. The timing of consortia formation and termination again indicates that consortia formation is more flexible and dynamic and thus able to react immediately to ups and downs of market development.

4.3 Consortia Performance

In order to measure the performance of standards consortia we apply a survival analysis over the whole sample of our survey. The survival or termination of consortia may be subject to multiple occurrences. In our preceding section we have discussed consortia termination as a result of technology or market shocks. Consortia termination may consequently be the implication of technology obsolescence or economic recession. However, reasons for dissolving a consortium may also be connected to organizational structures or performance.

In some cases the purpose to form a consortium is to standardize a specific technology without the intention to continue development once the project is finalized. Consortia termination would thus be the consequence of previous decisions. Furthermore, consortia often operate similar to commercial corporations with permanent employees, a budget, income streams and customers. If business goals cannot be achieved anymore consortia may dissolve and go bankrupt. Since the purpose of standardization is always connected to coordination of firms, disputes and discrepancies may be another reason why a consortium is dissolved. We have discussed that consortia are special interest groups that pursue a common goal. If these interests and goals diverge, collective activities may be ended.

In the following we seek to measure which consortia structures would survive longer in technology and market conjunctures. We therefore calculate the Kaplan-Meier estimates of the probability that a consortium terminates. Survival estimates are the likelihood that an observation will "survive" for a specific time. At each time in our analysis, only consortia that have been observed are taken into account. The following statistics are therefore not subject to truncation problems. Downward steps of the survival function represent failures. The y axis denotes the percentage of consortia that survive over time as to years on the x axis.

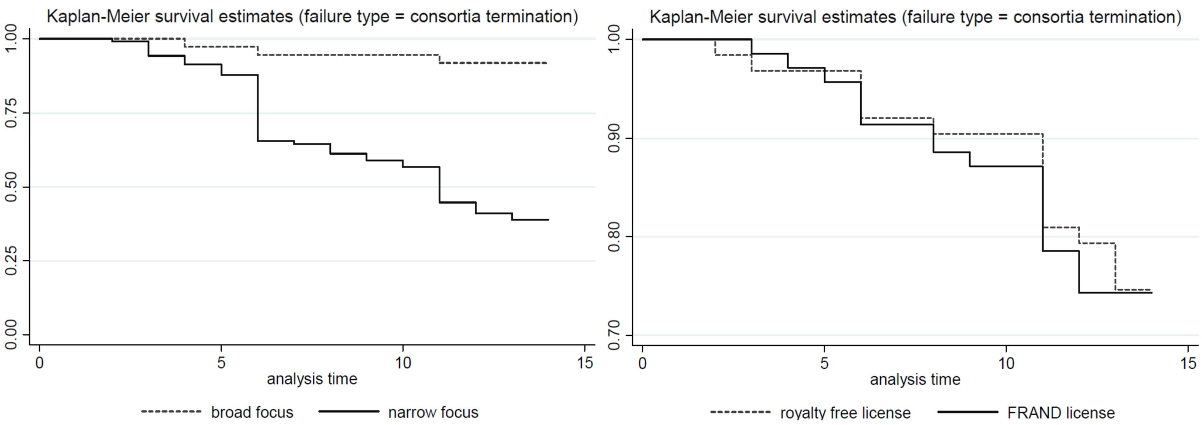

Figure 7 Kaplan-Meier survival estimates of consortia termination by consortia focus and IP policy

Results from figure 7 represent the survival functions of consortia as to consortia focus and IP policy. The left graph shows that standards consortia which pursue a broad focus in their standards projects survive respectively longer compared to narrow purpose consortia. Results indicate that after 10 years almost 50% of narrow focused consortia are terminated. This finding may confirm the notion that consortia are in some cases formed to solve a very specific problem over a limited period of time. Survival of these so called "one purpose consortia" would thus be subject to planned termination. However one could also argue that consortia which are able to extend their business focus to additional standards projects are more successful and thus survive respectively longer.

In the right graph in figure 7, we estimate whether the differences of IP polices have an influence on consortia survival. To make results of the Kaplan-Meier survival test visible we changed the scale of our y axis. However, survival developments seem to show no significant differences between the two licensing schemes. Only in periods after seven years consortia with a royalty free policy seem to survive longer, while the survival rate decreases after ten years to the same level as FRAND policy consortia. These developments may furthermore be connected to the technology that is developed (figure 4). We argued earlier that FRAND commitments also include royalty free agreements. Yet analysis is far from conclusive to explain the effects of IP policies on the survival of consortia.

Consortia size is a crucial factor that influences both; consortia coordination among members and market power. The costs of coordination increase with the number of members. Large groups may inhibit coordination failures such as “free riding” or “war of attrition” (Olson, 1971; Farrell and Simcoe, 2012). This may result in disputes and in cases of hardship lead to consortia termination. In comparison, we argued that the success of a standard is connected to a large group of companies that sponsor the standardized technology (David and Greenstein, 1990; Axelrod et al., 1995). Figure 8 compares five categories of consortia membership quantity and observes the survival curve over time. Again we adjusted the scale of survival rates in our y axis to make results visible. Large consortia with 200-300 and 300-1000 members survive the longest over the years. Rather small consortia in comparison <50 and 100-200 terminate in earlier periods. These results support the argument that consortia which gather a larger number of industry players are more successful and seem to operate significantly longer than small consortia. However, we have to keep in mind that narrow “one purpose consortia” with a planned termination are considerably smaller than others.

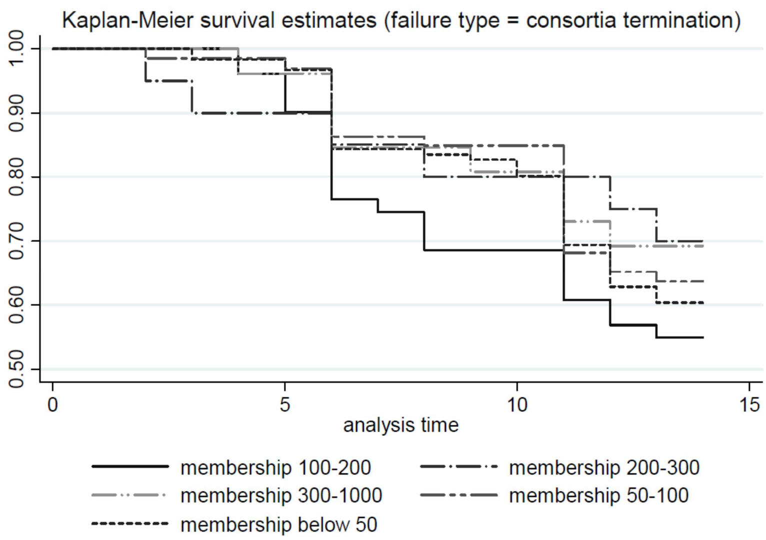

Figure 8 Kaplan-Meier survival estimates of consortia termination by membership size

Consortia membership may influence termination not only by size but also by membership structures. We conduct another survival analysis and estimate if different membership arrangements influence survival rates. Figure 9 illustrates that for consortia with individual membership structures termination is more likely compared to others. Individual members participate not as a corporation but as individual persons. Members may still serve the interest of a group or company but participate in meetings and conferences individually. These consortia are often very technical and seek to solve specific problems which may not be subject to corporate strategies. Again we assume these consortia to be limited in time and scope which would result in earlier termination.

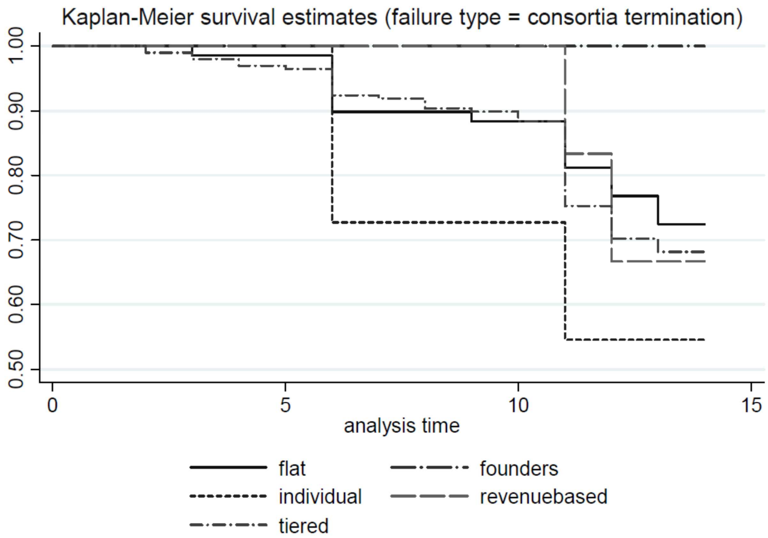

Figure 9 Kaplan-Meier survival estimates of consortia termination by membership tiers

In consortia where membership fees are revenue based or tiered, members which pay higher dues obtain more rights than others. As to the categorization of member levels in figure 3, *leader* firms may get full and early access to information, may participate in all meetings, may have certain veto or voting rights and may be part of the organizational management of the consortia (Updegrove, 2008). Tiered member levels thus ensure that strong market players can better influence standardization outcomes and bypass smaller entities which only participate as spectators or followers. Compared to flat membership and founder based membership, consortia with tiered structures more likely terminate over time (figure 9). However, we would expect that coordination failures would be solved by hieratical tiered structures. In comparison, in flat membership structures all members have the same rights, which may lead to discrepancies. Even though theoretical considerations are opposed to our finding, we could argue that tiered member structures are subject to a selection effect. Companies that pursue certain interests or seek to sponsor technologies that are not shared by other market participants may rather choose to join consortia where they can suppress others. Thus consortia with tiered structures would experience participation of companies that would generate more coordination problems compared to consortia with flat structures.

5. Conclusion and Discussion

This paper intends to give a broad overview of standards consortia, its characteristics, organizational structures, policies and developments in the past ten years. Even though empirical analysis is rather descriptive, results already introduce coherences in terms of the consortia features and survival. Several characteristics differentiate the consortia phenomenon from other standard setting activities. By combining the assessed consortia information, relationships are revealed to deliver a more transparent picture of the consortia landscape. The stereotypical consortium could hence be described as having usually less than 100 members, following only one purpose of business, being hierarchical in its decision making structures and due to tiered membership fees, is often dominated by vendors and commercial entities. The stated IP policy is strongly connected to the produced technology. In contrast to formal standard bodies, consortia are very flexible and react to market developments. This either results in a formation as well as termination of businesses or mergers with other consortia. Involvement in consortia standard setting enables members to gain quick and flexible participation to influence the standardization process. Especially solvent vendors and commercial entities can use their strong membership positions to strategically direct a certain standard or specification.

This article further estimates survival rates to assess which consortia are successful and stable and how consortia features correlate with termination and continuity of business. In consideration of theoretical implications we show that especially structures of member coordination as well as focus and positioning on markets determines consortia survival over time. While termination may be planned for some consortia, others may close their business due to problems that can be connected to a consortium’s organizational approach. We show that larger consortia survive significantly longer compared to smaller consortia. However, when membership levels are tiered termination is more likely. Furthermore a narrow focus on certain technologies also leads to earlier termination, while the adopted IP policy seems to have no effect.

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Joint innovation in ICT standards: How consortia drive the volume of patent filings

Abstract

The development of formal ICT standards is a loose form of collaborative innovation: firms first develop rival technologies, some of which are then eventually selected in the standard. Against this background, firms often use informal consortia to define a clearer technology roadmap ahead of the formal standard setting process. The paper aims to assess how such consortia influence the volume of patents filed around standards, and whether this is efficient. We show that their effect actually depends on the strength of firms' incentives to develop the standard. Consortium membership triggers a higher number of patent files when insufficient rewards for essential patents induce underinvestment in the standard. This effect is necessarily pro-efficient. In situations where excessive rewards induce patent races, consortium membership only moderately increases or even reduces their volume of patents. At least in the latter case, the effect of consortia membership is also pro-efficient.

Contents

1. Introduction

Over the past twenty years, the number of essential patents claimed on ICT standards has strongly increased (Simcoe, 2007). This evolution firstly denotes the importance of these patents for firms: they can generate substantial licensing revenues, and can be used as bargaining chips to obtain freedom to operate on rivals' patent portfolios (Rysman & Simcoe, 2008). Another explanation lies in the growing complexity of ICT standards. As compared with other sectors, standardization in ICT has indeed evolved from the definition of mere specifications enabling interoperability to the joint development of large technology platforms including critical technologies. Consequently, they tend to embody a growing number of patented components.

While the conditions for licensing essential patents have been widely discussed (see e.g., Shapiro, 2001; Lerner & Tirole, 2004; Layne-Farrar & Lerner, 2011), the peculiar type of collaborative innovation they proceed from has received less attention so far. Formal ICT standards are developed in standard setting organizations (SSOs)–such as ETSI (telecommunications) or IEEE (electronics)–that are open to a broad range of stakeholders. Besides the large number of participants, the originality of this process is that it does not involve any ex ante contracting between the firms preparing to develop a standard (Ganglmair & Tarentino, 2011). The choice of standard specifications rather takes place ex post in ad hoc working groups, based on the merit of rival technologies available to solve a given technical problem. Firms thus compete in R&D ahead of the working group meetings, thereby generating a large volume of patented innovations of which only a fraction will eventually become essential.

This formal process generates costly R&D cost duplications and delays due to vested interests (Farrell & Simcoe, 2012; Simcoe, 2012). Firms therefore increasingly rely on informal consortia to take the lead in the standard setting process (Cargill, 2001; Lerner & Tirole, 2006). Such consortia are fora wherein a group of firms seek to agree on a common design that they will jointly push as a standard. While some of them substitute for the lack of formal SDOs and issue their own standards (e.g., Blu-Ray alliance or W3C for web protocols), most consortia actually accompany formal standardization . They are then a means for members to better focus their R&D investments on a common roadmap (Delcamp & Leiponen, 2012), thereby saving useless development costs while enhancing their chances to obtain essential patents (Pohlmann and Blind, 2012). Leiponen (2008) furthermore shows that participation in a consortium improves the capacity of firms to influence the technological decisions taken at the formal SSO.

This paper aims to assess how such consortia influence the volume of patents filed around formal standards, and whether this is efficient. We show that their effect actually depends on the strength of firms' incentives to develop the standard. Consortium membership induces a higher number of patent files in situations where insufficient rewards for essential patents induce underinvestment in the standard. This effect is necessarily pro-efficient. In situations where excessive rewards induce patent races, consortium membership only moderately increases or even reduces their volume of patents. At least in the latter case, the effect of consortia membership is also pro-efficient.

The implications of these results are twofold. They first highlight the cost entailed by the loose coordination of R&D investments in formal SSOs. In this context, they also suggest that the creation of informal consortia can be an efficient way to supplement formal SSOs. Consortia are indeed an effective means to unlock the development of standards when firms have insufficient incentives to contribute technology, while they do not significantly amplify the race for essential patents when these incentives are strong.

The paper proceeds in two steps. We first develop a theoretical model to analyze the efficiency of distributed innovation into a standard. We then assess empirically the actual impact of consortia over a large panel of ICT standards.

Our model allows for some degree of rivalry between the firms' innovations, so that only a fraction of their patents eventually become essential. We firstly establish that the level and efficiency of firms' investments depends on the share of the standard's value that accrues to owners of essential patents. A public good pattern involving sub-optimal investment prevails in equilibrium when the licensing revenue of essential patents holders is not sufficient to cover their R&D costs. Conversely, firms engage in a wasteful patent race when licensing profits exceed total R&D costs.

Against this background, we introduce consortia as a means to mitigate technology rivalry between member firms. By joining a consortium, a firm may thus deflate its volume of patents by cutting irrelevant R&D investments, or inflating it by seeking to develop more relevant innovations. We show that consortium membership is always pro-efficient if the first effect dominates. A patent-inflating consortium is also pro-efficient in a public good equilibrium, but it may actually harm efficiency in a patent race equilibrium if it induces an excessive inflation of patents around the standard.

Drawing on this framework, we use a large panel of ICT standards to assess the actual effect of consortia empirically, respectively for standards entailing over- and underinvestment. For this purpose, we have developed an original dataset of standard-related patent applications at firm level, which we use as a proxy for firms' R&D investments. We also use information on the participation of pure R&D firms in the standard development process in order to identify over-investment patterns. We find that firms entering a consortium strongly increase their patent files in most of the cases. This is however not true for standards featuring an over-investment pattern: in these cases, consortia membership has a smaller, and in some cases negative effect on firms' patent applications. These results thus suggest that consortia tend to enhance the efficiency of innovation in the development of standards.

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

2. Theoretical Framework

2.1 Value of the standard

We consider a set N of n firms that take part in the development of a standard. The standard embodies $x = \sum_{i \in \mathcal{N}} x_i$ essential patents contributed by the firms, and its implementation is expected to generate aggregate profits $v(x)$ in the industry. These profits increase with the amount of embarked technology, but with decreasing returns: $v'(x)>0$ and $v''(x)<0$[1].
There are two ways in which firms can derive revenues from the standard. Patent holders firstly appropriate a share $r \in [0,1]$ of the standard's value through the royalties they charge to implementers of the standards. Parameter r can thus be thought of as reflecting the IP licensing policy of the standard setting organization ($r=0$ denoting a royalty free policy). In line with common practices regarding ICT standard, we assume that the share of the licensing revenues that accrues to firm $i \in \mathcal{N}$ is proportional to its share of the essential patents (x_i/x).

The remaining part of the revenues, $(1-r)v(x)$, accrue to the firms that implement the standard in their products. Let s_i denote firm i's share of these revenues, which can be thought of as its share of the market for standard-compliant products. We assume that all firms with $s_i>0$ are involved in the standard setting process (so that $\sum s_i = 1$). Other firms ($s_j=0$) may also contribute patented inventions provided they have appropriate R&D

[1]These assumptions account for various possible specifications. The standard's value $v(.)$ can in particular reflect a dynamic innovation process, if we define it as the expected outcome $\lambda x\pi/(\delta+\lambda x)$ of a Poisson process with hit rate λx, discount rate δ, and aggregate profits π.

capabilities, but they will get a return only through royalty revenues. Taking into account both sources of profits, the expected benefit of firm $i \in \mathcal{N}$ is thus:

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

2.2 R&D investments

The definition of a standard is the outcome of an open innovation process wherein firms submit innovations, some of which only will be included in the standard specifications. Assuming constant and symmetric per unit R&D costs *c*, the R&D cost function of firm $i \in \mathcal{N}$ is proportional to y_i, the number of patents it develops for the standard:

$$C_i = cy_i$$

Equation (1) in turn posits that only a fraction of these patents eventually become essential.

$$\frac{x_i}{y_i} = \gamma_i \in (0,1) \tag{1}$$

Firm *i*'s *selection rate* γ_i denotes the chance that one of its patented inventions be eventually included in the standard specifications. Conversely, γ_i^{-1} measures the number of patents that firm *i* must develop in order to obtain one essential patent. We define *technology rivalry* between the firms as follows:

$$m = \sum_{i \in \mathcal{N}} \gamma_i^{-1} \geq n \tag{2}$$

This parameter can be interpreted as a measure of the degree of complementarity or substitutability between the firms' innovations. Setting $m=n$ implies in particular that the firms' innovations are perfect complements: each of them can be adopted without evicting another one. More generally, the ratio m/n provides us with a measure of the degree of rivalry between the different technology alternatives promoted by the firms. For instance, a ratio $m/n=10$ means that only one out of ten innovations developed for the standard will become essential. At the firm level, observe finally that firm *i* has a relatively weak position vis-à-vis other firms if $\gamma_i<n/m$.

2.3 Public good or patent race

We first highlight two types of coordination failure that may prevail in this context. Each firm $i \in \mathcal{N}$ defined by $\{\gamma_i, s_i\}$ makes its investment decision so as to maximize $B_i - cy_i$. Solving this problem over x_i yields the first order condition below:

$$v'(x)\left[r\frac{x_i}{x} + (1-r)s_i\right] + rv(x)\frac{x - x_i}{x^2} = \frac{c}{\gamma_i} \quad (3)$$

The term in brackets captures the public good nature of the standard. It implies that firm *i*'s direct incentive to develop the standard is proportional to the share of the value it can appropriate. The second term captures a patent race effect: To appropriate part of the expected profit, firm *i* needs to invest more the higher the number of essential patents held by its R&D competitors. It is easy to check that the LHS of equation (3) is decreasing in *x*, so that the firms' decisions are strategic substitutes. Summing the FOC of all firms *i*=1, *n*, we derive the joint R&D investment x^* in equilibrium.

$$\frac{1}{n}\left[v'(x^*) + rv(x^*)\frac{n-1}{x^*}\right] = c\frac{m}{n} \quad (4)$$

The aggregate marginal profits (LHS) again combine the properties of a public good investment (marginal benefits are diluted when the number of firm increases) and a patent race (when $r>0$, extra incentives are stronger the larger the number of competitors). On the RHS, the aggregate marginal cost of essential patents is higher when *technology rivalry* is strong (large *m*/*n*).

Observe also that the aggregate marginal cost depends on the distribution of the γ_i between the firms, but only on the degree of *technology rivalry* at the aggregate level (*m*/*n*). We use this property to study how the structure of the incentives affects the efficiency of firms' investments. Let us consider a social program wherein a unique representative firm with *selection rate* $\overline{\gamma} = \left(\frac{m}{n}\right)^{-1}$ maximizes aggregate profits:

$$\max_x \Omega = v(x) - cx/\overline{\gamma}$$

Comparing the outcome of this program with the equilibrium outcome, we can establish the following result.

Proposition 1 *Aggregate investment in equilibrium is efficient if the licensing revenues* $rv(x^*)$ *equals the total R&D cost* $cx^*/\overline{\gamma}$*. Firms invest in excess if licensing revenues exceed total cost and they underinvest in the reverse case.*

Firms' incentives to innovate can induce either too much (patent race pattern) or too little (public good pattern) investment. Which one prevails in equilibrium depends on the balance between total licensing profit and the total R&D cost at equilibrium. Firms engage a patent race if

$$rv(x^*) > \frac{cx^*}{\overline{\gamma}}. \tag{5}$$

Intuitively, a patent race takes place when licensing is profitable per se, so that firms will compete in R&D in order to preempt the essential patents. Conversely, the public good equilibrium emerges when firms' incentives are primarily driven by the possibility to use the standard. Observe that condition (5) also implies that the participation of a pure R&D firm i (s_i=0) with average success rate $\gamma_i = \overline{\gamma}$ is profitable only in a patent race equilibrium:

$$(5) \quad \Leftrightarrow \quad \frac{x_i^*}{x^*} rv(x^*) - c\overline{\gamma} x_i^* > 0 \tag{6}$$

Corollary 2 *The participation of pure R&D firms signals a patent race pattern in equilibrium.*

We will use this result in the empirical section to infer the existence of a patent race equilibrium from the participation of pure R&D firms. We can finally observe that the number of firms does not determine the type of equilibrium that prevails, but its magnitude. Hence Proposition 1 and its corollary are robust to allowing free entry of firms in the standardization game.

Corollary 3 *The inefficiency pattern prevailing in equilibrium does not depend on the number of firms, and is thus robust to free entry.*

2.4 Efficiency of consortium membership

Recall that the consortia we are interested in do not involve any formal contracting or joint R&D decisions. They rather function as fora wherein participating firms seek to agree on a mutually acceptable roadmap for specifications that they will jointly push in the SDO. Accordingly, we posit that consortium members can better focus their R&D effort, thereby saving useless investments and enhancing their chances of obtaining essential patents. Assuming that a subset of firms $\mathcal{K} \subset \mathcal{N}$ have created a consortium to support the standard setting process, members thus benefit from a higher selection rate[2]: $\gamma_{k\in\mathcal{K}} > \gamma_{k\in\mathcal{N}\backslash\mathcal{L}}$ where $\mathcal{L} = \mathcal{K}\backslash\{k\}$.

We focus on the consequences of firm *k*'s decision to join the consortium[3]. Formally, this firstly translates into a positive shock on the new member's selection rate ($d\gamma_k>0$). Since firm *k* can better screen irrelevant innovation opportunities, this in turn induces a fall in the degree technology rivalry at the aggregate level: $dm/d\gamma_k = -\gamma_k^{-2}$. It thus follows directly from (4) that the number of essential patents embodied in the standard increases in equilibrium. Since the firm's decisions are strategic substitutes, it is moreover clear from (3) that firm *k* develops more essential patents while the other firms react by developing less of them. Lemma 4 summarizes these results.

Lemma 4 *Joining the consortium enables the new member to develop more essential patents in equilibrium, while the other firms develop less essential patents. The net effect is positive, and thus induces an increase of the equilibrium value of the standard* $v(x^*)$.

This result does not necessarily imply that an enlarged consortium coalition is efficient, since it does not take into account the induced variation of firms' R&D costs. Indeed, deriving firms' aggregate profits $\Omega = v(x^*) - c\sum_i x_i^*/\gamma_i$ with γ_k and rearranging makes it possible to highlight the following three effects:

[2]We implicitely assume here that the size of the consortium coalition does not change the success rate of former members or consortium outsiders. In other words, the only effect of consortium membership is a better access to information of future specifications. The entry of a new member in the coalition nevertheless indirectly affects former members and outsiders through the new member's stronger ability to preempt essential patents in the standard.

[3]In practice, firms have to pay significant membership fees to join consortia, and therefore decide to do so only if they have significant stakes in the standard. The benefits in terms of information and influence strongly depend on idiosyncratic factors such as the degree of compatibility between the firms' technology profiles and strategic agenda.

$$\frac{\partial \Omega}{\partial \gamma_k} = \underbrace{\frac{c x_k^*}{\gamma_k^2}}_{A} + \underbrace{\frac{\partial x^*}{\partial \gamma_k}\left[v'(x^*) - \frac{c}{\overline{\gamma}}\right]}_{B} + \underbrace{c\sum_i \frac{\partial x_i^*}{\partial \gamma_k}\left[\frac{1}{\overline{\gamma}} - \frac{1}{\gamma_i}\right]}_{C} \tag{7}$$

The first effect corresponds to R&D costs savings induced by firm *k*'s ability to reduce the volume of non-essential patents (*A*). It is clearly positive. The second one is the net (cost/benefit) value of adding new essential patents to the standard (*B*). It is clear from the term in brackets that it is positive in a *public good* equilibrium. Indeed new patents can then mitigate firms' lack of investment in the standard. By contrast, developing more essential patents reduces joint profits in a *patent race* equilibrium. Finally, the third effect captures the cost or benefit of reallocating the development of essential patents between the firms (*C*). Its sign may be positive or negative, depending on the selection rate of firm *k* as compared with the other firms. Lemma 5 summarizes these findings.

Lemma 5 *A firm's entry in the consortium deflates the volume of non-essential patents, which is clearly efficient. By contrast, the inflated volume of essential patents may be inefficient if i) a patent race pattern prevails in equilibrium and/or ii) it entails a reallocation of R&D effort from efficient to inefficient firms.*

In order to carry further the analysis, we now focus on the direct effects of firm *k*'s patenting strategy on joint profits, aside from the other firms' reactions[4]. We are especially interested in relating joint profits with the (empirically observable) total volume of patents filed by firm *k*. Assuming that firm *k* has average selection rate $(\gamma_k = \overline{\gamma})$, we can establish that

$$\frac{c x_k^*}{\gamma_k^2} + \frac{\partial x_k^*}{\partial \gamma_k}\left[v'(x^*) - \frac{c}{\overline{\gamma}}\right] > 0 \quad \Leftrightarrow \quad dy_k^* < \Delta \frac{dx_k^*}{\overline{\gamma}}$$

where

$$dy_k^* = \frac{dx_k^*}{\overline{\gamma}} - x_k^* \frac{d\overline{\gamma}}{\overline{\gamma}^2} \tag{8}$$

is the variation of the total number of patents filed by firm *k* (that is, the difference between the volumes of spared patents and new essential patents) and $\Delta = \overline{\gamma} v'(x^*)/c$. Since $\Delta > 0$, condition (8) clearly holds if the total volume of firm *k*'s patents is deflated. This is

[4]This can also be interpreted as an approximation of the full effects when the reactions of the other firms are negligible. We will see in the next section that this interpretation is actually supported by empirical evidence.

quite intuitive, since firm *k* then develops more essential patents and saves at the same time the R&D cost of an even larger volume of useless patents.

The effect of firm *k*'s move is more ambiguous if joining the standard has a patent inflating effect. Indeed the benefit of enhancing the standard's value must then be balanced with the cost of a larger volume of patents. As stated in Proposition 6, the new member still invests more efficiently provided the *public good* pattern prevails in equilibrium. Indeed, it thereby provides more of the missing essential patents, and it does so at a lower cost thanks to consortium membership. By contrast, inflated volume of patents filed by the new member may harm efficiency in a *patent race* pattern, unless the volume of extra non-essential patents remains sufficiently small to be compensated by the benefit of new essential patents.

Proposition 6 *Assume that a firm with average success rate joins the consortium:*

- *A deflated volume of patents filed by the new member is efficient whatever the inefficiency pattern prevailing in equilibrium.*
- *An inflated volume of patents filed by the new member is efficient in a public good equilibrium. It becomes inefficient in a patent race equilibrium when it exceeds a positive threshold* $T \in (0, dx_k^*/\overline{\gamma})$.

Proof. Observe also that $\Delta > 1 \Leftrightarrow v'(x^*) - v'(x^*) - c/\overline{\gamma} > 0$, which is the condition for the *public good* pattern to prevail in equilibrium. Since $dy_k^* < dx_k^*/\overline{\gamma}$, it directly follows that condition (8) is also verified in a *public good* equilibrium when firm *k* inflates its volume of patents. By contrast, the *patent race* pattern prevails when 0 < Δ < 1. Hence joint profits can increase only if the inflation of firm *k*'s patents remains moderate, that is if $dy_k^* < T \in (0, dx_k^*/\overline{\gamma})$. Otherwise, a strong inflating effect induces a fall of joint profits.

3. Empirical Analysis

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

3.1 Data and indicators

Our empirical analysis draws on a comprehensive dataset of technological standards including essential patents[5]. Our sample includes all ICT standards issued between 1992 and 2009 by one of the major formal SSOs which operate on an international level[6]. Since we aim to focus on the interaction between formal standardization and companion consortia, we exclude standards that are exclusively developed by informal standards consortia (e.g. BluRay).

We furthermore restrict the analysis to standards including essential patents of at least two different companies, thereby limiting the sample to 578 standards. Companies that own IPRs which are essential to a standard provide this information to the respective SSO. We downloaded these patent declarations at the websites of the above-mentioned SSOs in March 2010. From the PERINORM[7] database we retrieve information on the date of first release, releases of further versions and amendments, number of pages from the standard document such as the technical classification of the standard.

Our sample includes 242 different companies declaring essential patents, observed over the whole period. For each firm, we collect yearly information on the amount of sales, R&D expenditure, employees and market to book ratio (Tobin's Q[8]). In addition we distinguish between pure R&D firms, manufacturer and net provider[9] and classify our sample by main active industry using SIC codes.

We connect the firm level data to the specific standard information and build a panel of 1,720 company-standard pairs observed over a time span of 18 years (1992-2009). For each company-standard pair, we observe the amount of patents filed by the respective company in the technological field for the respective standard, and include a dummy variable indicating whether the company takes part in a consortium supporting the development of this standard. Other time-variant control variables are either company- or standard-specific. Time-invariant factors affecting the firm, the standard or the relationship between both are captured by company-standard pair fixed effects.

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

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

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

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

[9]We used the extended business model description in the Thomson One Banker database and compared our classification to the list of companies identified by Layne-Farrar and Lerner (2010).

3.1.1 Mathcing between informal consortia and formal standards

To identify informal consortia accompanying the formal standardization process, we use data from 15 editions of the CEN survey of ICT consortia and a list of consortia provided by Andrew Updegrove. We identify approximately 250 active ICT consortia[10]. We categorize these consortia as to industry, function (spec producer, promoter) and years of activity (see Appendix 1). The connection to a standard in our sample is analyzed by using liaison agreements and information from consortia and SSO web pages. For instance, a connection was identified, when a consortium explicitly references a formal standard, or when a standard has been submitted to the formal SSO by an informal consortium. We are conservative in establishing the connections, resulting in a narrow list of 54 consortia. We use supplementary information for the selected consortia and further restrict the list to 21 consortia that technologically (spec producer) and significantly contribute to this specific standard (excluding pure promoting consortia)[11]. 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.

3.1.2 Standard specific patents

The most intuitive approach to track firms' R&D investments in standards is to count the patent declarations they state for these standards. However, former empirical analyses have shown that the timing of declaration is not connected to the dynamics of standardization (Baron and Pohlmann, 2010). Moreover essential patents only represent a very small amount of patenting around standards (Bekkers et al., 2012). To avoid these shortcomings, we thus build up a new measure of firms' standard-specific R&D investment. In a first step we count patents filed from 1992 to 2009 by the companies in our sample at the three major patent offices (USPTO, JPO and EPO), using the PatStat database and the company assignee merging methods of Thoma et al. (2010). We restrict the count of patent files to IPC classes in the relevant technological field of each standard, identified by using the IPC classification of declared essential patents[12]. We measure the dynamics of patenting over the standard lifecycle

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

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

[12]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

(details can be consulted in Appendix 3). Our mean value analysis shows a patenting increase before standard release and a decrease thereafter. This finding reassures us that our variable captures the innovation for a specific standard, which indeed is expected to culminate in the period immediately preceding standard release.

3.1.3 Public goods and patent race patterns

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

3.1 Descriptive statistics

3.1.1 Pairwise correlations

In the following Table 1, we provide pairwise correlations of firm-specific, standard-specific and firm-standard-specific variables at the company-standard-pair level. The volume of patents around standards is negatively correlated with both consortium membership and the existence of a consortium on the standard. This could indicate that consortia attract companies with smaller standard-related patent portfolios. On the other hand, consortium membership is positively correlated with the value of sales and the number of employees. The existence of consortia is positively correlated with the number of firms per standard and with standard age. As for the correlation analysis, effects are yet not strong enough to derive conclusive interpretations.

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to be a sufficient indicator of standard-related R&D investment. The methodology and the various tests have been presented at the Patent Statistics for Decision Makers Conference 2011 at the USPTO and can be reviewed in Appendix 3.

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

N= 1,046, All correlation coefficients above |0.2| are significant at $p < 0.05$.

Table 1: Pairwise correlations on the company-standard level

3.1.2 Difference in means

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

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

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

3.3 Multivareat analysis

3.3.1 Estimation methodology

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

To account for unobserved heterogeneity of standards and companies, we systematically include fixed effects for company-standard pairs. As our dependent variable is a count variable with overdispersion with respect to a poisson distribution, we will use a poisson estimator with robust standard errors unless explicitly stated otherwise[13]. We furthermore cluster standard errors by companies in order to exclude that unobserved shocks to a company's patenting level bias the standard errors and lead to an insufficiently restrictive confidence interval[14]. Unsurprisingly, we found strong evidence for persistent effects of transitory shocks to our explained variable, as indicated by positive autocorrelation of standard errors. We therefore include the lagged dependent variable as explanatory variable in all models. Our basic regression model has the following specification:

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

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

[13]We prefer the poisson estimator with robust standard errors over a negative binomial estimator with fixed effects, because the negative binomial estimator cannot totally control for fixed effects and thus account for unobserved heterogeneity.
[14]All presented results are robust to clustering standard errors by standard instead of by company.

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

We furthermore wish to account for external shocks such as the business cycle or technology-related policy. As we already control for standard fixed effects and standard age, it is impossible to include year dummies as a further control because of a collinearity problem. We therefore control for external shocks by including the overall number of triadic patent priorities filed per year in the relevant technological category (respectively IPC class G for telecom and IPC class H for IT standards) and the overall number of patent declarations made to any formal ICT standard per year in order to capture policy shocks that are more specifically relevant to essential patents.

3.3.2 Estimation model 1-4

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

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

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

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

Note: All models are estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. Models 2-4 are restricted to a limited time period 2002-2009. ***, **,and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible. [2] Values are reported in thousand.

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

In order to deal with these concerns we restrict the observation period to 8 years from 2002 to 2009. Furthermore, we also reduce the cross-section dimension of the panel, by restricting the sample to stock-market listed companies. These companies are more likely to react in a similar fashion to external events. Finally, we identify positive or negative shocks to the number of employees in a one year period[15], indicating mergers, acquisitions, restructuring etc. If this shock takes place after 2005, all observations after the shock are dropped for this company, if the shock takes place earlier, we drop all previous observations. Companies with more than one shock are dropped altogether for our third model (M3), reducing the sample to 174 groups and 999 observations.

In our last model M4 we furthermore tackle endogeneity more directly by including time-varying firm characteristics as control variables. We choose to include the value of sales, and Tobin's Q as a measure of expected profits (both lagged by one year to exclude immediate feedback). We opt for not including employees, which is highly correlated with sales in the within dimension (both reflecting company growth). Furthermore, the number of employees, with respect to the value of sales, is likely to be more important for determining whether a company has the possibility to participate in a consortium, but less important in independently determining the evolution of patenting[16]. By including the value of sales as a control, we nevertheless face the risk to bias downwards the estimates of the consortia effects for smaller companies refraining from joining an expensive consortium. We therefore divide the level of consortia member fees[17] by the value of sales of the company at the time of consortium creation. The first percentile of observations according to this value (the companies-standard pairs characterized by the highest consortia fees relative to the value of sales) is most at risk to be affected by this effect. We therefore decide to exclude these observations, leaving us with 158 company-standard pairs and 884 observations in model 4. M1-M4 show robust results. The magnitude of the coefficients decreases but the effects are yet more significant, and the signs of the coefficients are unchanged.

3.3.3 Robustness

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

[15]distribution, the lower 5% are labeld as negative shocks.
[16]The primary cost of consortium participation is workload, while the cost of patenting is primarily financial
[17]Since our goal is to estimate the financial burden to join a consortium we use the low range of membership fees (find an overview of highest and lowest membership fees in the appendix 1).

suggested in Blundell et al. (1999), substituting pre-sample means for fixed effects. The results displayed in Appendix 5 are mainly consistent with the results from the fixed effect analysis.

3.3.4 Effect of consortium member share model 6-8

So far we have estimated the effect of consortium membership on the volume of patents of the respective company. In this section, we will estimate the effect of the consortium member share (indicating how many of the firms contributing to the standard are a member of the consortium) on the volume of patents filed by members and outsiders. Finally, by estimating the effect of consortium member shares on patents filed by all companies, we obtain a measure of the net effect of consortia. As compared to the previous analysis, this method is less prone to endogeneity biases, as the decisions of other companies to join a consortium are probably relatively unrelated to a firm's own current or expected future R&D efforts. We are therefore less restrictive regarding the sample, and only drop observations for 2001 or earlier and of standards with no consortium within the observation period. On the other hand, the member share is sensitive to the membership decision of the firm itself, especially if the number of firms on the standard is low[18]. In order to check for robustness to this sensitivity, we present all results for a narrower subsample of standards including at least 6 contributing firms.

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

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

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

Notes: All models are estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. ∗∗∗, ∗∗,and ∗ imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible. [2] Values are reported in thousand.

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

Consortium members react to increasing consortium member shares by inflating their patent filings, but this effect decreases with the level of overinvestment (model 5). Consortium outsiders do not react in a statistically significant way to changes in consortium member shares (model 6). The overall effect (the effect indistinctly for members or outsiders) of increasing consortium member shares on the volume of standard-specific patents is positive and significant, but this effect decreases significantly with the level of over-investment (model 7).

3.3.5 Net effects

Our results suggest that nearly all effects of consortia depend upon the initial level of overinvestment. In order to be able to discuss the effect of consortia on patenting, one should therefore relate the estimated coefficients to the sample values of the overinvestment indicator. We calculate the net effects from the results of model 5 (for the effect of consortium membership) and model 7 (the overall effect of consortium member share in the whole sample). We find that the effect of consortia membership is positive for any share of non-practicing entities not exceeding 6 %. This is the case for 92,12% of the observations. The effect of consortia member shares of overall volume of patents is positive for any share of non-practicing entities below 9 %. This is the case for 94,13% of the observations. These results indicate that the effects of consortia membership and consortia member shares on standard-specific R&D are positive in a broad majority of standards[19]. However, they also suggest that consortia can have a deflating effect in a minority of standards that are characterized by a particularly strong patent race pattern.

4. Conclusion

The purpose of the paper is to assess how consortia influence the volume of patents filed around formal standards, and whether this is efficient. In the first theory section, we defined consortia as a means to reduce the degree of rivalry between the firms' innovations. Accordingly, consortium members can obtain essential patents at a lower average cost, by better targeting R&D investments. The effect on the volume of patents filed around the standard is however ambiguous. By joining a consortium, a firm may indeed file fewer patents by cutting irrelevant R&D investments or more of them if it seeks to develop more technology inputs for the standard. We have established that consortium membership is always pro-efficient if the first effect dominates. A patent-inflating consortium is also pro-efficient in a *public good* equilibrium, but it may actually harm efficiency in a patent race equilibrium if it induces an excessive inflation of patents around the standard.

Our empirical analysis makes it possible to assess which effect actually dominates, depending on the investment pattern – *public good* or *patent race* – prevailing for a given

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

standard. When joint investments are suboptimal (*public good* pattern), the observed rise in patent files indicates that consortium membership induces firms to develop more innovations, rather than saving R&D costs. Since royalty-based incentives are weak in this case, this suggests that their reaction is chiefly driven by the opportunity of enhancing the value of the standard by developing more essential components. Consortia are thus an efficient way to supplement the lack of R&D investments when incentives to develop the standards are not sufficient.

Empirical results differ when the *patent race* pattern prevails. For most standards, new consortium members still increase their patent applications, but in significantly lesser proportions than in the *public good* cases. Since firms have strong strategic incentives to develop essential patents, this suggests that there are few opportunities left for developing innovations that are relevant to the standard. For some standards featuring strong overinvestment, we even observe that consortium members reduce their investments – consortia being then used to save R&D costs by eliminating irrelevant R&D investments. These results thus indicate that the creation of consortia does not significantly accentuate patent races, and rather has a pro-efficient deflating effect for at least a minority of standards around which overinvestment is particularly strong.

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APPENDIX

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

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

N= 247 All correlation coefficients above |0.2| are significant at $p < 0.05$.

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

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

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

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

Note: All models are estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. Model 2-4 are restricted to a limited time period 2002-2009. ***, **,and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible. [2] Values are reported in thousand.

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

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

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

*Notes: All models are estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. ***, **,and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible. [2] Values are reported in thousand.*

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

Appendix 1 Summary of relevant variables

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

Appendix 2 Linkages between standards and informal consortia

Consortia Name	MatchStandard	Incl	Consortia Name	MatchStandard	Incl	Consortia Name	MatchStandard	Incl
EPCglobal	EN300220	No	WiMax	IEEE802.16	Yes	MPEGIF	ISO/IEC14496-14	Yes
DVB	EN300468	No	Cable Laboratories	IEEE802.1Q	Yes	MPEGIF	ISO/IEC14496-15	Yes
DVB	EN301192	No	FCIA - Fibre Channel Industry Association	IEEE802.1Q	No	MPEGIF	ISO/IEC14496-16	No
DVB	EN301199	Yes	MEF	IEEE802.1X	No	MPEGIF	ISO/IEC14496-18	Yes
DVB	EN301790	No	IETF	IEEE802.21	Yes	MPEGIF	ISO/IEC14496-19	No
DVB	EN301958	Yes	(GEA	IEEE802.3	No	ISMA	ISO/IEC14496-2	Yes
EPCglobal	EN302208	No	AUTOSAR	IEEE802.3/ISOIEC8802-3	No	MPEGIF	ISO/IEC14496-2	No
DVB	EN302304	No	FCIA	IEEE802.3/ISOIEC8802-3	No	MPEGIF	ISO/IEC14496-20	No
DVB	EN302307	No	HGI	IEEE802.3/ISOIEC8802-3	No	ISMA	ISO/IEC14496-3	Yes
DVB	EN302583	No	IETF	IEEE802.3/ISOIEC8802-3	Yes	MPEGIF	ISO/IEC14496-3	Yes
DVB	EN302755	No	MEF	IEEE802.3/ISOIEC8802-3	No	MPEGIF	ISO/IEC14496-4	Yes
DVB	ES200800	Yes	ODVA	IEEE802.3/ISOIEC8802-3	No	MPEGIF	ISO/IEC14496-5	Yes
IETF	ES201108	Yes	OIF	IEEE802.3/ISOIEC8802-3	No	MPEGIF	ISO/IEC14496-6	Yes
IETF	ES202050	Yes	Rapidio	IEEE802.3/ISOIEC8802-3	No	TAHI	ISO/IEC14543-2-1	No
IETF	ES202212	Yes	IETF	IEEE802.5/ISOIEC8802-5	No	IETF	ISO/IEC15444-1	No
WORLDDAB FORUM	ETS300401	Yes	INCITS	ISO/IEC10118-2	No	IETF	ISO/IEC15444-12	No
DVB	ETS300814	Yes	INCITS	ISO/IEC10118-3	Yes	IETF	ISO/IEC15444-2	No
DVD	ETSIEN300468	No	INCITS	ISO/IEC10536-3	No	IETF	ISO/IEC15444-3	Yes
IETF	G.711	Yes	INCITS	ISO/IEC10918-1/ITU-TT.81	Yes	IETF	ISO/IEC15444-5	No
IETF	G.722	Yes	TOG	ISO/IEC10918-1/ITU-TT.81	No	EPCglobal	ISO/IEC15693-2	No
IETF	H.263	Yes	INCITS	ISO/IEC11172-1	No	EPCglobal	ISO/IEC15693-3	No
IMTC	H.323	Yes	DVD	ISO/IEC11172-2	No	EPCglobal	ISO/IEC18000-1	No
IMTC	H.324	No	INCITS	ISO/IEC11172-2	No	EPCglobal	ISO/IEC18000-2	No
IETF	IEC6183411	No	DVD	ISO/IEC11172-3	No	EPCglobal	ISO/IEC18000-3	No
TOG	IEEE1003.1/ISOIEC9945	Yes	INCITS	ISO/IEC11172-3	Yes	EPCglobal	ISO/IEC18000-4	No
PICMG	IEEE1101.1	Yes	INCITS	ISO/IEC11693	No	EPCglobal	ISO/IEC18000-6	Yes
OCP-IP	IEEE1149.1	Yes	INCITS	ISO/IEC11694-1	No	AIM	ISO/IEC18000-6	No
BPMI	IEEE1226.5	No	INCITS	ISO/IEC11770-3	No	AIM	ISO/IEC18000-7	No
OMG	IEEE1226.5	No	INCITS	ISO/IEC11889-1	Yes	EPCglobal	ISO/IEC18000-7	Yes
PWG	IEEE1284	Yes	INCITS	ISO/IEC11889-2	Yes	ECMA	ISO/IEC18092	No
1355 Association	IEEE1355	No	INCITS	ISO/IEC11889-3	Yes	EUROSMART	ISO/IEC18092	No
1394TA	IEEE1394	Yes	INCITS	ISO/IEC11889-4	Yes	NFC Forum	ISO/IEC18092	Yes
AUTOSAR	IEEE1394	No	DMPF	ISO/IEC13818-1/ITU-TH.220.0	No	INCITS	ISO/IEC19794-3	No

DVD	IEEE1394	No	DVD	ISO/IEC13818-1/ITU-TH.220.0	No	INCITS	ISO/IEC19794-6	Yes
HAVi	IEEE1394	No	INCITS	ISO/IEC13818-1/ITU-TH.220.0	Yes	ECMA	ISO/IEC23651	No
PWG	IEEE1394	No	DVD	ISO/IEC13818-2/ITU-TH.262	No	GS1 – (Formerly EAN)	ISO/IEC24730-2	No
ODVA	IEEE1588/IEC61588	Yes	INCITS	ISO/IEC13818-2/ITU-TH.262	Yes	ECMA	ISO/IEC28361	No
ACCELLERA	IEEE1800/IEC62530	No	TOG	ISO/IEC13818-2/ITU-TH.262	No	TAHI	ISO/IECDIS29341	No
ACCELLERA	IEEE1801	Yes	DVD	ISO/IEC13818-3	No	UPnP Forum	ISO/IECDIS29341	Yes
Homeplug	IEEE1901	No	INCITS	ISO/IEC13818-3	Yes	ECMA	ISO/IECDIS29500	No
IVI	IEEE488.1/IEC60488-1	No	INCITS	ISO/IEC13818-7	No	3GPP2	Q.703	No
ASTM	IEEE802.11/ISOIEC8802-11	No	EUROSMART	ISO/IEC14443-1	No	DVB	TS102474	No
Bluetooth	IEEE802.11/ISOIEC8802-11	No	INCITS	ISO/IEC14443-1	No	DECT Forum	TS102527	No
DLNA	IEEE802.11/ISOIEC8802-11	No	NFC Forum	ISO/IEC14443-1	No	DVB	TS102584	No
ewc	IEEE802.11/ISOIEC8802-11	No	EUROSMART	ISO/IEC14443-2	No	DVB	TS102611	No
HGI	IEEE802.11/ISOIEC8802-11	No	INCITS	ISO/IEC14443-2	Yes	TV Anytime Forum	TS102822	No
IETF	IEEE802.11/ISOIEC8802-11	No	NFC Forum	ISO/IEC14443-2	No	DVB	TS102825	No
Wi-Fi Alliance	IEEE802.11/ISOIEC8802-11	Yes	EUROSMART	ISO/IEC14443-3	No	IMS FORUM	TS123002	No
100VG-Anylan Forum	IEEE802.12	No	INCITS	ISO/IEC14443-3	Yes	3GPP2	TS123401	No
IETF	IEEE802.12/ISOIEC8802-12	No	NFC Forum	ISO/IEC14443-3	No	3GPP2	TS123402	No
Bluetooth	IEEE802.15.1	No	EUROSMART	ISO/IEC14443-4	No	3GPP2	TS133402	No
WiMedia Alliance	IEEE802.15.3	Yes	INCITS	ISO/IEC14443-4	Yes	DRM	TS201980	No
DISA	IEEE802.15.4	No	NFC Forum	ISO/IEC14443-4	No	IETF	V.44	No
IETF	IEEE802.15.4	No	ISMA	ISO/IEC14496-1	Yes	3GPP2	X.509	No
TAHI	IEEE802.15.4	No	MPEGIF	ISO/IEC14496-1	No	ASTM	X.509	No
ZigBee	IEEE802.15.4	No	ISMA	ISO/IEC14496-10	Yes	Cable Laboratories	X.509	Yes
IETF	IEEE802.16	No	MPEGIF	ISO/IEC14496-10	No	ISMA	ISO/IEC14496-10/ITUH.264	Yes
			MPEGIF	ISO/IEC14496-12	Yes			

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

We identified the relevant technological field for each standard by using the 7-digit IPC[20] classification of the declared standard essential patents, to then count patents filed by each company in the identified IPC classes. We counted all patents filed from 1992 to 2009 by the companies in our sample at the three major patent offices (USPTO, JPO and EPO), using the PatStat database and company assignee merging methods of Thoma et al. (2010). This merging yields 13 million patent files. We aggregated these patents to INPADOC patent families and informed the IPC classification and the year of priority. To create our explained variable, we computed for each company-standard pair and year the number of patents filed in the relevant IPC classes for the standard of observation.

This method is a novel way of measuring standard-specific R&D investment, and we therefore have to conduct a reliability analysis. We compute for each company-standard pair the mean number of patents filed in one year periods before and after standard release (t=0) and report the standard derivation for high and low values (figure1). The resulting pattern is a convincing description of the innovation process around standardization: the number of patents filed is highest in the years immediately preceding standard release, and sharply decreases after the release of the standard. The further we move away from the development phase of the standard, the lower are the calculated numbers of relevant patents. We believe that these findings are important arguments corroborating our methodology.

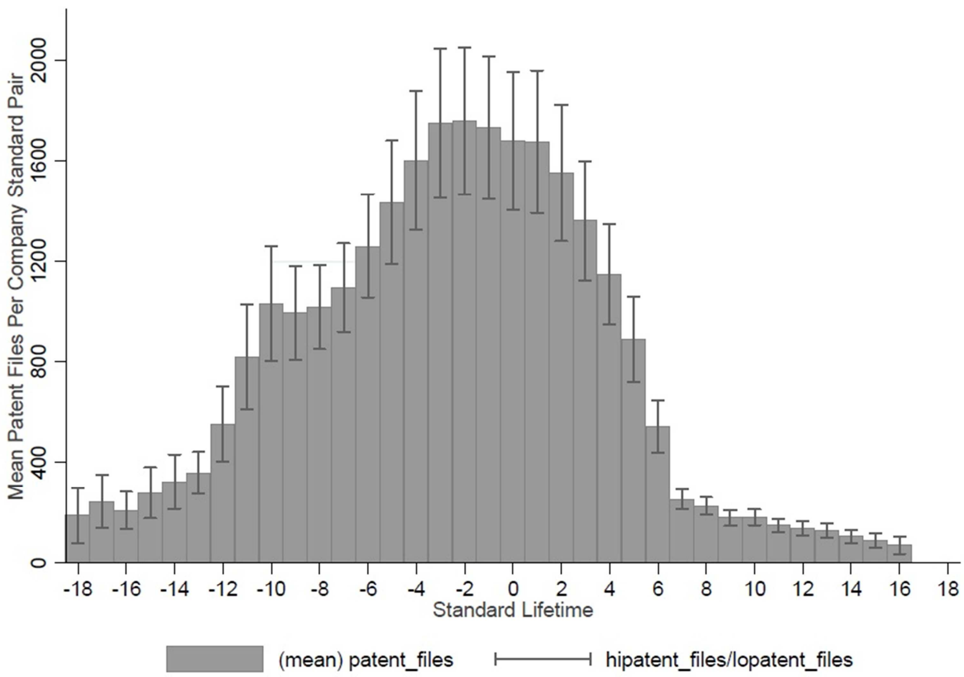

Figure1: mean number of patents filed in years before and after standard release

[20] International Patent Classification

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

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

Using this classification, we create two sub samples, one where pure R&D firms contribute to the standard and one where pure R&D firms are not at place. We test over- and underinvestment by predicting the residual values of our specification. We run a linear fixed effect regression of our firm-standard pairs explaining patent files per year, controlling for standard dynamics and year trends and estimate the linear residual values[21]. We then compare the means of our residual values in both subsamples (pure R&D firms participate or not) conducting a t-test analysis.

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

T-test of linear residual values by pure R&D firms contribution

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
pure R&D firms do not contribute	16,121	-0.2435	0.0193	2.4512	-0.2814	-0.2057
pure R&D firms contribute	11,441	0.1145	0.0237	2.5347	0.0680	0.1609
combined	27,562	-0.0949	0.0150	2.4924	-0.1244	-0.0655
diff		-0.3580	0.0304		-0.4176	-0.2984

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

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

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

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

We apply the methodology developed by Blundell et al. (1999) to control for predetermined regressors. The authors suggest substituting the pre-sample averages of the dependent variable for the group fixed effect. While the fixed effects are estimated over the sample period, and are thus affected by the feedback of predetermined regressors, the pre-sample means are exogenous to the sample period values of the regressors. Analogous to our previous analysis, we set the period of observation from 2002 to 2009. In choosing the appropriate pre-sample period (1982-1992 or 1992-2001), we have to trade off endogeneity (several consortia memberships observed in the sample period have already existed in the period from 1992 to 2001) against heterogeneity (closer pre-sample values are a better approximation of the sample fixed effect than more remote pre sample information). As this model is intended to complement a fixed effect analysis, we choose the average of the period from 1982 to 1992 as pre-sample values[22]. We control for the same variables and operate the same sample restrictions as in the main models of our empirical tests. As our dependent variable is over-dispersed with respect to a poisson distribution and we no longer include group fixed effects, we now opt for a negative binomial regression. This allows us to further add standard dummies. The results are displayed in table 6. The coefficients of the consortia membership variables of models 11-1 and 11-2 as well as 12-1 and 12-2 are similar to our previous poisson fixed effect analysis with clustered standard errors. Models 11-1 and 11-2 estimate the firm level membership effect, while models 12-1 and 12-2 estimate the overall membership net effect. We run two models including and excluding the lagged sales variable and restricting the observations to 2002-2009. Our estimations provide significant results for the consortia variables in all models. Furthermore the coefficients of the pre-sample means are positive and significant in all specifications, which indicates that controlling for unobserved heterogeneity of the patent behavior is important.

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

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

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

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

Cooperate to Declare

Firms' Cooperative Activities as Driving Factors of Patent Declaration on Technological Standards

Abstract

Cooperative activities are crucial to influence technology development in situations of divided technical leadership. In standard setting, firms develop and agree on a common technology platform. Voluntary Standard Setting Organizations (SSOs) coordinate the transition of technology generations. Due to consensus decision making rules, firms have to commonly agree on technology proposals. Standards consortia are informal venues were firms can pre develop and sponsor technologies with likeminded peers. Within standards consortia firms build up relationships to tighten partnerships through channels of control and trust. This article empirically tests if participation in standards consortia increases a firm's ability to introduce patented proposals to formal standards. We exploit data on 250 companies which participate in international SSOs declaring over 60,000 essential patents to technology standards. We conduct panel analysis to test our research question. Regression results indicate that memberships in technically related standards consortia increase a firm's ability to introduce patented components into formal standards. Consortia connections in technically unrelated standard consortia show no significant effects. Our empirical analysis further provides evidence that consortia size positively influences the likelihood of member firms to introduce patents into standards.

Contents

1. Introduction

In the past ten years theoretical and empirical research about the interplay of IPR and technological standards has been increasing and as a consequence has revealed new implications for microeconomic analysis. On the one hand this is due to the growing importance of technological standards in our interconnected information and communication society, where interoperability and common agreement on a technology is crucial to unlock innovation (Blind and Gauch, 2008). On the other hand recent problems of IPR and standards such as hold-up or patent ambush behavior have caused expensive litigation cases and raised the question about the driving factors of patenting in standards (Shapiro, 2001; Simcoe, 2007; Hovenkamp, 2008).

Especially in ICT (Information and Communication Technology) industries, standards frame innovative technologies which are constantly updated in their scope and complexity (e.g. GSM, Wi-Fi, RFID, MPEG). Therefore the number of patents essential to commonly agreed standards has been increasing during the last decades (Bekkers et al., 2002; Simcoe, 2007). In the context of patent thickets, which is a web of overlapping patents, empirical studies evidence an excessive patent filing behavior. The assumption is that companies try to protect their innovation preferably with a high number of patents. The increasing number of patent files may cause coordination problems and in cases of hardship even leads to litigation (Shapiro, 2001). When standardized technologies are patented, patent holders may hold up whole technologies even if the patent only protects a minor part of the standard. Patents that are essential to a standard are these that one would necessarily be infringe when the standard is implemented (Lemley and Shapiro, 2006; Farrell et al., 2007).

Standard setting organizations are inclusive groups which are open to all interested parties. This open character increases the need for coordination. Especially when IPR is involved firms may have commercial stakes on standardized technologies. These situations have raised the issue of coordination failures in standardization. Farrell and Simcoe (2007) make the case of vested interest, where firms favor their own technological solutions over others. Farrell and Saloner (1985) state that coordination failures in standard setting might result in non-optimal adoption rates. Consensus on technology selection is only feasible when all involved participants face the same benefits. However, goals to include patents into standards are not necessarily connected to financial returns in terms of royalties (Shapiro &

Variant, 1999) [1]. Participation in standard setting rather depends on the firms private expectations on externalities of technologies (Katz and Shapiro, 1985).

In light of the growing technological complexity and coordination failures within formal standard setting organization (SSOs), firms increasingly enter informal industry alliances around standardization to better promote and sponsor their proprietary standard solutions. Coordination in standard setting facilitates consensus-building to better control technology inputs into standards (Axelrod et al., 1995). In order to influence outcomes of standardization, firms need to use their market power, political and promotional skills and form exclusive industry alliances (Weiss and Sibru, 1990). Recent empirical research provides evidence that consortia members have advantages to influence the selection of standardized technologies (Leiponen, 2008). In ICT, these technologies are often patented. Bekkers et al. (2011) show that firms' patent declarations are more related to involvement in standard setting compared to a patent's technical merits.

This article empirically measures the effects of firms' participation in technologically related and unrelated standards consortia on the inclusion of essential patents in standards. We construct a dataset that combines membership information of over 45 standards consortia, of which 21 have a direct liaison link to a formal standard, and add information on 45 patent pools. Our unit of observation is firm pair per standard. Firms were paired when they co-declare on the same standard. The explained variable is co-declaration of patents on the same standard. We thus measure patented technology contributions to the standard. Using panel data analysis we track 250 essential patent owning companies over ten years and observe more than 60,000 patent declarations to all international standard bodies. We further inform the whole sample of firms with characteristics such as size, financial measures and patent counts. Results of our estimations provide positive significant effects on a firm's ability to introduce patented technology to a standard when being member of technologically related standards consortia. In contrast, technologically unrelated consortia ties have no significant influence on patent declaration. We further test if the size of the consortia influences the consortia effect. Again, results of our regressions support our argument that an increase in consortia memberships also increases a firm's ability to introduce patents on standards.

This article is structured as follows. We start with a discussion of the relevant literature and construct our hypothesis. In the following we present our database and analyze first descriptive results. We then describe our empirical strategy and test our hypothesis in two

[1] Shapiro and Variant (1999) describe the case of the HDTV standard, where Zenith undertook enormous effort to get their technology and patents in the standard even though cross-licensing agreements were already agreed upon.

specifications of a panel analysis. In conclusion, we review our previous hypothesis and discuss our results.

2. Theoretical Background and Hypothesis

2.1 Standard Setting in ICT Markets

During the past decades, standard setting in ICT has emerged to be an important mechanism of coordinating the transition of different technology generations (Besen and Farrell, 1994; Simcoe 2012). Standards promote interoperability by ensuring a common language of communication. This enables different technologies or products to work together. Standards especially evolve in markets where returns increase when a large number of firms rely on the same technology. This, the success of a standard depends on the installed base of consumers (Arthur, 1988; David and Greenstein 1990). In general, standards are set as de facto or de jure standards. De facto standards are often proprietary technologies promoted by dominant firms or industry coalitions. If a de facto standard is supported by the market, bandwagon effects might rule out competing technologies. A strand of theoretical literature discusses effects of standards when network externalities are at place (Farrell and Saloner, 1986; Katz and Shapiro, 1986).

In comparison, de jure standards are the results of a joint technology development within a standard setting organization (SSO). SSOs help to overcome coordination problems and ensure common agreement on standardized technologies. SSOs are non-profit organizations, pursue consensus decisions and are voluntary and open to all interested stakeholders (Farrell et al., 2007). Especially in ICT, SSOs have gained increasing importance. Standards influence the value of technology or product markets that are created upon a standardized platform (Simcoe, 2007). Owners of panted technologies often participate in standard setting activities to influence the development of technology and promote their own proprietary methods (Bessen and Maskin, 2009; Axelrod, 1995). This development has increased competition within SSOs and fostered contributions of multiple participating firms. Therefore standardized technologies are often subject to fragmented ownership of intellectual property rights (IPRs) which have consequently raised issues of hold-up problems, ambush strategies or royalty stacking (Shapiro, 2001).

Due to the rising number of patents that are declared to be essential to formal standards (Simcoe, 2007) and the participation of firms that peruse a wide range of different business models (Aoki and Nagoaka, 2004), achieving agreements in formal SSOs has become more difficult (Lamley, 2007). When firms prefer their own technology contribution above others, vested interest may yield a war of attrition. This may slow down standardization and delay consensus decision making processes (Farrell and Saloner, 1988; Farrell and Simcoe, 2012). One the one hand participating in SSOs enables firms to receive network effects benefits from common development and promotion of a standard. On the other hand competition is more intense because technology specification in SSOs determines which firms are able to compete in constructive product or technology markets (Katz and Shapiro, 1986; Bekkers et al., 2002).

2.2 Firm Alliances and R&D Consortia

In order to overcome coordination problems in formal SSOs and to promote certain technologies in more exclusive venues, firms increasingly form industry alliances to better influence the evolution of technology standards (Leiponen, 2008, Rosenkopf et al., 2001). Explicit industry alliances are formed to control technology inputs over the development of standards. In such alliances firms divide R&D investments among members and exploit firm specific specialties (David and Greenstein, 1990). R&D consortia are welfare enhancing when supporting knowledge sharing opportunities and spill-over effects. Branstetter and Sakakibara (1998) provide empirical evidence that consortia participation may increase R&D investments. When firms sell substitute products, coordination in consortia might alleviate wasteful duplication of R&D efforts to reduce investment costs (Katz, 1986; d'Aspremont and Jacquemin, 1988).

In light of a strand of literature that discusses forum shopping activities of firms choosing the best venue to introduce their technology contributions (Lerner and Tirole, 2006; Chiao et al. 2007), firms may also participate in multiple standard setting organizations to develop or promote the adoption of a particular standard (Axelrod et al., 1995). Especially in ICT markets where technologies often indispensably work together, it is crucial to influence the development of common standards in different alliances (Leiponen, 2009). Empirical studies further support the argument that market power of coalitions, political skills or promotional activities support technology selection in SSOs (Weiss and Sibru, 1990).

2.3 ICT Standards Consortia

In practice, consortia coexist with formal standardization rather than replacing it. In an empirical analysis Blind and Gauch (2008) find a mostly complementary relationship between standards consortia and formal standard bodies. Estimations claim that over 60% of all standards in the ICT sector are consortia standards. Albeit the discussions that standards consortia are competing organizations to formal standard setting (Cargill, 2002), the current standardization landscape tends to provide several forms of cooperation. 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.[2] 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 later approved by ETSI (European Telecommunications Standards Institute). Gauch (2008) shows how ECMA (European Computer Manufacturers Association) specified DVD technologies that were later approved at ISO (International Organization for Standardization).

Yet, there is no common definition for a standard consortia and the consortia landscape has come to be very heterogeneous in characteristics such as technical issues, structure, members, transparency and intellectual property policies (Hawkins, 1999). However, some standards which were developed by consortia are widely accepted and of great importance. When it comes to the question of IPR, voting procedures are not always transparent. Standards consortia may thus function as a platform to lobby certain technologies which are protected by patents (Lemley, 2002).

At firm level, membership in consortia and formal SSOs often overlap. Leiponen (2008) finds that especially consortia with a close technical relationship to 3GPP tend to have members that also participate in ETSI working groups. In this regard Hawkins (1999) names different coordination benefits that arise from simultaneous participation in formal and informal standard setting. From a firm's perspective, a consortium is a forum to meet and discuss technical contributions before introducing them to formal SSOs. Consortia members jointly draft specifications to adjust them to market needs. However, standardizing firms especially focus on promoting their own technology stakes (Simcoe, 2012). More predictable outcomes in a cooperation help to control partners (Das and Teng, 2004). A consortium can therefore also be an opportunity to better target the development of a firm's own components. This increases consensus with other members on technical issues that will later form the standard.

[2] The IETF (Internet Engineering Task Force) publishes all liaison agreements per specification https://datatracker.ietf.org/liaison/ or the DVB liaison database in http://www.dvb.org/technology/standards/index.xml.

As to the statement of a practitioner, firms especially support technologies of peers they trust. Trust can be built by regular meetings and cooperation on related topics. As to Das and Teng (1998) control and trust are the most important sources to support confidence in partner cooperation. Trust is particularly important when firms have to rely on the performance of their partners. Standard setting is a major example of partner reliability, since standards determine constructive markets for technology and products. When a firm seeks to promote its own technology input to formal SSOs, it would consequently get more support from co-members trusting them. Trust is especially relevant when firms propose patented solutions. Holders of essential patents can hold-up the use of a whole technology, even if the patent only protects a minor component (Lemley and Shapiro, 2006; Farrell et al., 2007).

Empirical analyses have proven that companies that pre develop their contributions in standards consortia find it easier to get a technology proposal accepted in a formal standard body (Leiponen, 2008). Firms may thus especially promote solutions including their patented technologies. Indeed, Bekkers et al. (2011) show that patent declarations are more related to involvement in standard setting compared to a patent's technical merits. Standard setting in formal SSOs always is in need of consensus decisions. It is thus indispensable to cooperate with other participating companies in order to influence technical trajectories in standardizations. Delcamp and Leiponen (2012) provide evidence for an increasing R&D cooperation between firms that enter standards consortia.

In conclusion, standards consortia are important for sharing knowledge, adjusting and targeting technology development to better foster and promote own and preferred patented technology solutions.

We thus derive our hypothesis that firms which participate in standards consortia find it easier to introduce their patented solutions to formal standards. Firms may either have direct or indirect consortia ties to co-members in SSOs. Indirect ties are ties where firms cooperate on different technology topics in different standards consortia. Repeated meetings to solve various technology problems might thus create trust and control in the partnership to declare essential patents to standards:

> **H1**: *Participation in unrelated standards consortia increases firms' ability to integrate patented components to formal standards.*

In comparison, firms can also cooperate in standards consortia that are technologically related to the formal standard of observation. In liaison agreements, standards consortia directly contribute to the development of the formal standard. Firms that are consortia members are thus able to pre-develop their patented solutions and introduce these to their co-members. Again we hypnotize that consortia enable channels of control and trust to better declare patents to formal standards:

> **H2**: *Participation in liaison standards consortia increases firms' ability to integrate patented components to formal standards.*

As to Axelrod et al. (1995), firms prefer joining large standard alliances in order to have a stronger sponsoring and a wider promotion of standards. Weiß and Sibru (1990) further underline that consortia size is a significant determinant for supporting particular technologies. We thus derive our third hypothesis:

> **H3:** *The size of standards consortia positively influences a firms' ability to integrate patented components to formal standards.*

3. Data and Variables

3.1 Data

Our data sample consists of 250 companies that declared at least one essential patent to a formal standard. To retrieve information on patent declarations, we exploited publicly available data form all formal standard setting organizations (SSOs) such as ISO, IEC, JTC1 – a joint committee of ISO and IEC – CEN/CENELEC, ITU-T, ITU-R, ETSI, and IEEE. All of these SSOs have a formalized and comparable IP policy and require a declaration of essential IPR. They further provide lists of patent declarations and give 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 SSOs (Blind et. al, 2011). Over 800 declaring entities could be distinctly identified. We only used the top 250 corporations that are publicly traded for our analysis, which together declared over 96% of all essential patents in our data.

SSOs suggest to firms to declare all IPR that is potentially essential to standards (Lamley, 2009). According to ETSI's IP policy all SSO members have to "*disclose every specific patent which might be essential to a specific specification before the specification is adopted or amended*". Furthermore declaring firms have to "*make a FRAND declaration* *(after the disclosure of the patent but in any event) before the specification is adopted or amended*”.[3]

Patent declarations differ in scope and quality depending on the provided information of declaring firms. Some firms broadly state to have essential IPR for a standard project or a bundle of standards, while others are very precise in indicating which patent they consider to be essential to which standards, which standard versions or standard amendments. Some patents are stated to be essential to several standards and some patents are only stated to be essential to one or two standards. In our analysis we therefore treat every combination of essential patents and standards as one declaration. If patents were declared to be essential to a whole standard project we counted each standard patent pair within the bundle of standards.

SSO members are not impelled to declare essential IPR and SSOs have no means to require a standardized form of declaration. However, the ETSI bylaws encourage participating firms to “*inform ETSI of essential IPRs in a timely fashion. In particular, a member submitting a technical proposal for a standard or technical specification*”.[4] A formal proposal thus always also requests a statement of possible essential IPR. All members contributing to standardization therefore have to declare whether or not they own IPR that might be essential to the proposal. As to the statement of a practitioner, members in SSOs very much rely on the accuracy of each other’s declaration behavior. Participants would more likely agree to a proposal of a firm that is trustworthy. Effective and credible patent declaration is thus a matter of self-control. Furthermore SSOs require consensus reaching in all standardization procedures. Firms might consequently veto against proposals that do not fulfill necessary requirements of IPR declaration.[5] SSOs are additionally able to adjust draft specifications in light of changes in technology usage rights (Lamley, 2002). Thus there is a collective incentive for all firms to disclose their standard essential IPRs. Due to consensus decision making processes, misbehavior can be sanctioned in repeated games of proposal voting procedures. However, coordination in standard setting might in cases of vested interests result in a war of attrition (Farrell and Simcoe, 2012).

[3] The ETSI Rules of Procedure (version of 30. November 2011) Annex 6: ETSI Intellectual Property Rights read in this respect on p. 34 and 35:

[4]Furthermore ETSI states “*When an essential IPR relating to a particular standard or technical specification is brought to the attention of ETSI, the Director-General of ETSI shall immediately request the owner to give within three months an irrevocable undertaking in writing that it is prepared to grant irrevocable licences on fair, reasonable and nondiscriminatory terms and conditions..”* The ETSI Rules of Procedure (version of 30. November 2011) Annex 6: ETSI Intellectual Property Rights read in this respect on p. 34 and 35:

[5] *“…general agreement, characterized by the absence of sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conicting arguments."* (ISO/IEC Directives 2004, page 26)

In recent years empirical research on evolutionary technology development (Bekkers et al., 2011; Bekkers and Martinelli, 2012) as well as research on patent filing strategies (Berger et al., 2012) or patent value analysis (Rysman and Simcoe, 2008) have proven that data on patent declaration is a valuable indicator for a patent's essentiality.

Table 1 gives a first overview of the industry sectors of essential patent owning companies. Large companies usually do not only operate in a single sector; therefore data analysis only includes primary sectors. Companies were informed by a four digit SIC code. Table 1 solely displays two and three digit codes to gain a broader picture. The results display a concentration on certain industries. Most companies (36.6%) operate in the electrical and electronic equipment sector (SIC code 36). The concentration is even higher when the results are weighted by the number of patent declarations per company and show a share of more than 70% in the sectors of communication equipment (336) and electronic components (367).

SIC code: industry sector	**number of companies**	**share**	**weighted by patent declaration**
35: Industrial Machinery & Equipment	10	4.59%	3.08%
38: Instruments & Related Products	12	5.50%	3.30%
48: Communications	24	11.01%	5.22%
365: Household Audio & Video Equipment	17	7.80%	7.90%
366: Communication Equipment	31	14.22%	42.31%
367: Electronic Components and Accessories	34	15.60%	31.12%
737: Computer & Data Processing Services	28	12.84%	5.14%
Others	62	28.44%	1.93%

Table 1 Essential patent owning companies by industry SIC code

3.2 Variables

We use our sample of companies to build up a data panel for the periods of 2000-2009. Since our goal is to measure inter firm behavior of co-declaration, we create a panel of firm pairs. Firms are paired when they have both declared at least one patent to a formal standard. Our unit of observation is firm pair per standard. Thus firms might be paired more than once when they co-declared on more than one standard together.

The dependent variable of our analysis is patent declaration, which is a statement of a company to own patents that are essential to a certain standard. We also create a variable that counts patent declarations when both firms declare at the same time for the same standard of observation.

To gain information about standards consortia, we apply the CEN surveys of ICT standards consortia from 2000 until 2009. We retrieved over 45 standards consortia and matched them with formal standards where at least one patent was declared to be essential. The matching was constructed by comparing the CEN survey's technology classification of consortia and the technical classification of standards' ICS (International Classification of Standards) classes provided by PERINORM[6]. In addition we tracked down all liaison agreements of standards consortia to identify direct connections between standards consortia and formal standards. A liaison agreement is an ad hoc statement between standards consortia and formal SSOs to cooperate on a certain standard. ISO has a formal fast track agreement, the PAS (Publicly Available Specifications), which allows sponsoring organizations to receive formal accreditation of their specification within six to nine months[7]. JTC1 has a similar policy of featuring Approved References Specifications (ARS).[8] In total 45 different informal consortia could be related to 115 formal standards including essential patents. Out of the 45 consortia, 21 have a direct liaison link to the standards (a list of the consortia standard match can be consulted in the appendix). An in-depth internet research revealed over 34,000 consortia memberships over ten years (2000-2009).[9]

We then identified 45 patent pools which can be related to formal standards[10] and discovered 84 pool licensors. To gather membership information of pools and consortia over the past ten years, we used information of outdated webpages from the search engine of www.archive.org.

Using the "Thomson One Banker" database, firms were informed by sales per year, employees per year, R&D expenditure per year, such as industry SIC (Standard Industrial Classification) codes. In addition we classify if firms are active on upstream or downstream markets, using the business description database of "Thomson One Banker" and the classification provided by Layne-Farrar and Lerner (2011). In addition we build variables that compare differences within our firm-pair analysis. For example we relate for each year the difference of the number of employees between two firms. Variables that compare the two

[6] PERINORM is the world's biggest standard database with bibliographic information on formal standards and is regularly updated by the SDOs DIN, BSI and AFNOR and includes all standards issued by the main formal international SSOs.

[7] For further information please read the draft of the PAS approval cycle by ISO: http://www.bsigroup.com/upload/Standards%20&%20Publications/PSS/PSS_servicecycle.pdf

[8] Examples of liaison agreements are the IETFs database in: https://datatracker.ietf.org/liaison or the DVB liaison database in http://www.dvb.org/technology/standards/index.xml.

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

[10] All pools that exist around standardized technologies explicitly state the included patents and related standards.

firms' industry activity, market positions (upstream or downstream) as well as other firm characteristics are created to control for firm size differences, industry differences as well as market constellation differences within firm pairs.

Variable	Description	Obs	Mean	Std. Dev.	Min	Max
Patent Declaration	Count of patent declarations per year	436,180	2	35	0	2,440
Both Firms Declare	Count of patent co-declarations of two firms per year	436,180	0	0	0	1
All Consortia Connections	Counts all ICT consortia connections of two firms	436,180	2	3	0	17
Liason Consortia Connections	Counts all consortia connections of two firms for a certain standard in liaison	436,180	0	0	0	1
Pool Member Connection	Counts all patent pool connections for two firms	436,180	0	1	0	9
Employees	Counts employees per year	390,776	92,429	114,493	50	484,000
Sales	Denotes sales per year	390,776	30,240	31,015	120	199,925
R&D Expenditure	Denotes R&D expenditure per year	390,776	1,881	1,981	454	9,010
Patent Files	Counts patent files per year (only G & H)	206,550	3,611	4,746	100	21,376
St Patent Files	Counts patent files per year (only standard specific IPCs)	206,550	193	370	88	5,274
Complement R&D Investment	Measures the relative difference of patent files in IPCs between two firms	163,566	0.018	0.045	0	1
Employee Difference	Counts the relative difference of employees between two firms	351,456	116,803	114,415	13	403,000
Sales Difference	Denotes the relative difference of sales between two firms	351,456	32,972	27,558	688	109,925
R&D Expenditure Difference	Denotes the relative difference of R&D exp. between two firms	351,456	2,176	1,771	233	8,710
Patent Files Difference	Counts the relative difference of patent files between two firms	138,660	4,559	4,929	9	19,376
St Patent Files Difference	Counts the relative difference of standard specific patent files between two firms	138,660	236	427	7	4,803
Same Industry	Counts one if two firms are active in the same industry (4-digit SIC code)	36,7880	0.093	0.291	0	1
Same Market	Counts one if two firms are active on the same market level	41,6500	0.567	0.495	0	1

Table 2 Variables and Descriptive Statistics (250 Firms)

To control for firms' technological capabilities and opportunities, we created two measures of patent files. Firstly a variable was constructed that counted all patent files per company and year, using the patent database PatStat[11] and the assignee firm matching methods of Thoma et al. (2010). Secondly we conducted a patent file search that was restricted to certain IPC (international patent classification) classes.

To distinctly reveal standard relevant IPC classes we used our data on patent declarations, where firms state the patent numbers that are essential to the respective standards. Firms' patent files were then counted only for the identified standard relevant IPCs.[12] Patent files restricted to standard relevant IPCs should account for a firm's technical capabilities. To measure firms' technological opportunities we created a second variable; a broader count of patent files that counts all patent files in IPC classes G and H.[13]

We are able to measure precisely in which IPC classes firms of our sample file patents. We furthermore know which of these IPC classes are relevant for which standards (exploiting the info of essential patents). In order to compare the technical contributions of two firms that have declared on the same standard, we relate the count of patent files per IPC class within firm pairs. Thus we are able to measure if two firms patented in the same or in different IPC classes that are relevant for the standard. In particular we proceeded as follows: We aggregate IPC classes to the four digit level. First we calculate the relative patent files per firm and per IPC class for the standard of observation. Secondly we compare ratios per IPC class between the two firms in our observations. Thirdly we sum differences per year and per firm pair connection. We are now able to compare the degree of complementary R&D investments in standards in our firm-pair observation over time. The higher the difference of our variable, the higher is the difference of technology development for the standard of observation.

[11] EPO Worldwide Patent Statistical Database.

[12] The relevant technological field for each standard is identified using the 7-digit IPC classification of the declared essential patents. We thus revealed more than 1,400 relevant IPCs. We are thereby able to identify the relevant technological classes (IPC) that are relevant for each standard at a very precise level. 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 tests 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

[13] Over 95% of all essential patents are classified in the IPC G (Physics) and H (Electricity).

4. Descriptive Results

Over the past twenty years, numerous consortia were created in relation to standardization.[14] Notwithstanding the notion that consortia compete with formal SSOs (Lerner and Tirol, 2006), in practice formal and informal standardization rather coexist (Blind and Gauch, 2008). Hawkins (1999) further stresses that consortia may influence formal standardization both at upstream and downstream levels and thus coordinate technological development. Figure 1 shows the development of consortia memberships in our sample between 2000 and 2009. We counted periods of membership separately for each standard firm pair observation. In addition we sum all patents as to the year of declaration. As to the limitations of our data, patent declarations declined after 2002, while consortia memberships seemed to increase sharply until 2004, but decreased after 2006.

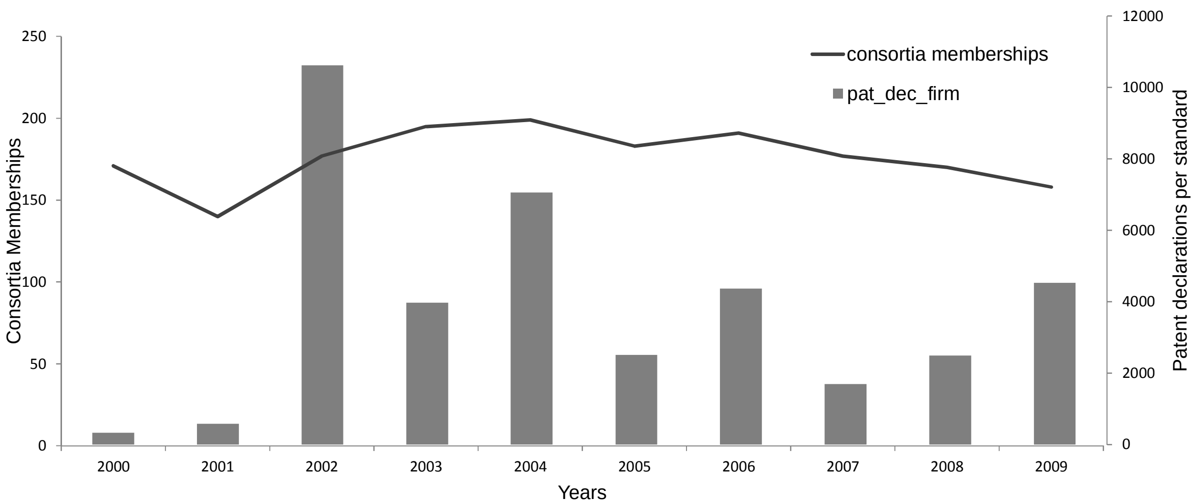

Figure 1 Active consortia memberships and patent declarations per year (2000-2009)

In order to have a better understanding of the timing of patent declaration we connected the patent data with bibliographic data on standard dynamics. We are thus able to compare the timing of declaration as to the timing of standard development.

Figure 2 shows that most of the patents are declared right before or right after standard release. However, we find observations where patents are declared up until 8 years before standard release and up until 9 years thereafter. In comparison, firms rather begin to join standards consortia in periods after standard release. The number of consortia memberships peaks 6 years after the standard was already published. Both of these findings

[14] Since 1995 the CEN survey provides a list of around 250 current ICT standards consortia, while Andrew Updegrove lists over 700 consortia under less restrictive criteria. See Appendix 1 for a summary overview over the Consortia listed in the surveys made by CEN and Andy Updegrove.

indicate that standardization is an ongoing process that evolves over time and where a great part of the innovation is still developed after the first version of the standard. Indeed especially in ICT, generations of standards (MPEG1-MPEG4, GPRS-UMTS-LTE) are constantly advanced to catch up with the pace of technology development (Bekkers et. al, 2002).

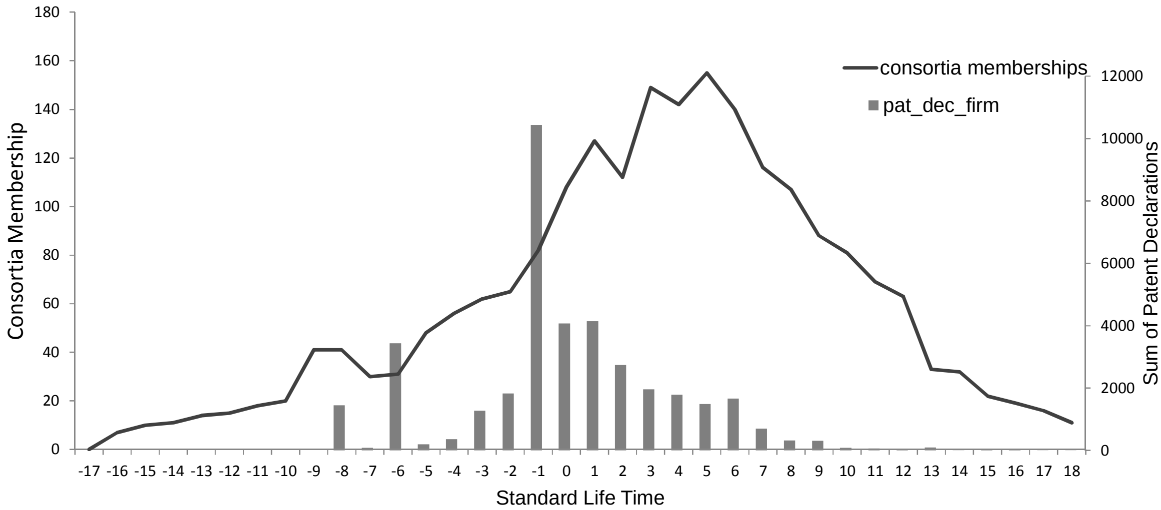

Figure 2 Active consortia memberships and patent declarations as to standard age

Companies that enter standards consortia have incentives that are connected to the development or promotion of a standard. In our sample we identify firms' consortia connections in a broad sample of ICT standards consortia. Some of these consortia in fact specify and develop technologies, while others rather promote the adoption or marketing of a standardized technology. In comparison, standards consortia that have a liaison agreement to cooperate on a specific standard project were only included in our sample when they contributed to standardization on a technical level. Thus we are able to compare two levels of consortia ties (direct and indirect). We seek to test whether the patent declaration behavior of firms is connected to these different types of cooperation in our firm-pair sample. Therefore we conduct a t-test analysis to compare if firms in our sample have a higher average number of patent declarations when they are in firm connections throughout our measure of liaison consortia, compared to no connections. We secondly conduct the same t-test for consortia connections of our broad measure of all ICT consortia connections, compared to no connections.

Results from table 3 show that firms that are members in consortia that are in liaison with a formal standard seem to less likely declare patents on formal standards. In comparison, firms that are connected throughout all ICT consortia declare on average significantly more than firms which are not members. However, analysis is yet only able to reflect a broad picture on the average number of patent declarations not differentiating among the sample of standards. Furthermore, the t-test is yet not able to take into account other variables in our sample that might explain the consortia membership effect. Differences of firm size, financial resources or technology stock might influence both; the likelihood to join a standard consortia and to declare patents on a formal standard.

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
not consortia member	40,486	18.039	0.828	166.653	16.416	19.663
consortia member	3,132	8.882	0.376	21.061	8.144	9.619
combined	43,618	17.382	0.769	160.674	15.874	18.890
diff		9.158	2.980		3.318	14.998
t = 3.073 degrees of freedom =	43,616 Pr(|T| > |t|) = 0.0021					

t-test of the cumulative number of patent declarations by all ICT consortia co-membership

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
not consortia member	12,908	9.717	1.098	124.695	7.566	11.868
consortia member	30,710	20.604	0.990	173.486	18.663	22.544
combined	43,618	17.382	0.769	160.674	15.874	18.890
diff		-10.886	1.685		-14.188	-7.584
t = 3.073 degrees of freedom =	43,616 Pr(|T| > |t|) = 0.0021					

Table 3 T-test of the cumulative number of patent declarations by liaison consortia co-memberships

Therefore we run a pair wise correlation analysis to test the coherence of patent declaration to all variables of our sample (results can be consulted in the appendix). The analysis yet reveals only weak correlations between firm pairs that both declare on the standard and direct liaison consortia co-memberships. There are no significant correlations for patent declarations and also no significant correlations for any of the two declaration counts. The strongest correlations appear among co-memberships in patent pools, in standard consortia and also in standards consortia that have a liaison with the standard of observation. These inter forum correlations might be subject to size or a company specific effect. We further observe that firms with high values in R&D expenditure, sales or employees tend to more often participate in standards consortia. Interestingly, this effect diminishes for the direct liaison consortia tie. R&D expenditure or patent files seem to have no correlation to patent declarations. Whereas our measure of ICT patent files (G&H) as well as the count of standard specific patent files shows strong correlations to size measures such as R&D expenditure, sales or employees. Results are straight forward: big companies have more financial resources to enter alliances and also to file more patents in standard related technologies. However, in order to better answer our hypothesis, we need to use a nonlinear regression estimator and control for firms characteristics such as the size effect. All of the other correlation coefficients are in the expected direction.

5. Testing the Hypothesis

We test our hypothesis of consortia firm tie effects using a poisson fixed effects estimation with robust, clustered standard errors. To account for unobserved heterogeneity, we systematically include fixed effects for our company-pair panel observations. As our dependent variable is a count variable and overdispersed with respect to a poisson distribution, we will use a poisson estimator with robust standard errors. We prefer the poisson estimator with robust standard errors over a negative binomial estimator with fixed effects, because the negative binomial estimator cannot totally control for fixed effects and thus account for unobserved heterogeneity. Our basic regression model has the following specification:

$$\begin{aligned} \textit{patent declaration}_{ijst} = \exp\big(\; & \alpha_1 \textit{all consortia connections}_{ijt} + \\ & \alpha_2 \textit{ liaison consortia connections}_{ijst} + \\ & \alpha_3 \text{ pool member connection}_{ijt} + \\ & \textit{firm differences}_{ijt-1}\text{'}\beta_1 + \\ & \textit{firm characteristics}_{it-1}\text{'}\beta_2 + c_t + \;\big) \end{aligned}$$

where $\textit{patent declaration}_{ijst}$ counts patent declarations by firm i to standard s in presence of co-declaring firm j in year t, $\textit{all consortia connections}_{ijt}$ denotes the total number of firm i's connections with the co-declaring firm j in all ICT consortia for year t, $\textit{liaison consortia connections}_{ijst}$ denotes a firm i's connections with the co-declaring firm j in year t in a consortium that is in liaison with standard s, $\text{pool member connection}_{ijt}$ denotes the total number of a firm i's patent pool connections with the co-declaring firm j in year t, $\textit{firm differences}_{ijt-1}$ denotes variables that control for firm differences in the number of employees, the amount of sales and R&D expenditure such as the counts of patent files between firm i and co-declaring firm j in year *t-1*, $\textit{firm characteristics}_{it-1}$denotes variables that control for dynamic characteristics of firm i in year *t-1* such as the number employees, the amount of R&D expenditure and the counts of patent files, c_t are year dummies and ε is an idiosyncratic error term.

In our first model (M1) we estimate the influence of all ICT consortia connections for the firm pairs in our panel. We control for firm characteristics such as R&D expenditure, employees and our two counts of patent files per year. We lag all control variables by one year to control for preceding changes. Unobserved heterogeneity between firms is controlled by using fixed effects for firm-pair standard observations. We furthermore wish to account for external shocks such as the business cycle or technology-related policy changes. We therefore include year dummies in all of our models. Our independent variable of consortia connections shows no significant results. The estimated consortia member ties consider all connections between two firms in the whole sample of 45 ICT standards consortia. Some of these consortia may thus not be technically related to the observed standard for which firms declare patents. Our results show that firm ties in unrelated standards consortia show no significant influence on patent declaration to a specific standard. In model two (M2) we only measure firm ties in standards consortia where we identified a liaison agreement between the observed standard and the consortia. M2 confirms that co-membership in technically related standards consortia positively influences the co-declaration of patents. When also including our broad measure of overall consortia connections in model three (M3), the liaison consortia connection remains positive and significant. The coefficient even increases. The correlation analysis has revealed that firms which are members in standards consortia are more likely to also be a member in patent pools, or vice versa. In model four (M4) we test for patent pool connections of our firm-pair observation to control if the consortia ties are subject to a pool membership effect. However, results again remain robust for our direct liaison consortia firm ties. Pool co-memberships have no significant influence on patent declaration. To further control for effects that accrue due to firm differences in size or technological stock (patent files) we include variables that measure firm pair changes. As to M5, differences in employees have a positive effect for co-declaration, while we find a negative correlation when firms differ in sales or R&D expenditure. In M6 we further control for differences of patent files in ICT technologies and standard specific technologies. Only ICT patent file differences show a significant negative correlation with co-declaration of patents. In comparison to our count of standard relevant patent files, where we measure firm capabilities, the ICT patent file variable reflects technological opportunities. The result indicates that firms with diverging technology opportunities find it harder to co-declare their patents. Our explanatory variable of direct liaison consortia connections remains significant and positive in all models, while we find no significant effects for technologically unrelated consortia. We thus reject H1 and confirm H2. Participation in liaison standards consortia increases firms’ ability to declare patents on formal standards, while participation in ICT consortia has no significant effect.

DV=Patent Declaration	M1	M2	M3	M4	M5	M6
Variable	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)
All Consortia	-0.064		-0.068	-0.068	-0.069	-0.068
Connections	(0.038)		(0.037)	(0.037)	(0.038)	(0.039)
Liaison Consortia		0.600***	0.656***	0.656***	0.663***	0.657***
Connections		(0.21)	(0.173)	(0.173)	(0.157)	(0.156)
Pool Member				0.484	0.487	0.497
Connection				(0.606)	(0.626)	(0.626)
Employee					0.002**	0.002**
Difference[1]					(0.001)	(0.001)
Sales					-0.004*	-0.004
Difference[1]					(0.003)	(0.003)
R&D Expenditure					-0.063**	-0.059**
Difference[1]					(0.027)	(0.025)
ICT Patent Files						-0.020*
Difference[1]						(0.012)
St Patent Files						-0.054
Difference[1]						(0.152)
L1.Employees	0.007	0.0092	0.00828	0.00829	0.00446	0.004
Firm[1]	(0.033)	(0.034)	(0.033)	(0.033)	(0.032)	(0.032)
L1.R&D	-0.094	-0.112	-0.089	-0.089	-0.059	-0.061
Expenditure Firm[1]	(0.121)	(0.126)	(0.122)	(0.121)	(0.122)	(0.121)
L1. Patent Files	0.056	0.058	0.057	0.057	0.048	0.062
Firm[1]	(0.042)	(0.045)	(0.041)	(0.041)	(0.038)	(0.040)
L1.ST Patent Files	-0.084	0.001	-0.126	-0.126	-0.057	-0.092
Firm[1]	(0.617)	(0.667)	(0.601)	(0.601)	(0.573)	(0.536)
Year Dummies	Included	Included	Included	Included	Included	Included
Log likelihood	-256,139	-257,408	-254,625	-254,623	-252,072	-251,601
Observations	85,170	85,170	85,170	85,170	85,170	85,170
Groups	8,517	8,517	8,517	8,517	8,517	8,517
AIC	512,306	514,843	509,281	509,279	504,182	503,245
BIC	512,437	514,974	509,421	509,429	504,359	503,441

Notes: All models are estimated using the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. ∗∗∗ p < 0.001, ∗∗ p < 0.05, ∗ p < 0.1 implies significance levels respectively. [1] Coefficients multiplied by 1,000 to make effects visible.

Our main argument is that firms which are members in standards consortia have more explicit knowledge on the standardized technologies, are more trustworthy for their consortia peers and promote their technologies at earlier stages to become establish control over co-members and become stronger in negotiating their patented technologies in formal standard setting procedures. As to our panel analysis this argument is only true if we assume variation of consortia memberships to be exogenous or constant over time. A firm might join a consortium because it has technical stakes such as patented solutions that fit the standardized technology.

Firms might further join consortia because they have enough employees, financial resources or enter new markets. As long as we are able to control for variance such as firm size, patenting or connections in other venues, we are able to isolate the effect of our consortia co-membership variable. A causal relationship of consortia participation on patent declaration can only be corroborated if unobserved effects do not change over time. Our results would e.g. be biased in situations where unobserved events change both; firms' incentives to join standard consortia and incentives to declare patents on standards. We therefore introduce two sources of exogenous variance that influence both, consortia participation and patent declaration behavior.

We change our estimated specification and only focus on our variable of direct liaison consortia ties, since we would like to exploit information on the direct connection between standards and consortia. Furthermore we now observe if two firms in our observation declare patents in parallel on the same standard in the same year. Simultaneous patent declaration indicates a consensus decision on the same proposal or on time wise related proposals. We therefore estimate the following equation:

$$
\begin{aligned}
patent\ co\_declaration_{ijst} = \exp (&\alpha_1\ liaison\ consortia\ connections_{ijt} + \\
&\alpha_2\ consortia\ size_{st} + \\
&\alpha_3\ complement\ R\&D\ investment_{ijst} + \\
&\alpha_4\ complement\ R\&D\ investment_{ijst}\ * \\
&same\ industry_{ijt} *\ same\ market_{ijt} + \\
&firm\ differences_{ijt}'\beta_1 + \\
&firm\ characteristics_{ijt-1}'\beta_2 c_t + \varepsilon\ )
\end{aligned}
$$

where $co\_patent\ declaration_{ijst}$ counts patent declarations by firm i and co-declaring firm j to standard s in the same year t, $liaison\ consortia\ connections_{ijt}$ denotes a firm i's connections with the co-declaring firm j in year t in a consortium that is in liaison with standard s, $consortia\ size_{st}$ denotes the number of memberships in year t for a consortium that is in liaison with standard s, $complement\ R\&D\ investment_{ijst}$ denotes the standard s relevant IPC class patent file differences between firm i and co-declaring firm j in year t, $same\ industry_{ijt}$ equals one if firm i and co-declaring firm j are active in the same industry, $same\ market_{ijt}$ equals one if firm i and co-declaring firm j are both active on the same market level, $firm\ differences_{ijt}$ denotes variables that control for firm differences such as employees, sales, R&D expenditure and patent files between firm i and co-declaring firm j in year t, $firm\ characteristics_{ijt-1}$ denotes variables that control for dynamic characteristics of firm i and j in year t-1 such as the number employees, the amount of R&D expenditure and the counts of patent files, c_t are year dummies and ε is an idiosyncratic error term.

We limit our observations to firm pairs on standards where we identified a liaison consortium. This reduces our sample to 23,496 observations and 2,450 firm pair standard groups. Our explained variable is now connected to both firms in our firm pair specification. We thus control for variances of firm characteristics for both firms in all models. Again we also control for between firm differences over time. In model six (M6) we introduce our liaison consortia tie variable to test if direct connections also have an effect when two firms declare patents in parallel. Again we find a significant positive effect. As to our third hypothesis (H3) we expected larger consortia to have a stronger effect on co-declaration behavior. In model seven (M7) we introduce a consortia size variable that counts membership over time. Our results confirm our H3 and reveal a positive effect of consortia size on a member's ability to introduce patents on standards. Our control variable of firm differences in sales now points to a negative connection to co-declaration. We argued that financial resources could in fact influence consortia participation due to membership fees or other expenses. Due to direct connections of consortia and standard pairs we are now able to inform membership fees for each consortium. These fees differ in prices depending on voting power and levels of participation. When consortia offer different tiers of membership or connect their fees to the participant's amount of sales, the difference between the highest and lowest fee is considerably large. We include a variable that measures the membership fee level differences and interact it with the between firm sales difference. Our membership fee variable is time invariant and thus not included in our fixed effect model separately. Results indicate that if consortia have a high difference in their price structure, the negative effect of sales difference decreases (M8). Tiered membership fees thus mitigate inequalities in the amount for sales. In model nine (M9) we introduce a variable that measures the degree of complement R&D investments in standards. This variable compares patent files in standard relevant IPC classes between the firms of observation. Thus we do not compare the amount of R&D investment but the technical direction of investment. Model nine shows a negative effect, meaning that in situations where firms increasingly invest in different technologies we find fewer co-declarations of patents.

DV=Both Firms Declare	M6	M7	M8	M9	M10
Variables	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)
Liaison Consortia	0.511***	0.312***	0.297**	0.289**	0.288**
Connections	(0.123)	(0.119)	(0.116)	(0.116)	(0.116)
Consortia		0.001***	0.001***	0.001***	0.001***
Size		(0.001)	(0.001)	(0.001)	(0.001)
Sales Difference*			0.001***	0.001***	0.001***
Consortia Fee Difference			(0.001)	(0.001)	(0.001)
Complement				-4.164**	-3.681**
R&D Investment				(1.68)	(1.46)
Complement R&D					-11.698***
Investment* Same Industry*Same Market					(3.563)
Employee	0.006	0.008	0.008	0.007	0.007
Difference[1]	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Sales	-0.015	-0.016*	-0.051***	-0.051***	-0.051***
Difference[1]	(0.010)	(0.010)	(0.012)	(0.012)	(0.012)
R&D Expenditure	-0.079	-0.080	-0.082	-0.097	-0.111
Difference[1]	(0.123)	(0.134)	(0.136)	(0.137)	(0.138)
Patent Files	-0.097**	-0.123**	-0.123**	-0.118**	-0.105*
Difference[1]	(0.049)	(0.055)	(0.055)	(0.055)	(0.055)
St Patent Files	0.041***	0.392***	0.382***	0.382***	0.382***
Difference[1]	(0.005)	(0.052)	(0.051)	(0.051)	(0.051)
Firm Characteristics	Included	Included	Included	Included	Included
Year Dummies	Included	Included	Included	Included	Included
Log likelihood	-10,224	-10,136	-10,123	-10,119	-10,118
Observations	23,496	23,496	23,496	23,496	23,496
Groups	2,450	2,450	2,450	2,450	2,450
AIC	20,478	20,305	20,279	20,273	20,272
BIC	20,599	20,434	20,408	20,410	20,417

Notes: All models are estimated using the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. $***$ $p < 0.001$, $**$ $p < 0.05$, $*$ $p < 0.1$ implies significance levels respectively. [1] Coefficients multiplied by 1,000 to make effects visible.[15]

We further want to test if effects of complementary R&D investment in standards are also connected to measures of inter-firm rivalry. We therefore interact our variable for

[15] We have tested all models of our second specifications by also including our measure of all ICT standard consortia connections and our control of patent pool co memberships. Results remain significant and coefficients do not change drastically.

complement R&D investment with a dummy variable that equals one if firms are active in the same industry (4 digit SIC code level) and further interact both variables with a variable that equals one if both firms are active on the same market level (upstream or downstream respectively). Our dummy variables are time invariant and thus not included in our fixed effect model separately. Results indicate that firms with a high degree of rivalry are less likely co-declare when they invest in technologically different standard components. Indeed as to Axelrod, et al. (1995), rivalry increases when firms provide technologically different or incompatible solutions to standard setting and when they are active in the same market segment. Our results further confirm that these firms less likely co-declare and thus mutually agree to integrate patented solutions into standards.

All of the models of our second specification show positive significant correlations between liaison consortia firm ties and patent declaration. We introduced two variables of exogenous variance to test if these events also influence our dependent variable and thus indicate somewhat causal effects of consortia participation. Our first variable of consortia size changes is, from the perspective of the participating firm, an exogenous event. The size of the consortia is caused by other firms entering or leaving the consortia. These decisions are firm individual and are usually not influenced by other consortia members. The second variable that represents exogenous variation is our measure of complementary R&D investments. Even though consortia co-members cooperate in standards consortia, R&D investments decisions are still independent to a certain degree. Moreover we especially find significant negative effects on co-declaration for rivalry firms of our sample. Independent investment decisions are especially expected for rivalry firms. Changes in complementary R&D investments for standards thus influence each firm’s ability to co-declare independently.

6. Conclusion

This article investigates cooperative activities of 250 firms that are active in formal ICT standards setting. Our results suggest that participating firms in industry standards consortia find it easier to introduce their patented technology components to formal standards, compared to others. However, we only confirm the positive consortia member effect when standards consortia have a liaison agreement with the standard of observation. We further provide significant results for a positive size effect of standards consortia. The increase in consortia memberships thus also increases a firm’s ability to introduce patented components into standards.

In this article we identified constellations in which two firms mutually agree to have patented components integrated into standards. Besides a firms' human capital, financial resources or technical capabilities, we investigated whether a firm's cooperative activities influences the technology selection processes. We especially highlight two channels of how firms influence their peers: control and trust. Control over partners is an important determinant to maintain negotiation power in promoting proprietary solutions. Standards consortia are venues where members coordinate to better target technology development to be introduced into the formal standard setting. More predictable outcomes in technology development foster partner control. Trust is crucial since essential patents can block whole technologies and enable firms to control whole markets. If a firm owns components of a commonly agreed standard, partner firms have to trust their co-members not to exploit these situations. In comparison to formal SSOs, standards consortia are industry alliances of likeminded companies. Standards consortia meet on a more regularly basis and thus provide a platform where firms can discuss and exchange ideas. Firms often pre disclose their technologies and adjust them to better target technology needs. Increasing cooperation, knowledge exchange and transparency help firms to build up trustworthy relationships among peers.

In this article we provide evidence that competition on standardized platforms is especially connected to firms' cooperative activities around standardization. It is crucial to coordinate with peers on technology development to better influence the technology selection process. However, firms have to carefully choose their standards consortia in terms of technical scope and focus. Membership in technically related consortia may increase the ability to position patented technologies into formal SSOs, while participation in unrelated consortia may have no effect. The results show that meeting peers in different venues for different technology problems is no channel of influencing specific technology standards. Furthermore firms should seek to enter consortia with a large member base. The more members consortia gather, the more support can be expected in sponsoring and promoting a standard. Especially when membership between standards consortia and SSOs overlaps, firm's ability to influence the outcome of standard setting is stronger when supported by more consortia co-members.

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Appendix

Consortium in Liaison	Standard	Average Fees	Fees High-Low Difference	Consortium in Liaison	Standard	Average Fees	Fees High-Low Difference
1394TA - The 1394 High Performance Serial Bus Trade Association	IEEE1394	5250	9500	INCITS	ISO/IEC11889-3	22500	25000
ACCELLERA	IEEE1800/IEC62530	10000	10000	INCITS	ISO/IEC11889-4	22500	25000
Cable Laboratories	IEEE802.1Q	.	.	INCITS	ISO/IEC13818-1/ITU-TH.220.0	22500	25000
DVB – Digital Video Broadcasting Project	EN300468	10000	0	INCITS	ISO/IEC13818-2/ITU-TH.262	22500	25000
DVB – Digital Video Broadcasting Project	EN301958	10000	0	INCITS	ISO/IEC13818-3	22500	25000
DVB – Digital Video Broadcasting Project	EN302304	10000	0	INCITS	ISO/IEC13818-7	22500	25000
DVB – Digital Video Broadcasting Project	EN302583	10000	0	INCITS	ISO/IEC14443-2	22500	25000
EPCglobal	ISO/IEC18000-6	.	.	INCITS	ISO/IEC14443-3	22500	25000
Homeplug	IEEE1901	6500	6000	INCITS	ISO/IEC14443-4	22500	25000
IETF	ES201108	0	0	ISMA	ISO/IEC14496-1	3000	1000
IETF	ES202050	0	0	ISMA	ISO/IEC14496-10	3000	1000
IETF	ES202212	0	0	ISMA	ISO/IEC14496-10/ITUH.264	3000	1000
IETF	G.711	0	0	ISMA	ISO/IEC14496-2	3000	1000
IETF	G.722	0	0	ISMA	ISO/IEC14496-3	3000	1000
IETF	H.263	0	0	MEF	IEEE802.1X	7500	15000
IETF	IEEE802.21	0	0	MPEGIF	ISO/IEC14496-12	1650	2700
IETF	IEEE802.3/ISOIEC8802-3	0	0	MPEGIF	ISO/IEC14496-15	1650	2700
IETF	IEEE802.5/ISOIEC8802-5	0	0	MPEGIF	ISO/IEC14496-18	1650	2700
IETF	ISO/IEC15444-1	0	0	MPEGIF	ISO/IEC14496-4	1650	2700
IETF	ISO/IEC15444-12	0	0	MPEGIF	ISO/IEC14496-5	1650	2700
IETF	ISO/IEC15444-2	0	0	MPEGIF	ISO/IEC14496-6	1650	2700
IETF	ISO/IEC15444-3	0	0	NFC Forum	ISO/IEC18092	25750	48500
IETF	V.44	0	0	OCP-IP	IEEE1149.1	12500	25000
IMTC	H.323	4250	8500	ODVA	IEEE1588/IEC61588	50500	99000

INCITS	ISO/IEC10918-1/ITU-TT.81	22500	25000	UPnP Forum	ISO/IECDIS29341	2500	5000
INCITS	ISO/IEC11172-1	22500	25000	Wi-Fi Alliance	IEEE802.11/ISOIEC8802-11	10000	10000
INCITS	ISO/IEC11172-2	22500	25000	WiMax	IEEE802.16	22500	35000
INCITS	ISO/IEC11172-3	22500	25000	WiMedia Alliance	IEEE802.15.3	13750	22500
INCITS	ISO/IEC11889-2	22500	25000	WORLDDAB FORUM	ETS300401	12000	0
INCITS	ISO/IEC11889-1	22500	25000	ZigBee	IEEE802.15.4	26750	46500

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Patent Declaration	1.00															
2	Both Firms Declare	0.04	1.00														
3	All Consortia Connections	-0.01	0.22	1.00													
4	Liason Consortia Connections	0.00	0.14	0.20	1.00												
5	Pool Member Connection	-0.01	0.04	0.46	0.09	1.00											
6	Employees	-0.02	-0.03	0.25	0.02	0.17	1.00										
7	Sales	-0.01	0.02	0.39	0.03	0.29	0.85	1.00									
8	R&D Expenditure	0.00	0.05	0.33	0.04	0.12	0.68	0.71	1.00								
9	Patent Files (G&H)	-0.02	-0.10	0.10	0.04	0.14	0.43	0.46	0.40	1.00							
10	Standard Specific Patent Files	-0.01	-0.05	0.07	0.08	0.07	0.19	0.24	0.27	0.62	1.00						
11	Complement R&D Investment	-0.01	-0.01	-0.14	-0.04	-0.07	-0.12	-0.14	-0.15	-0.15	-0.10	1.00					
12	Employee Difference	-0.01	-0.03	0.12	0.00	0.02	0.52	0.40	0.30	0.18	0.06	-0.11	1.00				
13	Sales Difference	-0.01	0.06	0.11	0.01	-0.02	0.33	0.37	0.22	0.13	0.05	-0.09	0.73	1.00			
14	R&D Expenditure Difference	-0.01	0.07	0.11	0.01	0.02	0.25	0.26	0.37	0.10	0.07	-0.11	0.50	0.52	1.00		
15	Patent Files Difference	-0.02	-0.14	-0.02	0.03	0.06	0.19	0.18	0.14	0.55	0.34	-0.19	0.18	0.18	0.09	1.00	
16	St Patent Files Difference	-0.02	-0.07	0.02	0.12	0.09	0.09	0.10	0.11	0.35	0.65	-0.11	0.02	0.02	0.03	0.54	1.00

N = 23,496

All correlation coefficients above |0.2| are significant at $p < 0$

Standard essential patents to boost financial returns

Abstract

This article investigates how patents that are essential to a technology standard influence firms' financial performance. Standards enable interoperability and communication on a technology platform. In practice, most innovative applications build upon interoperable standardized technologies. In recent years, a large part of the competition on technology has been moving upwards at the standard setting level. Especially in ICT (information and communication technology) where innovation is often cumulative, it is crucial to own essential patents to maintain market positions. We test the influence of declaring a patent to a standard on financial performance using a rich dataset of firms active in ICT standard setting. Our results indicate a curvilinear (inverse U-shaped) relationship of patent declarations on firms' return on assets (ROA). This effect lasts for one year, while the incremental effect is higher for patents declared to informal SSOs (standard setting organizations) when comparing declarations to formal SSOs. We further estimate the optimal number of patent declarations and find a higher optimal level of financial return for declaring patents to formal standards. The curvilinear relationship suggests that firms should balance their patent portfolio by introducing a share of patents into standards and by holding a share of patents on standard constructive technologies. Our results indicate that the effects of patenting around standardization depend on the standardizing SSOs as well as the level of patenting. In order to realize an optimal level of financial returns, we suggest firms evaluate their patent portfolio before selecting a standard setting forum. Valuable patent portfolios generate higher incremental returns in informal SSOs, while larger patent portfolios reach higher optimal return levels in formal SSOs.

Contents

1. Introduction

A firm's innovative capacity is crucial to maintaining competitive advantages in knowledge resources, technology advances, price competitions and market positions. In recent years scholars have increased their investigations of intellectual property rights (IPRs) and their influence on firms' financial performance (Hall et al., 2005; Reitzig and Puranam, 2009). While most of the research examines different factors of patent value, only few analyses have been conducted that shed light on the positioning of patents, such as a patent's essentiality to a technology standard. The commercialization of a technology in ICT (information and communication technology) markets often requires licensing agreements among multiple patentees (Shapiro, 2000; Graevenitz et al., 2011). In this context, ICT standardization has developed to be much more demanding in terms of R&D and now represents a key strategic stake for companies to foster the value of their (patented) technology by having it approved as part of an industry-wide standard. Patents that would necessarily be infringed by any implementation or adoption of a standard are called essential patents (Bekkers et al., 2001; Simcoe, 2007). The essentiality of a patent has an indispensable character in the adoption of standardized technologies. Patents incorporated into standards can hold-up the use of a whole technology, even if the patent only protects a minor component (Farrell et al., 2007). The empirical analyses of Bekkers et al. (2002,2011) have shown that standard essential patents qualify firms to control market positions in network industries.

Yet, there is only little research that examines the impact of standard setting on a company's financial performance. Waguespack and Fleming (2009) show that participation in SSOs increases the likelihood of a buy-out of start-ups, yet without analyzing performance measurements. Aggarwal et al. (2011) provide empirical evidence of a positive relationship of a companies' participation in standard setting and returns on stock markets.

The aim of this article is to extend the current analyses by examining the impact of standard essential patents on a company's financial performance measured by ROA. While applying measurements of patent value, such as the average number of forward citations and the average patent family size of a company's patent portfolio (Narin and Noma, 1987; Trajtenberg, 1990), we focus on information of a patents' declaration to a standard. We therefore compiled over 65,000 patent declarations by formal SSOs[1] (Standard Setting Organizations) and informal SSOs[2]. Patent declaration statements provide information on the patent number, the patent holder and the timing of declaration. To control for a company's licensing strategy we further added information on firms' patent pool memberships connected to essential patents. We created a data panel built upon company level and gathered information on the total amount of sales, R&D expenditure, number of employees and return on assets per year and per company between 2000 and 2007.

To assess the impact of essential patents on a company's financial performance, we conducted bivariate as well as multivariate analyses, using return on assets (ROA) as our explained variable. Our results provide evidence that declaring essential patents to formal and informal SSOs has a curvilinear (inverted U-shaped) effect on financial returns. When comparing the coefficients of our explanatory variables, we further find the incremental impact of essential patents declared to informal SSOs to be stronger compared to patents declared to formal SSOs. We employed additional analyses to identify the optimal level of patent declarations which is higher for formal standards. Patents declared to informal

[1] ISO, IEC, JTC1-a joint committee of ISO and IEC, CEN/CENELEC, ITU-T, ITU-R, ETSI, and IEEE.
[2] IETF, TIA, OASIS, OMA, the Broadband Forum and the MSF Forum.

standards in comparison may even have negative effects on ROA beyond an optimal level of patent declaration. To also assess the lasting effects we further tested models with time lags. The effect of patent declarations remains robust up to a time lag of one year. Essential patents start to have no significant impact when lagged by two years or more.

The curvilinear relationship of a firm's patent declaration and ROA suggests that firms need to balance their patent portfolio by introducing patents into standards not beyond an optimal level. Depending on the quality and size of a firm's patent portfolio firms should further select the most beneficial forum of standard setting. Our results show that incremental returns are higher for declaring patents to informal SSOs, while the optimal level of patent declaration that generates positive returns is higher for formal SSOs. We thus suggest firms with large scale patent portfolios to declare to formal SSOs, while high quality patents should be introduced to informal SSOs where patents gain higher returns.

The remainder of this paper is structured as follows. In our theoretical section we discuss the measurement of patent value indicators as well as the role of patents in standard setting and indicators of financial performance. We then motivate our hypothesis, describe our database and define our methodological approach. Subsequently we run regression models to test our hypothesis. We conduct further robustness tests and finally conclude in our last section.

1. Literature and Theory

The influence of a company's technology assets on its financial performance has been studied extensively. Analyses by Griliches (1981) and Narin and Noma (1987) were among the first to measure different indicators of patents to influence a company's sales, profits or market value. In the following we will discuss several indicators of patent value, patent essentiality to standards as well as the measurement of financial performance.

2.1 Patents and Patent Value Indicators

Patent applications and patent grants are probably the most important indicators for the technological output of innovation processes within companies. Especially in high-tech areas, such as ICT and software, the number of patents can be assumed to exert a positive influence on the financial performance of a company (e.g. Hall et al., 2007; Hall and MacGarvie, 2010). Large patent portfolios reflect increased R&D efforts and thus greater innovative output, which has been shown to influence a firm's performance in various ways. A large patent output can be seen as a positive market signal (e.g. Hall et al. 2005) also affecting firms' profitability (Bloom and van Reenen, 2002, Ernst, 2001). Large patent portfolios are also strategically useful, for example to block other market participants' innovative endeavors, to displace smaller competitors in relevant markets, to increase the chances for license or commercial agreements, ease the access to the capital market and increase a company's reputation (Blind et al., 2006).

Since patents, however, differ from one another both in economic and technological value, just counting patents could lead to a distorted picture of a company's technological base. Therefore, some additional indicators have been proposed to correct for the quality or value of patents. The most common and widely used indicator to determine patent quality is patent forward citations (Narin and Noma, 1987; Trajtenberg, 1990). The number of forward citations (citations a patent receives from subsequent patents) is assumed to measure the degree to which a patent contributes to further developing advanced technology. Thus, forward citations can be regarded as an indicator of the technological significance of a patent (Albert et al., 1991; Blind et al., 2009; Hall and Ziedonis, 2001), although it has been evaluated to be rather noisy indicator (Alcacer et al., 2009; Alcacer and Gittelman, 2006; Hall and Ziedonis, 2001).

Another patent value indicator is family size. It is determined by the number of countries or patent offices, where a patent has been filed (Putnam 1996), and can therefore be seen as a measure of patented market coverage. This patented market coverage, however, is associated with additional expenses for patent application, information search, translation, examination etc., which are even amplified when patenting in foreign jurisdictions (Hanel 2006). Thus, it can be assumed that a patentee only files a patent abroad, if he expects a corresponding return on the sale of the protected technology that outweighs the patenting costs.

This article extends the analyses on patent counts and patent value indicators to the measurement of the positioning of patents to be essential for standardized technologies. In particular, we use information on the essentiality of a patent to ICT standards.

2.2 Essential Patents and Standard Setting

The goal of standard setting is to commonly agree on the specifications of a technology (Lyytinen and King, 2006; Markus et al, 2006). This is often crucial to enabling interoperability and to unlock innovation in complex technologies based on various components provided by different suppliers. However, the process of setting a standard can be very costly for participating firms, since standard development seizes employee workforce and creates traveling expenses for regular meetings and presentations around the world.[3] Firms' benefits from standard setting are versatile, such as the facilitation of technology and products (Weitzel et al., 2006; Peek, 2010), reinforcing user confidence and user acceptance (Brynjolfsson and Kemerer, 1996; Blind et al., 2010) and consequently the emergence of new

[3] Chiao et al. (2007) interviewed practitioners in standard setting and retrieved information on IBM which spent more than 500 USD million on standard setting expenses, representing almost 8.5% of their R&D budget in 2005.

and the growth of already existing markets (Blind, 2004). Due to the public good character of a standard, these benefits may accrue to all market participants. While some companies provide their R&D outputs for standard setting, others do not. Introducing essential patents to a standard is a practice to recoup a company's investments in standards setting (Farrell and Saloner, 1985).

Essential patents are those that a company would necessarily infringe when adopting or implementing a technology standard. Especially in the field of ICT, standards may incorporate technology components which are protected by a large number of patents (e.g. GSM, UMTS, Wi-Fi, MPEG)[4]. While standards have to ensure interoperability and should be open to all interested stakeholders, granted patents provide its holders with a temporally limited monopoly right on a technology. In the field of standard setting, companies have to declare patents that might affect the standardized technology and agree to license their rights under fair, reasonable and non-discriminatory (F/RAND) conditions. These F/RAND agreements are still far from conclusive and there is an ongoing discussion about what a reasonable license for an essential patent should be (Layne-Farrar et. al, 2007). It is still a common belief that essential patent owning companies are able to exploit their positions of technology ownership, when standards are commercialized. The decision to include a patent in a standard is a consensus decision and a validation of a patent's technological merit. Recent literature findings show that patents increase in value, when they are included in a standard (Rysman and Simcoe, 2008; Layne-Farrar and Padilla, 2011). Bekkers et al. (2001) give further evidence that a company's position in a particular network market strongly depends on the number of essential patents declared. Firms seem to have strong incentives to introduce

[4] GSM (Global System for Mobile Communications), UMTS (Universal Mobile Telecommunications System), Wi-Fi (The Standard for Wireless Fidelity), MPEG (Moving Picture Experts Group)

patents to standards, as an empirical study by Goodman and Myers (2005) illustrates over-declaring of essential patents in the field of 3G technologies. Berger et al. (2012) show that firms even apply strategic behaviors in the patent application process to adjust their patent claims to the standardized technology.

2.3 The Return on Assets

To assess the value of a company, a large number of indicators have been used up to now. Within this analysis we intend to focus on the return on assets (ROA) as a measure of the financial performance of companies. ROA is a measure of contemporaneous profitability, or in other words, present day profits. It is formally defined as earnings before interest and taxes π divided by the total assets A of a company. Assuming that a company will live indefinitely and there is no uncertainty, the following relationship is expected to hold for any company i:

$$ROA_{0i} = \pi_{0i} / A_{0i}$$

ROA is one of the most widely used measures for the financial success of a company that is subsumed under the expression return on investment (ROI) or rate of return (ROR).

2.4 Theory and Hypotheses

Previous studies have shown that owning patents in ICT markets (Hall. et al., 2007; Hall and MacGarvie, 2010) and participating in standard setting (Aggarwal et al., 2011) may increase the financial performance of firms. When declaring a patent as essential to a standard, patent owning companies may be in the position to control whole markets that are based upon standardized technology to thus increase their financial performance. However, including patents in a standard is always a result of consensus agreements on a standardized technology. Decision making is only feasible, when all involved participants face the same benefits. If possible, side payments are solutions to reach common agreements. These payments might resolve e.g. royalty fees from essential IPR (Farrell and Saloner, 1985). In consensus decision making, it seems plausible that side payments increase with a higher number of essential patents. This would in turn negatively affect firms' financial performance. Bekkers et al., (2011) show that firms which declare too many patents seem to declare patents of lower quality. If "over-declaring" increases side payments and is subject to a decreasing patent quality, we predict that the effect on a firm's financial performance also decreases with the number of patents declared.

Aggarwal et al. (2011) state that coordination in standard setting leads to homogeneity of knowledge distribution among participants and thus may reduce a firm's competitive advantage. When companies declare their patents to a standard, SSOs oblige the patent holder to license the patented technology (Layne-Farrar et. al, 2007). This is different for patents outside standardization where the patentee is able to block competitors by not licensing out but enforcing the patent. In order to maintain competitive advantage it thus appears to be advantageous for a company to balance their patent portfolio. We predict that it is beneficial to introduce a certain share of patents into standards to guarantee freedom to operate and increase bargaining positions in cross licensing agreements (Blind et al., 2011), while the remaining share of a company's patent portfolio should be placed to secure differentiation of product designs and complementary applications. Over-declaring would thus not only decrease marginal returns e.g. by side payments, but further decrease the competitive advantage in a market. Firms' R&D decisions are thus always subject to the trade-off between investing in technologies for standard platforms and investing in constructive components. Based on these considerations, we derive the hypothesis that there is a positive incremental effect of essential patents on a firm's ROA up to a certain level. Beyond an optimal level of patent declaration we assume a decreasing effect. We thus derive our first hypothesis:

Hypothesis 1:

The declaration of standard essential patents has a curvilinear effect on a company's financial performance, with a slope positive effect at low and moderate levels and a negative incremental effect at high levels.

Patents may be essential to formal or informal standards. Lerner and Tirole (2006) first introduced the option of SSO selection as a concession parameter in relation to technology ownership. An owner of a strong technology will select an SSO aiming to capture much of users' welfare via collecting licensing revenues. In the case of a weak technology or the existence of strong alternatives, the technology owner has to make concessions to users, e.g. by signing a royalty free agreement for his patents included in a standard. Chiao et al. (2007) provide empirical evidence for the hypotheses derived from the model on the decision parameters of SSO selection. Companies may thus choose to introduce their technologies to standards in formal or informal SSOs in view of the most beneficial financial returns.

The standard setting arena is divided into formal and informal SSOs that generally work on complementary technologies (Blind & Gauch, 2008). Estimations claim that over 60% of all standards in the ICT sector are developed in informal SSOs (Tapia, 2010). Formal and informal SSOs pursue different standardization processes but also differ in their IPR rules. While technology selection in formal standardization is a result of consensus agreement, informal SSOs mostly only demand majority voting. Formal standardization is open to all interested stakeholders, while informal SSO membership is more exclusive (e.g. by demanding rather high membership fees). Due to these differences, formal standardization is often seen to be more bureaucratic and thus slower in the decision making processes, while informal SSOs often face shorter standardization processes (Cargill, 2002). In formal SSOs, licensing fees for essential patents are restricted by F/RAND commitments. Informal SSOs allow less restrictive licensing agreements. When considering these differences and the findings of Lerner and Tirole (2006), we conclude that companies with strong technologies would rather choose informal SSOs, where majority voting might help to push technology proposals without agreeing to concessions, e.g. resolving royalties. Furthermore, informal SSOs' less restrictive licensing cap might result in higher royalty fees. We thus predict that the impact of essential patents on a firm's financial performance is stronger in informal SSOs compared to formal SSOs and derive our second hypothesis:

> **Hypothesis 2:**
>
> *The declaration of essential patents to informal standards has a stronger incremental effect on companies' financial performance compared to patent declarations to formal standards.*

Patents in the field of ICT may have a strong effect on a company's financial performance (Hall et al., 2007; Hall and MacGarvie, 2010). Griliches (1990) also predicts a positive lagged correlation of patents and firm performance. Bloom and Von Reenen (2002) provide further evidence that effects of patents on financial performance may have immediate, but also lagged effects. Furthermore, Ernst (2001) found that patents have a lasting effect on a company's amount of sales for up to 3 years after priority year. We believe that declaring a patent to be essential to a standard might also have a lasting effect on a firm's financial performance. However, we assume this effect decreases over time. This is due to the fact that ICT markets are usually subject to short product lifecycles and the survival of technologies is often at pace. Evidence for this fast pace can be found when analyzing patent data in ICT sectors. In particular, the technology cycle time (TCT) can be used to measure the speed of innovation (Deng et al., 1999; Narin 1993). It is calculated as the median age of cited patent references in a company's patent portfolio. Companies with shorter cycle times than their competitors advance more quickly from prior to current technology. The literature suggests that the cycle time ranges from about three to five years in electronics (Narin, 1993).[5] Since technology life cycles are rather short in electronics and firms declare their patents in average four to six years after priority date (Blind et al., 2011), we believe that declaring a patent to be relevant to the standard is limited in time and has a yearly decreasing effect on a firm's performance. Thus, we derive our third hypothesis:

Hypothesis 3:

The effect of essential patents, declared to formal as well as informal standards, is limited in time and has a yearly decreasing effect on companies' financial performance.

[5] In order to get the most recent data on the TCT we calculated it again using the EPO Worldwide Patent Statistical Database (PATSTAT). It can be shown that the TCT ranges between four and five years in ICT sectors, such as computers and communication engineering, as well as in pharmaceuticals. On average, patents declared essential are between four to six years old (as to the application year).

2. Methodology

3.1 Model Setup

In order to test our hypotheses we set up a mathematical model that we can estimate by regression techniques. In particular, we regress a firm's ROA on formal and informal patent declarations, including its squared terms to test for non-linearity, the number of pool membership seats, the number of patent filings and patent quality indictors as well as other innovation and financial performance related control variables, i.e. sales per employee, R&D intensity as well as company size. In addition, we include the one year lagged ROA into our model to account for autocorrelation and endogeneity issues, since it can be assumed that the ROA in a given year is influenced by the ROA in the previous year. By doing so, we seek to isolate the causal effects of formal and informal patent declarations on a firm's ROA. Our benchmark model, which is suitable for H1 and H2, can be described as follows:

$$\begin{aligned} ROA = {} & \alpha_1 ROA_{t-1} + \alpha_2 PDC + \alpha_3 PDC^2 + \alpha_4 CDC + \alpha_5 CDC^2 \\ & + \alpha_6 PLS + \alpha_7 PAT + \alpha_8 CIT + \alpha_9 FAM + x'\beta + c + u \end{aligned} \tag{1}$$

where ROA denotes the Return on Assets, PDC and CDC are formal and informal patent declarations, respectively, PLS is the number of pool membership seats, PAT is the total number of patent applications, CIT and FAM are the average number of total forward citations to a company's patent portfolio and the average family size of the respective patent portfolio. Furthermore, x is a vector of control variables, c is a company-specific effect and u idiosyncratic errors. We omitted time subscripts for the sake of simplicity. In our multivariate analysis we estimate several models by including and excluding different control variables. By doing this, we try to capture the influence of companies' varying investments (R&D expenditures), assets (patent applications, employees) or performance (sales).

With respect to H3, we expand our model by including timely lagged effects of the PDC and CDC variables, including the squared terms. The equation looks similar to equation (1), with the extension of the lagged effects of PDC and CDC as well as the lagged squared terms:

$$\begin{aligned} ROA = {} & \alpha_1 ROA_{t-1} + \alpha_2 PDC + \alpha_{2'} PDC_{t-v} + \alpha_3 PDC^2 + \alpha_{3'} (PDC^2)_{t-v} \\ & + \alpha_4 CDC + \alpha_{4'} CDC_{t-v} + \alpha_5 CDC^2 + \alpha_{5'} (CDC^2)_{t-v} \\ & + \alpha_6 PLS + \alpha_7 PAT + \alpha_8 CIT + \alpha_9 FAM \\ & + x'\beta + c + u \end{aligned} \tag{2}$$

where t is a time subscript and v denotes the annual lag for each additional lagged variable in the model for PDC and CDC starting at a value of $v = 0$, ranging from $v = 0,...,n$. We include each of the lagged variables as well as the contemporaneous variable into one model to calculate the yearly influence of informal and formal patent declarations controlling for the influence of the other years' declarations respectively. This way we can model the hypothesized yearly decreasing effect on ROA and are also able to make sure causality runs from patent declarations to the ROA.

3.2 Definition of the hypothesized effect on ROA

Equation (1) shows that H1 is defined in terms of the signs associated with the baseline coefficients $\alpha_2,...,\alpha_5$. These measure the impact of formal and informal patent declarations on ROA. H1 predicts that patent declarations have a curvilinear (inverted u-shaped) effect on the ROA. This implies that the coefficients of PDC as well as CDC, α_2 and α_4, must have a positive sign in order to support our hypothesis, whereas at the same time the coefficients of the squared effects of both variables α_3 and α_5 are expected to have a negative sign. H2 postulates that the effect of informal declarations on ROA is higher than the impact of formal declarations. This does not target the signs of the coefficients, but rather indicates that the value of coefficient α_4 has to be higher than the value of coefficient α_2 in order to confirm our H2.

	H1	H2	H3
ROA	$\alpha_2 > 0$ $\alpha_3 < 0$ $\alpha_4 > 0$ $\alpha_5 < 0$	$\alpha_4 > \alpha_2$	$\alpha_2 > \alpha_{2't-1}$ $\alpha_{2't-1} > \alpha_{2't-2}$ $\vdots$ $\alpha_{2't-p} > \alpha_{2't-v}$ *and* *with* $p < v$, $\alpha_4 > \alpha_{4't-1}$ $\alpha_3 ... \alpha_{3't-v} < 0$ $\alpha_{4't-1} > \alpha_{4't-2}$ *and* $\alpha_5 ... \alpha_{5't-v} < 0$ $\vdots$ $\alpha_{4't-p} > \alpha_{4't-v}$

Table 1: Summary of the hypotheses

Regarding H3, we need to look at Equation (2). We hypothesize that essential patents, formal as well as informal, have a limited, lasting effect on the financial performance of companies in terms of ROA, which decreases over time. This again targets the strength of the coefficients compared to the coefficients of its lagged versions, implying that the contemporaneous effect of the coefficients is larger than the effect with a one, two or three year lag. In order to support H3 for formal patent declarations, α_2 has to be larger than $\alpha_{2't-1}$, $\alpha_{2't-1}$ has to be larger than $\alpha_{2't-2}$, etc. up to $\alpha_{2't-p}$, which has to be larger than $\alpha_{2't-v}$. For informal declarations, the same assumptions hold for α_4. Since we have no theoretical reason to believe that the assumed decrease in the slope of PDC and CDC that we stated in H1, is more or less strongly pronounced with additional time lags, we do not make any further assumptions about the strength of the coefficients in the lagged specifications. However, as in H1, we assume that they have a negative sign meaning that $\alpha_3 ... \alpha_{3't-v} < 0$ and $\alpha_5 ... \alpha_{5't-v} < 0$. In addition, as we do not know how long the effect of PDC and CDC on ROA might last, this approach remains exploratory and we will let the empirical model decide up to which time lag significant results can be found. A summary of the formal modeling of our hypotheses is shown in Table 1.

3.3 Estimation Method

Since the data used for our analysis is in the form of a company-level panel, the econometric specifications have to take account of the peculiarities of this data structure. Our model can be estimated by a fixed effects regression model, i.e. a within estimator, that eliminates the fixed effects by centering each variable on its individual-specific mean, taking into account potentially endogenous individual effects. In order to control for non-constancy in the residual variance of the variables in our regression model, we employ cluster robust standard errors by company, which are heteroscedasticity-consistent (White, 1980).

If models are subject to unobserved heterogeneity, which is correlated with the explanatory variables, simple pooled OLS estimators are asymptotically biased. To account for this problem, linear panel-data models are used in order to eliminate time constant unobserved heterogeneity. To decide between fixed or random-effects, we additionally employed a Hausman-Test, which showed that the random-effects assumption (that explanatory variables are uncorrelated with company-specific effects) is violated. This would lead to systematically biased coefficients as well as standard errors. Therefore, only a fixed-effects estimator results in unbiased estimates. In particular, the linear panel-data model is as follows:

$$y_{it} = x_{it}\beta + c_i + u_{it} \qquad i = 1,\dots,n \qquad t = 1,\dots T$$

where y_{it} is the explained variable of unit i in period t, x_{it} is a vector of explanatory variables, β is a coefficient vector, c_i is a company-specific effect and u_{it} idiosyncratic errors. In order to test the influence of each of the individual explanatory variables on ROA, we calculate several models and add the respective variables gradually.

3.4 The Data

The construction of the dataset is based on the DTI-Scoreboard from the year 2001, in which a total of 500 companies were listed. Data on previous and following years were added. If one of the 500 companies was not listed in the DTI-Scoreboard in the years before or after 2001, we treated the respective observations as missing. In the case that mergers or acquisitions between the companies listed in the DTI-Scoreboard occurred in a given year, all data for the respective companies was summarized. Thus, the companies were treated as if they were already merged at the beginning of the observation period.[6]

In a second step, we added the relevant information on patenting behavior to this database. Relevant patent data was extracted from the "EPO Worldwide Patent Statistical Database" (PATSTAT). The annual sum of patent applications filed by each company in a given year at the European Patent Office (EPO) was calculated. The same was done for the patent value indicators, i.e. for patent forward citations and family size. All patent data from the PATSTAT database are dated by their priorities, i.e. the year of world-wide first filing. We believe that our restriction to analyze value indicators of EPO patents only is sufficient, since over 90% of the essential patents are also filed at the EPO. The priority dates of our data also take into account worldwide offices.

To identify the companies listed in the DTI-Scoreboard in PATSTAT, we employed keyword searches. The keywords included not only the company names[7] in different spellings

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[6] We chose this approach to preserve comparability over time, as the separation of the individual company information is no longer possible after a merger (compare Frietsch, 2006).
[7] Information about the names of the relevant subsidiaries by company was added from the LexisNexis (lexisnexis.com) and Creditreform Amadeus (creditreform.com) databases.

but also the names of the companies' subsidiaries held by the parent company with a direct share of at least 25%. This assures comparability of patent data with the financial data from the companies' balance sheets.

In a next step, we added financial data of the companies – such as total assets or earnings before interest and tax – that are needed to calculate the company's ROA from Standard & Poor's COMPUSTAT Global and COMPUSTAT North America databases.

Then we added information about a patents' inclusion in a standard. In total, we extracted over 65,000 patent declarations by formal SSOs such as ISO, IEC, JTC1-a joint committee of ISO and IEC, CEN/CENELEC, ITU-T, ITU-R, ETSI, IEEE. In addition, we added patent declarations by informal SSOs such as IETF, TIA, OASIS, OMA, the Broadband Forum and the MSF Forum. All of the listed SSOs provide public databases about patent number, declaration date and company of declaration.[8] To ensure that each company in our final sample is active in standard setting and is thus able to include their patents in a standard, we only included members of the above mentioned SSOs.[9]

We further added information on a company's participation in a patent pool. This is important to account for specific licensing strategies of firms. As to Layne-Farrar and Lerner (2011) pool participation is not automatic and firms only join pools when it fits to their specific licensing business model. Our data includes all pool memberships since 1999. Patent pool administrators state which standards are affected by the patent pool. In combination to our data on patent declarations we precisely differentiate between companies that license their patents individually and companies that pool their patents. Patenting on standards increased in the late nineties when the licensing of essential patents became a new challenge to standard

[8] E.g.: www.iso.org/patents or: http://ipr.etsi.org/ or: https://datatracker.ietf.org/ipr/search/
[9] We employed membership information from the SSO's web pages. If the membership information was not at hand, we added information of attendee lists of conferences organized by the respective SSOs.

setting (Simcoe, 2005). Regarding this rather recent development and to ensure data conformity in our sample we limited our observations to the years between 2000 and 2007.

Due to these limitations and the fact that we use an unbalanced panel, in which data for some observations in the respective years may be missing, we calculate our models for 817 observations of 134 companies in total. All further analyses in the study are based on this final sample.

3.5 Variables and Summary Statistics

In this section we briefly discuss the variables used in the following regression models. The summary statistics of these variables are presented in Table 2. Following the theoretical discussion from Section 2, we use the ROA as a measure of a firm's financial performance, which is also added as an explanatory variable with a lagged specification in our models to minimize autocorrelation and account for endogeneity issues.

The number of formal and informal patent declarations per year (both in thousands), as well as the respective squared terms, are our main explanatory variables. A patent declaration is a statement by a company to own patents that are essential to a standard. This statement is not mandatory and in some cases made after a standard has already been released. In most cases the issue of essentiality is not tested by objective authorities (only in the case of a patent pool). However, research on evolutionary technology development (Bekkers et al., 2011; Bekkers and Martinelli, 2012) as well as research on patent filing (Berger et al., 2012) or patent value (Rysman and Simcoe, 2008) have proven that data on patent declaration is a valuable indicator for a patent's essentiality. One patent can be declared to be essential to several standards. The number of patent declarations is therefore by far higher than the number of essential patents.

We further add data on patent pool memberships. In patent pools IPR owners pool their patents to agree on a single license. Patents in patent pools have to pass a test of essentiality concerning a standardized technology. Since license agreements as well as patent declaration behavior change when companies enter a patent pool (Simcoe, 2007), we matched the membership data of 54 patent pools to the companies of our sample. Companies may be a member of more than one pool depending on the standardized technology. Our patent pool variable differentiates the company of observation into pool member and pool outsider.

The number of patent applications at the EPO (in thousands) is a count of a company’s issued patents per year. The average number of forward citations is calculated as the number of forward citations in a four year time window divided by the number of applications with forward citations (also in a 4 year time window). The time window assures that all patents have the same amount of time to be cited. The average family size is the average number of distinct patent offices where a company's patents were filed.

Variable	Mean	Std. Dev.	Min	Max	# Obs.	# Firms
ROA	0.068	0.081	-0.520	0.387	817	134
# patent declarations (in thousands)	0.048	0.513	0.000	11.413	817	134
# consortia declarations (in thousands)	0.001	0.005	0.000	0.065	817	134
# pool licensor seats (in thousands)	0.001	0.002	0.000	0.018	817	134
# patent applications (in thousands)	0.224	0.373	0.001	3.084	817	134
R&D (in m)/sales (in m)	0.074	0.065	0.002	0.708	817	134
Sales (in m)/employees	0.189	0.108	0.042	0.974	817	134
# employees (in thousands)	78.912	88.616	1.030	484.000	817	134
Avg. # FW-Citations	2.391	1.223	1.000	14.861	817	134
Avg. Family Size	5.179	1.671	2.000	14.000	817	134

Note: *The summary statistics are only reported for the number of cases that are used in the multivariate regressions.*

Table 2: Summary statistics of sample variables

With respect to potentially confounding firm characteristics, we include further control variables. We include the number of employees (in thousands) to control for size effects. The share of sales (in millions) by employee is introduced as a proxy of how efficiently a firm generates sales. In addition, we use R&D intensity (R&D expenditures (in millions) divided by sales (in millions)) in our models, which can be regarded as a proxy of how well a firm converts results of R&D processes into revenues. R&D intensity is supposed to affect firm profitability, especially in our sample of relatively large, R&D performing firms. Finally, we use time dummies to account for confounding level effects that occur over our panel period.

3. Empirical Results

4.1 Bivariate Analyses

As a first step to assess the influence of formal and informal patent declarations on a company's financial performance in terms of ROA, we run a pair wise correlation analysis, which allows us to assess correlations among variables of our sample. As hypothesized, we find no significant linear correlation between the ROA and formal and informal patent declarations. Furthermore, no significant correlation of a company's patent applications with the ROA can be observed, whereas the patent value indicators and ROA correlate. A significantly positive correlation between the average family size and the ROA can be observed, yet the average number of forward citations shows a rather small, but significantly negative correlation with ROA. The number of employees is also negatively connected to ROA, implying that smaller companies in terms of the number of employees have a lower ROA compared to larger ones. Also our R&D intensity measure is negatively correlated to ROA. This could be interpreted insofar, as R&D expenditures first of all are a significant cost factor and therefore have a negative influence on ROA. The sales per employees measure on the other hand shows a significant positive correlation with financial performance.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1 ROA	1								
2 # formal declarations	0.05	1							
3 # informal declarations	0.05	0.21***	1						
4 # pool licensor seats	-0.01	0.02	0.03	1					
5 # patent applications	-0.03	0.11***	0.09***	0.41***	1				
6 R&D/sales	-0.15***	0.10***	0.24***	-0.07*	0.05	1			
7 Sales/ employees	0.09**	0.06*	0.14***	-0.01	-0.04	0.01	1		
8 # employees	-0.06*	0.00	-0.01	0.27***	0.53***	-0.25***	-0.09***	1	
9 Avg. # FW-Citations	-0.06*	-0.01	0.00	-0.12***	0.01	0.04	0.02	-0.07**	1
10 Avg. family size	0.13***	0.04	-0.03	-0.09**	-0.04	-0.03	-0.01	-0.10***	0.35***

*Significance Level: ***p<0.01, **p<0.05, *p<0.1*
***Note**: The correlation analysis is based on the number of cases that are used in the multivariate regressions.*

Table 3: Pair wise correlation matrix of sample variables

In order to extend the analysis of our bivariate effects and to model the hypothesized curvilinear effect of patent declarations on ROA, we need to conduct a multivariate analysis to obtain conclusive results.

4.2 Multivariate Analysis

The results of our first multivariate analysis are presented in Table 4. As stated in Section 3, we estimated several models and added the respective variables gradually up to our final model that corresponds to Equation (1).

In all our models (M1-M6) we are able to show that patent declarations in formal and informal SSOs, ceteris paribus, have a curvilinear relationship (inverted U-shape) with a firm’s ROA. Therefore, we are able to confirm our first hypothesis H1: Companies’ patent declarations significantly increase their ROA up to a certain point. We further confirm that there is a maximum in this relation, which is modeled by the negative squared effects of formal and informal declarations. From this maximum point onwards, the incremental effect of declaring patents on ROA becomes negative. These results support the assumption of an over-declaration effect, where declaring a too high number of standard essential patents decreases firm performance.

Our empirical findings further confirm our second hypothesis H2. The incremental impact of declaring essential patents related to informal standards has a stronger effect on companies’ financial performance compared to patent declarations on formal standards. Companies are able to choose to participate in different SSOs depending on the strength of their technology and assumptions of technology returns (Lerner and Tirole, 2006). We argue that the return on essential patents is higher for standards released by informal SSOs. Our results indicate that a company with strong technology assets rather declares its patents to informal SSOs.

The effects of our explanatory variables also hold when adding the number of pool licensor seats of a company as a control variable to our models. Compared to other patent owning firms, a firm that is a member of a patent pool does not individually license its patents. Patent pool memberships indicate a certain licensing strategy of a firm (Layne-Farrar and Lerner, 2011). However, our results show that different licensing strategies do not influence a firm's financial performance. Goals to include patents into standards are not necessarily connected to revenues from licensing.[10] Furthermore firms' licensing strategies are also subject to different IP policies of SSOs. Our differentiation into formal and informal patent declarations might thus already capture the licensing effect. Similar assumptions can be derived for the rest of our control variables, which are added in M5 and M6. When controlling for size effects, increased R&D intensity, patent applications and the value of the patent portfolio, our results remain consistently significant. However, it can be shown that the firm-specific as well as the innovation related indicators strongly increase the R^2 of the models, implying that the chosen indicators also affect firm performance. The statistical tests show that R&D intensity (R&D expenditures/sales) has a significant negative influence on ROA. This negative effect can be explained by the characteristics of our variable. R&D investments are costs which might pay off several years later. For example, a company invests in new innovative processes or technologies. Yet, it is unsure whether or not these investments are successful and contribute to a company's performance. Therefore, at least from a short-term point of view, R&D investments are first of all costs which consequently have a negative effect on the ROA.

Our variable of labor productivity (sales by employees) does not show any significant results in M5 and M6. The same holds for the number of patent applications, for which we also do not find any significant effects. This result points once more to the fact that it is not sufficient to account for a company's technological performance by solely measuring the number of patent filings. We therefore include patent value indicators in our final model

[10] Shapiro and Variant (1999) describe the case of the HDTV standard, where Zenith spent enormous effort to get their technology and patents in the standard even though cross-licensing agreement were already fixed before.

(M6). However, in our estimation the patent family size has no effect on ROA and the number of forward citations even shows a negative effect on our explained variable, although this effect is rather small. There has been evidence in the literature stating that patents, which are essential to a standard have a higher number of forward citations (Rysman and Simcoe 2008; Layne-Farrar and Padilla, 2011). We thus believe that the patent value effects are captured by our main explanatory variables: formal and informal patent declarations.

dV: ROA	M1			M2			M3			M4			M5			M6		
	Coef.		S.E.	Coef.		S.E.	Coef.		S.E.	Coef.		S.E.	Coef.		S.E.	Coef.		S.E.
L1.ROA	0.322	***	0.061	0.327	***	0.061	0.326	***	0.061	0.325	***	0.061	0.216	***	0.071	0.216	***	0.071
# patent declarations	0.013	*	0.008				0.014	**	0.006	0.014	**	0.007	0.022	***	0.007	0.023	***	0.008
# patent declarations sq[1]	-0.001		0.001				-0.001	*	0.001	-0.001	*	0.001	-0.002	***	0.001	-0.002	***	0.001
# consortia declarations				2.355	*	1.343	2.360	*	1.334	2.253		1.366	2.816	**	1.178	2.663	**	1.110
# consortia declarations sq				-0.052	**	0.021	-0.053	**	0.020	-0.051	**	0.020	-0.056	***	0.019	-0.052	***	0.018
# pool licensor seats										1.251		1.744	-0.320		1.891	-0.415		1.979
# patent applications[1]													1.617		13.195	-0.420		13.617
R&D/sales													-0.610	***	0.095	-0.614	***	0.094
Sales/employees													0.106		0.074	0.109		0.072
# employees[1]													-0.043		0.186	-0.034		0.182
Avg. # FW-Citations																-0.005	**	0.002
Avg. Family Size																0.002		0.002
Constant	0.054	***	0.008	0.052	***	0.008	0.052	***	0.008	0.051	***	0.008	0.093	***	0.032	0.088	***	0.031
Time Dummies	YES			YES			YES			YES			YES			YES		
Number of companies	134			134			134			134			134			134		
Observations	817			817			817			817			817			817		
R^2 within	0.259			0.262			0.263			0.263			0.357			0.363		
F	13.667			14.436			12.404			11.888			12.604			12.135		

*Significance Level: ***p<0.01, **p<0.05, *p<0.1*
Note: *[1] Coefficient multiplied by 1,000 to make effects visible. L1. means that the variable is lagged by one year. The number of observations in each model was adjusted to the model with the fewest observations (M6) in order to conserve comparability of the effects over all models.*

Table 4: Results of the fixed-effects panel regression models

In our theoretical section we have also argued that owning essential patents may enable a company to control markets. Thus, we expect the consequence of patent declarations to also have a timely lasting effect on the financial performance of firms, which has been shown for several other innovation related indicators in the literature (Bloom, Van Reenen, 2002; Ernst, 2001; Griliches, 1990). However, we assume that this effect would decrease over time, since ICT markets in particular are subject to short product lifecycles (Narin, 1993). Consequently, we stated in our H3 that essential patents declared in formal as well as informal standards have a limited lasting and yearly decreasing effect on companies' financial performance. The formal modeling can be found in Equation (2).

In M6-1 we add the lagged number of formal and informal patent declarations as well as squared effects to the model (Table 5) [11]. By doing so, we regard the yearly effects of patent declarations. From a four year time lag onwards we find no more significant effects of our explanatory variables on ROA, which is why we added the variables in their lagged specifications only up to four years.

[11] We are aware of the fact that models including several lagged versions of one variable might become instable and therefore difficult to interpret due to multicollinearity issues. Although this approach remains exploratory, we believe that the chosen specification including the lagged versions of the PDC and CDC variables - up to the time lag where the variables become insignificant - serves as an indication of the lasting effect of patent declarations on ROA.

dV: ROA	M6-1		
	Coef.		S.E.
L1.ROA	0.200	***	0.075
# patent declarations			
L0	0.032	**	0.015
L1	0.027	**	0.012
L2	-0.004		0.009
L3	-0.023		0.014
L4	-0.041		0.029
# patent declarations sq			
L0[1]	-0.003	*	0.001
L1[1]	-0.002	*	0.001
L2[1]	0.001		0.001
L3[1]	0.002	**	0.001
L4[1]	0.004		0.003
# consortia declarations			
L0	1.882	***	0.655
L1	3.170	**	1.275
L2	4.384		3.268
L3	3.140	*	1.805
L4	-0.656		1.100
# consortia declarations sq			
L0	-0.047	***	0.014
L1	-0.078	***	0.026
L2	-0.095		0.058
L3	-0.060	*	0.034
L4	0.022		0.017
# pool licensor seats	-1.974		1.916
# patent applications	-0.013		0.015
R&D/sales	-0.595	***	0.092
Sales/employees	0.125	*	0.067
# employees[1]	0.017		0.162
Avg. # FW-Citations	-0.004	*	0.002
Avg. Family Size	0.003		0.003
Constant	0.081	***	0.028
Time Dummies	YES		
Number of companies	134		
Observations	817		
R^2 within	0.397		
F	3272.027		

Note: *[1] Coefficient multiplied by 1,000 to make effects visible. L. stands for the lagged versions of the variables. L0 is the contemporaneous effect, L1 means that the variable is lagged by one year etc. Significance Level: ***p<0.01, **p<0.05, *p<0.*

Table 5: Results of the fixed-effects panel regression models with lagged explanatory variables

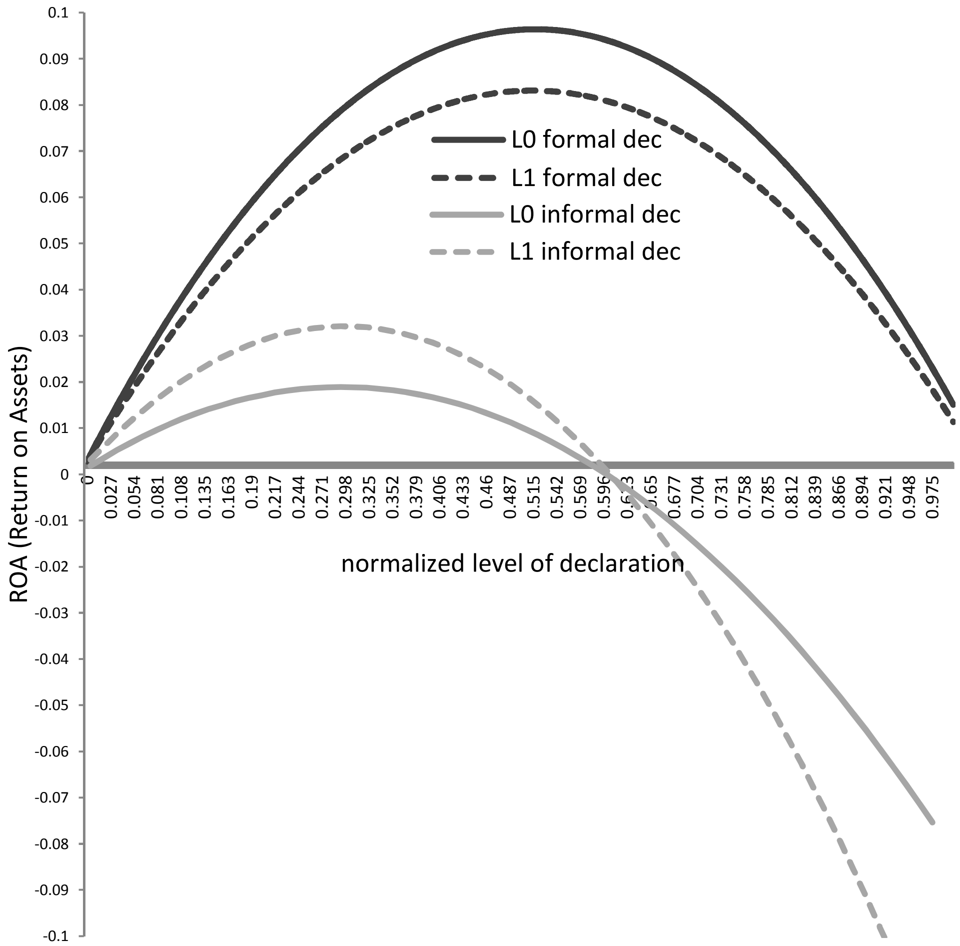
Our results still show that the hypothesized curvilinear effect of patent declarations in formal and informal SSOs on ROA holds. Results up to a significance level of 5% remain robust up to a time lag of one year for both SSO types. However, in the dynamic comparison we can observe that the coefficient decreases in the case of formal SSOs and increases in the case of informal SSOs up to a lag of one year. Therefore, we can only partly confirm our H3.

The hypothesized lasting, timely decreasing effect can only be observed for formal declarations, while it is increasing in the case of informal declarations at least in the one year time lag. This effect might occur because declarations related to formal standards generally occur at a later point in time than declarations linked to informal standards. On average, declared patents to standards released by formal SSOs are older (in average 6 years from the priority year) than patent declarations to standards published by informal SSOs (on average 4 years from the priority year). These dynamic differences are connected to different standardization processes, because informal SSOs are expected to standardize technology in earlier stages (Cargill, 2011). Patents might thus still increase in their value while the technology is yet emerging. Our results provide indications of such an effect related to the influence on financial returns. In the case of declarations to formal standards, the effect becomes insignificant from a two years time lag onwards (although the squared effect is still significant in the two year lag specification).

In the case of declarations in informal SSOs, the effect becomes insignificant in a two years lag, but again appears in the three years lag specification. At first sight, this is a puzzling result. However, the timing of patent declaration is often very volatile and can also be subject to policy shocks in the different SSOs.

Our multivariate results support our predictions related to the effect of essential patents and illustrate a curvilinear correlation with a firm’s ROA. However, our analysis has not yet provided specific information on an optimal level of declaration. We therefore multiply the coefficients of our last model (M6-1) with patent declarations to formal and informal SSOs and plot the distribution over the normalized number of total declarations per firm. We graph the normalized number of total declarations and compare the optimal level of declaring to either a formal or informal SSO. Our empirical models have shown that the incremental effect of one declaration is higher for informal SSOs compared to formal SSOs. However, graph 1 illustrates that the optimal level of patent declaration is higher for formal SSOs, meaning that firms are able to introduce a higher number of patents to formal standards until the incremental effect on ROA turns negative. While the optimal level of patent declarations to formal SSOs has a lower level after a lag of one year, it is reversed in the case of informal SSOs. For both cases the correlation of patents and ROA shows a comparable distribution for lagged periods. While in the case of formal SSOs the effect of patents on ROA decreases, but stays positive after the optimum, patents introduced to informal standards may also have a negative effect beyond the optimum.

The analysis of an optimal level of patent declarations should be interpreted cautiously, indicating a general tendency rather than precise effects and benchmarks. Firms participate in very specialized standard working groups, where they work on technical problems that may differ strongly among SSOs. Since we plot aggregated results of our sample of companies, graph 1 especially illustrates different effects depending on the SSOs and the level of patenting.



Graph 1 Coefficients of M6 multiplied by the normalized number of formal and informal declarations

The reason why formal standardization allows a higher number of patented contributions in general (Blind et al, 2011) and a higher optimal level in our estimation, can be explained by the different technological specialization of SSOs. Informal SSOs mostly concentrate on IT standardization, while formal SSOs specialize in telecommunication technologies. Standards in the field of telecommunication (e.g. GSM, UMTS, WiFi, etc.) are subject to very complex technologies that are often standardized on a specific physical layer. These standards have to be very precise in e.g. specifying protocols for communication (Bekkers et al., 2001). In comparison, IT standards are rather focused on application layers and standardized solutions are rather generic. Our estimation results confirm these differences. Essential patents introduced to standards set by informal SSOs have a stronger incremental effect on a firm's ROA. This would confirm that informal standards concern a broader field of technology. In comparison, rather specific formal telecommunication standards allow a higher number of patents (reflected by the higher optimal level), while the incremental effect of each patent is lower.

4.3 Robustness Check

We perform additional robustness checks to test if our results remain robust over different model specifications. All of the robustness checks are performed on the basis of the final model specification (M6), not including the lagged specifications of the explanatory variables.

Our first concern regarding our model is that the dependent variable ROA does not hold the normality assumption. To stabilize the variance of our dependent variable we perform a z-standardization, a log-transformation as well as a Cox-transformation of the ROA variable and re-ran our model with each of the transformed variables. All three models with standardized dependent variables show similar effects of the explanatory variables. Coefficients for formal and informal declarations and the squared terms show slightly smaller values when the Cox-standardized ROA was used. Yet, the coefficients did not change signs and remain significant at the 5% level in the case of formal declarations. The number of consortia declarations, however, is only significant at the 10% level and the squared number of consortia declarations loses significance. In the case of the z-standardized ROA variable, the strength of the effects even increases and all coefficients show the same significance levels as in the original specification. For the log-transformed ROA, the coefficients become a little stronger, but slightly less significant than in the original model. However, the coefficients remain significant at the 5% level. Turning the argument the other way around, we also z-standardized and log-transformed the declaration variables and used them as explanatory variables in our models. As for the z-standardized explanatory variables, the values of the coefficients for formal and informal declarations become smaller but remain significant. As for the log-transformed explanatory variables, we find increasing values of the coefficients for each of the variables and also a slight decrease in significance. Yet, all variables remain significant at least at the 10% level.

	# patent declarations	**# patent declarations sq**[1]	**# consortia declarations**	**# consortia declarations sq**
dV: ROA (Original Model (M6))	0.023***	-0.002***	2.663**	-0.052***
dV: Cox-transformed ROA[2]	0.012**	-0.001**	3.392*	-0.076
dV: z-standardized ROA	0.259***	-0.022***	29.924**	-0.586***
dV: Log-transformed ROA	0.026**	-0.002**	2.495**	-0.044**
dV: ROA, z-standardized declaration variables	0.004***	-0.049***	0.004**	-0.0001***
dV: ROA, Log-transformed declaration variables	0.070**	-24.153*	2.746**	-53.662***
dV: ROA, EBITDA instead of EBIT used for ROA calculation	0.017**	-0.001*	1.665	-0.04**
dV: ROIC	0.036**	-0.003**	3.928**	-0.072**
dV: EBIT as a share of sales[2]	0.072***	-0.006***	5.542**	-0.09*
dV: ROA, Lagged control variables[2]	0.022***	-0.002**	2.721**	-0.054***
dV: ROA, Declarations as shares on all patent applications	0.006**	-0.173**	0.106	-0.05

*Significance Level: ***p<0.01, **p<0.05, *p<0.1*
Note: *[1] Coefficient multiplied by 1,000 to make effects visible. [2] These measures could only be calculated with a reduced number of cases due to the construction of the dependent variable or the lagged specifications. Only the coefficients for the relevant explanatory variables are shown. The full results of the models can be consulted in the appendix.*

Table 6: Coefficients of the explanatory variables for the modified models

A second approach to testing the robustness of our results is to replace our explained variable ROA by different, yet similar, dependent variables that account for a firm’s financial performance. In a first step, we replaced the earnings before interest and tax in the ROA calculation by earnings before interest, taxes, depreciation and amortization (EBITDA). With the help of this specification, we are able to test if potential effects of amortization or depreciation, which are implicitly represented in our original ROA specification, are responsible for the effects we find for formal and informal patent declarations. Second, we built a variable for the return on invested capital (ROIC), which is calculated as the share of earnings before interest and tax divided by the invested capital of a company in a given year, and used this as a dependent variable in our model. Third, we calculated earnings before interest and tax divided by sales, which is closely related to the net margin of a firm per year. As we can see in Table 6, the signs of the coefficients do not change in all of the three models and the values of the coefficients are higher than in the original model. Yet, the significance level drops slightly, but not below the 10% level. An exception is the ROA specification with EBITDA, where the values of the coefficients are slightly smaller than in the original model and the consortia declarations variable loses significance (p=0.117).

In a third approach, we specify the patent related control variables in the model – namely the number of patent applications, the average number of forward citations and the average family size – with a one year lag to account for a possible timely delayed effect on ROA, which might mitigate the results found for our main explanatory variables. However, this is not the case. The coefficients remain robust and significant at least at the 5% level.

Finally, in order to balance our declaration variables to the size of the patent portfolio of a company, we calculate the share of formal as well as informal patent declarations to all patent applications of a company (as well as squared effects) and replace them with our original explanatory variables. As to the results in table 6, the coefficients still have the same signs, but informal declarations do no longer show a significant effect. However, one has to keep in mind that the specification of this share is rather vague, since the timing of patenting and declaring a patent to SSOs might strongly differ.

All in all, we conclude that our model seems to deliver robust results over several different specifications, ranging from the standardization and transformation of the dependent and independent variables to changes in the dependent variable as well as changes in the timing of the control variables.

4. Discussion of the Results

Our results provide evidence that the financial performance of companies active in technology markets is not only connected to their innovative capabilities and resources, but further depends on the strategic management of their patent portfolio. Most companies own big patent portfolios to protect their innovations and to block competitors. We show that firms should strategically position their patent portfolios on standard platforms as well as on complementary applications in order to generate optimal financial returns.

This article assesses firms’ patent portfolios on count and value measures and tests the effect of a patent declaration to a standard on a company’s ROA. Our first hypothesis (H1) suggests a curvilinear relationship between the declaration of essential patents and firm performance. Indeed, empirical tests show that the declaration of patents has a positive influence on a firm’s performance up to an optimal level and then decreases. From a manager’s perspective it is important to influence technological development in SSOs and to control standardized platform with patented components. However, in standard setting, firms have to cooperate with competitors (Leiponen, 2008) and share their innovative knowledge with rival market participants. A firm’s individual knowledge may thus become collective knowledge and firms risk losing their differentiation advances (Aggarval et al., 2011). Our findings of a curvilinear relationship of patent declarations and financial returns support this argument and suggest that companies should diversify their patent portfolios. On the one hand, firms need to declare a share of patents to SSOs to freely operate and control standardized technology platforms. On the other hand, firms also have to maintain competitive advantage by patenting their platform constructive innovations outside standard setting. The curvilinear relationship of essential patent declarations illustrates this balancing of a firm’s patent portfolio, which only has a positive influence on firm performance up to an optimal level and then decreases.

The results of our estimations also provide evidence to confirm our second hypothesis (H2) suggesting the positive incremental effect of a patent declaration to be stronger for informal SSOs compared to formal SSOs. Standard setting allows firms to freely choose their preferred forum for standardization. Firms would thus always select SSOs where technology contributions generate the highest returns (Lerner and Tirole, 2006). Formal SSOs cap royalties of essential patents by demanding F/RAND commitments of participating firms. We predict that patent declarations to informal SSOs might thus generate higher royalties. Furthermore, formal SSOs are open to all stakeholders and seek consensus decisions when selecting technology proposals. Firms may find it less risky to share their valuable contributions in a more exclusive, informal forum. Our estimations confirm a stronger incremental effect of patent declarations to informal SSOs; however, a more precise analysis indicates a higher optimal level of patent declarations for formal SSOs. We argue that this is due to the differing specialization in technology between formal and informal SSOs. Our results suggest that firms carefully choose which SSOs to join, depending on their individual portfolio of technologies. Even though declaring a patent to informal SSOs generates more returns, our results show that patent declaration will decrease a firm's performance at a lower level. Additionally, we only find a possible negative effect of too many patent declarations when declared to informal SSOs. This is different for formal SSOs where the positive incremental effect is weaker, but the optimal level of declaration is higher. Companies with a small but very valuable patent portfolio might thus prefer informal SSOs, while companies with a large portfolio but rather incremental patents would prefer formal SSOs. These results suggest that a firm's patenting decision in the context of standardization should also consider choosing the appropriate standard forum in order to generate higher financial returns.

In our last hypothesis (H3) we predicted that patent declarations also have a lasting effect on a firm's financial performance. Our estimations provide evidence that a company's current and also near future financial performance is connected to patent declarations up to a time lag of one year. We further predicted a decreasing effect, which can only be empirically confirmed in the case of formal SSOs. The effect of patent declarations to informal SSOs even increases in a lag of one year. Again, this suggests that firms with valuable patents may find it more beneficial to declare their patents to informal SSOs. However, the lagged negative effect of over-declaration is also stronger for informal SSOs.

Although prior research has provided evidence for the effects firms' patent portfolios on performance measures as well as effects of firms joining standard setting or contributing to standard setting, this study is the first to acknowledge the case of patents in standardization. We illustrate optimal levels of patent declaration and further show that these levels change among standard settings SSOs. In particular we aggregate SSOs to formal and informal fora and identify different effects for patents. Depending on a firm's patent portfolio in terms of quality and quantity, we are able to indicating which share of patents is financially beneficial to be introduced to which SSOs. Furthermore, we are able to predict future benefits from declaring essential patents.

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Appendix: Robustness checks

	***dV: ROA* (Original Model (M6))**			***dV: Cox-transformed ROA*[2]**			**dV: z-standardized ROA**			**dV: Log-transformed ROA**			***dV: ROA*, z-standardized declaration variables**			***dV: ROA*, Log-transformed declaration variables**		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
L1.dependent variable	0.216	***	0.071	0.199	***	0.056	0.216	***	0.071	0.127		0.082	0.216	***	0.071	0.215	***	0.071
# patent declarations	0.023	***	0.008	0.012	**	0.005	0.259	***	0.090	0.026	**	0.010	0.004	***	0.001	0.070	**	0.030
# patent declarations sq[1]	-0.002	***	0.001	-0.001	**	0.000	-0.022	***	0.008	-0.002	**	0.001	-0.049	***	0.019	-24.153	*	13.234
# consortia declarations	2.663	**	1.110	3.392	*	1.870	29.924	**	12.470	2.495	**	1.059	0.004	**	0.002	2.746	**	1.120
# consortia declarations sq	-0.052	***	0.018	-0.076		0.052	-0.586	***	0.206	-0.044	**	0.021	0.000	***	0.000	-53.662	***	20.010
# pool licensor seats	-0.415		1.979	-0.388		1.415	-4.665		22.234	-0.675		2.103	-0.415		1.979	-0.528		1.886
# patent applications[1]	-0.420		13.617	-4.186		11.534	-4.724		153.002	0.256		14.225	-0.420		13.617	-1.679		13.687
R&D/sales	-0.614	***	0.094	-0.370	***	0.081	-6.899	`***	1.059	-0.712	***	0.093	-0.614	***	0.094	-0.615	***	0.095
Sales/employees	0.109		0.072	0.081		0.066	1.226		0.804	0.093		0.075	0.109		0.072	0.112		0.071
# employees[1]	-0.034		0.182	-0.099		0.157	-0.377		2.049	-0.039		0.200	-0.034		0.182	-0.025		0.177
Avg. # FW-Citations	-0.005	**	0.002	0.001		0.003	-0.054	**	0.026	-0.005	*	0.003	-0.005	**	0.002	-0.005	**	0.002
Avg. Family Size	0.002		0.002	0.001		0.002	0.027		0.027	0.003		0.003	0.002		0.002	0.002		0.002
Constant	0.088	***	0.031	-0.299	***	0.036	0.272		0.349	0.101	***	0.035	0.089	***	0.031	0.087	***	0.031
Time Dummies	YES			YES			YES			YES			YES			YES		
Number of companies	134			665			134			134			134			134		
Observations	817			125			817			817			817			817		
R^2 within	0.363			0.368			0.363			0.311			0.363			0.364		
F	12.135			9.410			12.140			10.850			12.140			12.040		

Table 6: Coefficients of the explanatory variables for the modified models (part 1)

	***dV: ROA*, EBITDA instead of EBIT used for ROA calculation**			***dV: ROIC***			***dV: EBIT as a share of sales*[2]**			***dV: ROA*, Lagged control variables[2]**			***dV: ROA*, Declarations as shares on all patent applications**		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
L1.dependent variable	0.246	***	0.064	0.124		0.104	-0.251		0.237	0.225	***	0.074	0.208	***	0.073
# patent declarations	0.017	**	0.008	0.036	**	0.016	0.072	***	0.020	0.022	***	0.008	0.006	**	0.003
# patent declarations sq[1]	-0.001	*	0.001	-0.003	**	0.002	-0.006	***	0.002	-0.002	**	0.001	-0.173	**	0.087
# consortia declarations	1.665		1.056	3.928	**	1.833	5.542	**	2.404	2.721	**	1.173	0.106		0.130
# consortia declarations sq	-0.040	**	0.016	-0.072	**	0.036	-0.090	*	0.049	-0.054	***	0.019	-0.050		0.105
# pool licensor seats	-0.138		2.186	3.144		4.142	-5.126		4.307	-0.463		1.890	0.110		2.026
# patent applications[1]	6.133		13.806	18.067		26.557	40.519	*	24.289	-1.398		17.436	4.445		12.462
R&D/sales	-0.565	***	0.086	-0.875	***	0.190	-2.685	***	0.603	-0.605	***	0.093	-0.620	***	0.098
Sales/employees	0.140	**	0.065	0.195		0.135	0.032		0.221	0.095		0.077	0.116	*	0.068
# employees[1]	0.121		0.153	-0.130		0.347	-0.053		0.392	-0.054		0.185	-0.043		0.176
Avg. # FW-Citations	-0.005	**	0.002	-0.008	**	0.004	-0.003		0.004	-0.002		0.002	-0.005	**	0.002
Avg. Family Size	0.002		0.002	0.005		0.004	-0.005		0.004	0.000		0.002	0.003		0.002
Constant	0.098	***	0.026	0.156	***	0.056	0.369	***	0.090	0.104	***	0.033	0.086	***	0.030
Time Dummies	YES			YES			YES			YES			YES		
Number of companies	134			134			131			131			134		
Observations	817			817			782			796			817		
R^2 within	0.361			0.250			0.438			0.364			0.365		
F	9.940			11.220			6.090			13.190			46.890		

Significance Level: ***p<0.01, **p<0.05, *p<0.1

Note: [1] Coefficient multiplied by 1,000 to make effects visible. [2] These measures could only be calculated with a reduced number of cases due to the construction of the dependent variable or the lagged specifications of the explanatory variables. L1.dependent variable means that the respective dependent variable was used as a lagged explanatory variable in the models.

Table 6 (continued): Coefficients of the explanatory variables for the modified models (part 2)