Essential Patents and Standard Dynamics

Justus Baron[1], Tim Pohlmann[2] and Knut Blind[3]

Abstract: *We investigate the effect of patents on the rate and direction of subsequent technological progress of standards. In particular, we focus upon the effect of including standard-essential patents. A recent stream of literature cautions against the negative effects of patents on subsequent innovation in complex technologies. We confront this idea with empirical evidence drawn from a large database of 3.500 ICT standards. In our analysis, we highlight more differentiated effects. First, the effect of patents depends upon the degree of fragmentation of ownership. Including essential patents on a standard has a strong positive effect on continuous technological progress of the standard. However, this effect weakens if ownership over patents is increasingly fragmented. Second, patents have opposite effects on continuous and discontinuous technological change of standards. While the inclusion of essential patents (in case of sufficiently concentrated ownership) encourages continuous technological progress, it significantly delays discontinuous standard replacements.*

[1] Department of Economics Sciences-Po Paris, 28 Rue des Saints Peres 75006 Paris FRANCE and Cerna, Centre d'économie industrielle. MINES ParisTech, 60 Boulevard Saint Michel, 75272 Paris Cedex 06 – France, Tel. : 33 (1) 40 51 90 00, E-Mail: justus.baron@ensmp.fr.
[2] Cerna, Centre d'économie industrielle. MINES ParisTech, 60 Boulevard Saint Michel, 75272 Paris Cedex 06 – France, Tel. : 33 (1) 40 51 90 00 and Berlin University of Technology, Chair of Innovation Economics, D-10623 Berlin Germany, Müller-Breslau-Straße 15, VWS 2, Tel: +49 (0) 30 314 76624, E-Mail: tim.pohlmann@tu-berlin.de.
[3] Berlin University of Technology, Chair of Innovation Economics, D-10623 Berlin, Germany, Müller Breslau-Strasse VWS 2, Fraunhofer Institute for Open Communication Systems and Rotterdam School of Management, Chair of Standardisation, Erasmus University, Tel:+ 49 (0) 30 314 76638 E-Mail: Knut.Blind@tu-berlin.de.

1. Introduction

Technological standards include an increasing number of standard essential patents (Bekkers et al., 2012). For patent holders, it is highly attractive to include their patented technologies into a technological standard (Rysman and Simcoe, 2008). The effect of essential patents on technological progress and standard adoption is however subject to lively debates. A patent is called essential if it is necessarily infringed by any implementation of the standard. The more essential patents are included in a standard, the more firms have a blocking power over the standard. Consistently, Simcoe et al. (2009) document an increase in patent litigation after patents are included into technological standards. It is therefore often alleged that essential patents discourage standard adoption and complementary investments in improving the standard, since standard users must fear to be faced with litigation and exorbitant requests for royalties (Lemley and Shapiro, 2006). These potential threats have received widespread attention and motivated initiatives for more binding regulatory action[4]. The actual or alleged effects of including SEPs on the subsequent evolution of standards have however so far not been examined empirically.

Research on the consequences of essential patents for standardization and standard users has focused on the downstream effects on static efficiency. The increasing number of standard essential patents has however also significant implications for the dynamic efficiency of standard development. Most prominently, Shapiro (2001) expresses the concern that a high number of patents may lead to patent thickets which hamper and slow down standardization. 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 can reduce the speed at which standards are developed (Simcoe, 2012). Practitioners report that consensus reaching and the speed of standardization processes can be negatively affected by standard essential patents (Blind et al., 2011). According to one practitioner, there are cases in which holders of patented technology "*would only agree to a certain standard if they are allowed to integrate their technology. This makes the standardization process more complex and time-consuming and sometimes even induces errors on products*"[5].

These possible costs have to be weighed against the innovation incentives provided by standard essential patents. The prospect of including standard essential patents is a powerful incentive to develop standard-

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[4] The U.S. Department of Justice, Antitrust Division (DOJ), and the U.S. Patent & Trademark Office (USPTO), recently published a position paper (available under: http://www.justice.gov/atr/public/guidelines/290994.pdf) that discusses the role of SEPs in light of recent litigation such as e.g. Apple vs. Samsung or Motorola Mobility vs. Microsoft.

[5] 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).

related technology and contribute to the standard setting effort (Layne-Farrar et al., 2011). Furthermore, once their proprietary technology included, firms have a private interest in improving the standard to protect it from becoming obsolete and being replaced by rival technologies. Holders of standard essential patents thus become platform leaders for the particular 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, standard 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 advancement, as outdated standards can become an impediment to technological progress. Hereby, 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 art. On the other hand, standard replacement can induce loss of backward compatibility and impose higher implementation costs upon standard users. Based upon these insights, we investigate the effect of standard essential patents on the frequency of upgrade and replacement of standards.

We rely upon a comprehensive database of ICT standards released from 1988 to 2008. This dataset includes detailed information for over 3,500 standards issued by formal standardization bodies (ISO, IEC, ISO/IEC JTC1, ITU-t, ITU-R, CEN and IEEE). We match this sample to a comprehensive database of patents declared to be standard 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. We further construct an appropriate control sample based upon the characteristics of standards. Subsequently, we estimate the hazard rate of standard update and replacement over time, controlling for relevant technological events. The results show that standard essential patents reduce the likelihood of standard replacement, but increase the likelihood of standard upgrade. We believe that the higher rate of updates mirrors continuous technological progress. The positive effect of patents on standard upgrades however decreases with increasing fragmentation of patent ownership. Furthermore, while standard upgrades do temporarily reduce the risk of standard replacement, the negative effect of essential patents on standard replacements cannot be fully explained by more frequent upgrades.

Our findings have several managerial implications. For potential standard adopters, essential patents may signal that a standard will be regularly improved and is less at risk of an early replacement. Essential patents could thus reduce technological uncertainty, increase standard related investments and encourage standard adoption. This is particularly true when one firm takes the lead in coordinating the technological progress of the standard. This positive effect of essential patents on standard adoption could outweigh 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 compromise future radical changes of the standard.

Our findings also contribute to an emerging body of empirical evidence on the effect of patents on subsequent innovation. While the theoretical literature provides a differentiated discussion on the potential effects of patents, recent empirical evidence points to a generally negative ex-post effect of patents on innovation (Murray and Stern, 2007; Williams, 2013), which may be particularly true in complex technologies such as ICT (Galasso and Schankerman, 2013). In contrast to these analyses, our findings rely upon a measure of technological progress which is dissociated from patent data. This allows us to measure the effects of patents on both continuous and discontinuous technological progress. Furthermore, we can differentiate the effects of patents in cases of concentrated and fragmented ownership. Our findings are coherent with existing evidence for a negative marginal effect of single patents on subsequent innovation in complex technologies, especially in technological areas characterized by dense patent webs. This is however not an appropriate measure for the overall effect of patents, which implies a comparison with a no-patent scenario. We show that compared to other standards without patents, including essential patents in standards strongly encourages continuous progress.

2. Analytical Framework

Progress and lock-in of technological standards

Standards need to keep up with technological progress, either through improvements of existing standards or through replacement by entirely new standards. Standard replacement denotes a radical change of technology and thus induces important costs to the users of the standards. Formal standards and informal dominant designs therefore often progress through continuous and somewhat incremental improvements. This type of continuous technological progress allows integrating new technological functionalities, while preserving at least partial backward compatibility. However, continuous technological progress also induces a risk of lock-in, because specific technological choices become increasingly difficult to reverse as the number of applications and technologies building upon the standard increases (Arthur, 1989).

The seminal contributions of Farrell and Saloner (1985, 1986) highlight the possibility of inefficient standard dynamics arising from coordination failures in the standard adoption decisions of multiple users. Inefficiencies in the rate and direction of technological progress of standards can be overcome if standard users can coordinate on their adoption decisions (Weitzel et al., 2006). In many cases, coordination on adoption decision can be achieved through a joint decision procedure inside more or less formal standard developing organizations (SDOs). Explicit coordination on standard setting substantially reduces the risk for developers and adopters to be confronted with new technology standards (Tassey, 2000, Aggarwal et al., 2011). SDOs can overcome the challenges of excessive inertia or momentum through organizing coordinated adoption decisions. Consistently, the survival time of formal ICT standards has been found to decrease with the intensity of technological innovation (Blind, 2007), indicating reactivity to technological opportunities.

While SDOs coordinate adoption decisions, and can therefore overcome demand-side coordination failures in standard dynamics, relevant R&D investments are undertaken by diverse competing firms. While the earlier literature on lock-in or change of technological standards has exclusively focused upon uncoordinated adoption decisions, the recent economic interest for standard essential patents has shed light on the complex coordination problems in the collective development for new standards in SDOs. Investment in R&D for new standards or applications of existing standards is subject to competition (Besen and Farrell, 1994), complex strategic alliances (Leiponen, 2008) and potential coordination failures (Baron et al., 2012). Even if technological choices and adoption decisions were perfectly coordinated through the working groups of SDOs, the competitive supply of technological solutions proposed to SDOs can still be subject to coordination failures.

To overcome coordination failures in the R&D for technological standards, SDOs are often supplemented by other tools of coordination, such as platform leadership (Cusumano and Gawer, 2002) or explicit coordination by less inclusive consortia following up formal standard development in the SDO (Baron and Pohlmann, 2013). In addition, the inclusion of Intellectual Property Rights can also function as a coordination device. In a next section we will review the available literature on the function of Intellectual Property Rights in coordinating technological change.

The effect of patents on subsequent innovation

The literature on the effect of patents on subsequent innovation provides two main streams of arguments, focusing respectively on the internalization of external effects and transaction costs (Williams, 2013).

The first stream goes back to Kitch (1977) and his argument that the main function of patents is to ensure incentives in continuous investment in improving upon the patented technology. More recent empirical findings confirm that patents reduce uncertainty in investments that are complementary to a specific technological choice (McGrath and Nerkar, 2004, Arora et al 2008). According to this view, existing patents induce incentives for the holders to invest in further improvements, as the licensing fees for their patents increase with the value of the technology. We can call this the *internalization effect* of patents.

The other important stream of arguments emphasizes the *transaction cost* of patents. In absence of transaction costs, the owner of an essential patent can enter into ex-ante licensing agreements with any potential subsequent innovator, thus inducing optimal levels of innovation (Green and Scotchmer, 1995). Such ex ante agreements are however often difficult to achieve because of information asymmetries and contract incompleteness. Bessen and Maskin (2009) for instance find that in the presence of information asymmetries, patent protection reduces incentives for subsequent downstream innovation.

The existing empirical literature suggests that on the balance a negative effect of patents prevails. Heller and Eisenberg (1998) go as far as to describe a “tragedy of the anticommons” in biotechnology, a situation where the proliferation of IPRs increasingly hampers sequential innovation. In the field of genetic engineering, several analyses find a negative effect of patents on subsequent innovation (Murray and Stern, 2007; Huang and Murray, 2009; Murray et al., 2008; Williams, 2013). In the case of ICT standards, there is the perception that cumulative innovation could be stifled in dense patent thickets (Shapiro, 2001). Llanes and Trento (2009) find that the accumulation of patents reduces ex-post innovation incentives, even though patent pools can attenuate this effect. Lampe and Moser (2012) produce historical evidence for a positive effect of compulsory patent licensing on subsequent innovation.

The existing empirical literature however only imperfectly implements the differentiated view from the theoretical analysis. For instance, transaction costs associated to patents are expected to vary depending upon the degree of fragmentation of patent ownership. If patents are distributed over many different owners, transaction costs for licensing contracts become increasingly prohibitive (Galasso and Schankerman, 2010). Consistently, very recent empirical work suggests that only complex technologies, where patent ownership is frequently highly fragmented, witness a negative effect of patents on subsequent innovation incentives (Galasso and Schankerman, 2013). This finding however calls for two further qualifications. First, even within the broad technological areas characterized as complex, many technologies are actually controlled by single firms or small groups of firms. Second, if the effect of patents on innovation depends upon the degree of fragmentation, the overall effect of patents can no longer be studied by analyzing the marginal effect of single patents. An increase in innovation subsequent to a patent invalidation does not necessarily imply a negative overall effect of patents, but merely confirms that reducing the thickness of the patent web reduces transaction costs.

The second limitation of the existing literature consists in its disregard for the type of subsequent technological change. A discontinuous technological change renders the existing patent obsolete, while a continuous technological change implements a progress upon the technology protected by the previous patent. Since Arrow (1962), we know that a patent holder has a disincentive to invest in discontinuous technological progress as long as he perceives a rent from his previous patent. We will call this the *replacement effect* of patents. Furthermore, it is also clear that the *internalization benefit* and *transaction cost* of patents only apply to continuous progress, i.e. those innovations building upon the previous inventions. The additional incentive to invest in continuous progress resulting from the internalization benefit may however be exacerbated in presence of the risk of discontinuous technological change, threatening to annul the rent from the previous patent. The holders of the incumbent patents have an incentive to develop improvements that avoid obsolescence of their technology and challenges from rivaling technologies.

The effects of essential patents: hypotheses

We thus draw the following hypotheses on the effect of standard essential patents: first, we have to distinguish between continuous and discontinuous technological progress. Let us first consider the effect of essential patents on continuous progress. Standard essential patents allow some degree of *internalization* of the costs of standard improvements and therefore provide incentives for patent holders to invest in costly standard upgrades. The internalization effect is however attenuated by the adverse effect of transaction costs. The internalization effect is expected to be strongest if all essential patents are held by one single firm, as this firm can theoretically fully internalize the benefit of improving the standard. When the concentration of essential patent ownership decreases, the private return on investment in improving the standard for the individual firm is increasingly dissipated. Holders of essential patents will free-ride on each other's effort in improving the standard, and the positive effect of patents on continuous technological progress decreases. Furthermore, with increasing fragmentation of essential patent ownership, transaction costs increase and reduce incentives for subsequent innovation.

The internalization effect is particularly strong if investing in standard upgrades is a way of reducing the risk of obsolescence and replacement by a different standard. Holders of standard essential patents benefit from a rent resulting from their past, sunk R&D investment, which would be lost in case of standard replacement. This rent is largest if there is a single holder of standard essential patents, capturing the full monopoly profit on the technology standard (Brandenburger and Stuart, 1996). When the number of patent holders increases, multiple marginalization not only reduces the rents of each single patent holder, but also the overall rent that patent holders retrieve from the existing standard (Shapiro, 2001). Following this argument, we thus again expect that the positive effect of patents on continuous standard progress positively depends upon the concentration of essential patent ownership.

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

> **Hypothesis 2**: *Fragmentation of ownership over standard essential patents reduces the internalization benefit, and increases transaction costs. Therefore fragmentation of ownership has a negative effect upon subsequent continuous progress, resulting in less upgrades.*

The inclusion of standard essential patents increases the persistence of existing standards and reduces the risk of standard replacement and discontinuous technological change. Through continuous investment in improvements of a technological standard, incumbent patent holders can prevent or at least delay standard obsolescence and replacement. The inclusion of essential patents furthermore exerts a direct replacement effect, a disincentive for the holders of incumbent essential patents to invest in discontinuous technological change. We therefore conjecture:

> **Hypothesis 3:** *The inclusion of essential patents reduces the risk of standard replacement.*

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

3. Empirical Methodology

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 (International Classes of Standards 33 and 35) issued by the main formal international SDOs (ISO, IEC, JTC1, CEN, ITU-R, ITU-T, IEEE). 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 standard 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*"[6]. 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 ISO/IEC 13818.2(2000)[7]. 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*

[6] http://www.iso.org/iso/standards_development/processes_and_procedures/stages_description.htm
[7] 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

safety requirements[8]*"*. By interviewing several standard setting practitioners, we are able to confirm that an essential change of technology will necessarily lead to a replacement of the old and the release of a new standard. Hence patents essential to the old standard would usually not be essential for the new standard. [9]

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 consequently 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 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[10].

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 claim 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

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

[9] We interviewed standard setting practitioners from ISO, IEC, ITU and IEEE using a standardized questionnaire on dynamics of version and standard withdrawal.

[10] 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)

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.

Our thorough database allows us to measure the amount and the timing of the declaration of standard essential patents. We further calculate the distribution of essential patents per standard among patent owners. Therefore, we compute for every standard which is subject to essential patents, the Herfindahl–Hirschman Index (HHI). Secondly, we compute the HHI with respect to standard relevant patents of a participating firm's patent portfolio. We follow the identification approach of Baron et al. (2012) to measure standard relevant patents in the patent portfolios of standard setting firms. Using these measures, we additionally relate standard relevant with non-relevant patents. Thus we seek to identify a firm's technological focus on a particular standard.

We further 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 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 the IPC classification of essential patents to all standards in a particular ICS class. 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)[11], 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 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.

4. Comparative Analysis

In this section, we will present results of a comparative statistical analysis. We compare the survival rates of standards and standard versions including essential patents with other, otherwise comparable standards and standard versions. We therefore start by building an appropriate control group. First, we eliminate standards issued before 1988. We then carry through a propensity score matching based upon a broad

[11] 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%).

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 2 and 3 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.

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). Our results indicate that survival rates of standard versions including essential patents decrease more rapidly than those of other standard versions. Figure 2b presents the same analysis for the survival estimate of standards (the likelihood that a standard is fully withdrawn by a certain time, indicated in years after the release of the first standard version). Our results indicate that survival rates of standards including essential patents decrease much more slowly than those of other standards.

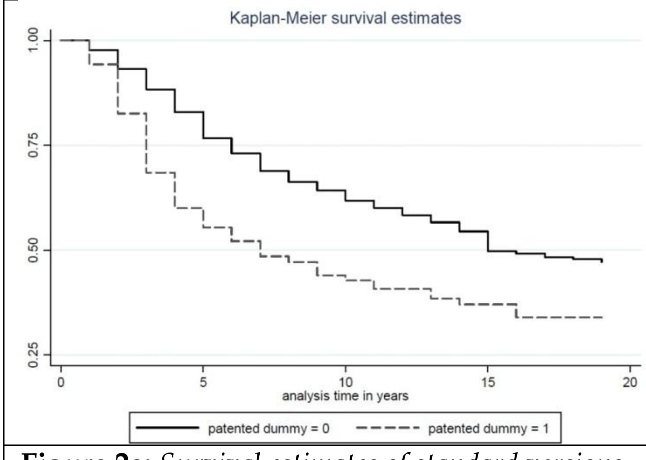

Figure 2a: *Survival estimates of standard versions, including and not including patents*

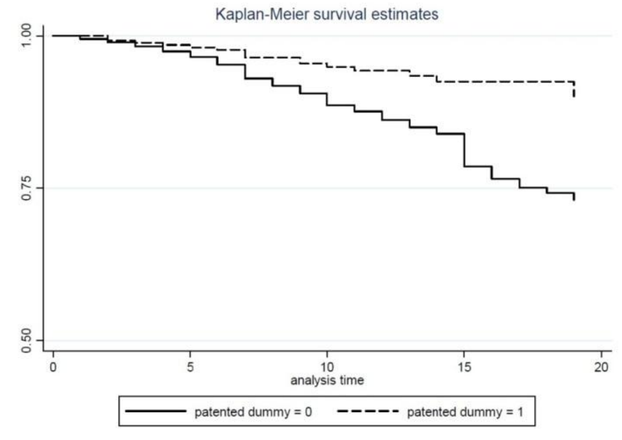

Figure 2b: *Survival estimates of standards, including and not including patents*

We perform a log-rank test to verify that this difference is statistically significant. We therefore divide the sample of treated and control standards into six strata of equal size according to their propensity score, and compare the observed survival rate of treated and control standards within each stratum. The test confirms that both observed differences are strongly significant. Details of the test can be consulted in the appendix 2 and 3.

The comparative analysis 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 hypotheses: essential patents induce more frequent standard upgrades, while reducing the likelihood of standard replacement. The sampling of the data according to the propensity score is meant to make sure that this difference is due to a causal effect induced by the inclusion of patents. The reliability of this claim depends upon the capacity of our propensity to capture relevant factors affecting both the likelihood to include essential patents and the risk of a standard to be upgraded or replaced. In order to test more reliably our hypotheses, we therefore now proceed to a multivariate panel analysis.

5. Multivariate Panel Analysis

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 1-5). 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 6). 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 7): 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 8). 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 9, 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 8 and 9 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 time. The Cox model 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 variables. This is the case for the issuing SDO, the technological field, and the period of standard release. In order to control for a time-variant effect of 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 for all standards. 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. 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 (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") to be essential for the standard. Second, we count the number of patents declared over time, and include this cumulative count as a second explanatory variable ("Patents_cumulative"). To estimate effects not only from the existence of patents and the amount of patents, we further include variables to account for the distribution of patents among participants of the standard committee. We therefore compute a HHI (Herfindahl–Hirschman Index) on the concentration of essential patents among patent owners (HHI SEP per Firm) and on the concentration of standard related patents in firms' patent portfolios (HHI Standard Related Patent Portfolios). To rule out a bias through extreme situations when only one firm holds essential patents on a standard, we include another control dummy (Dummy for at least two Firms with SEPs) for model 2-4. The results are presented in Table 3 and 4[12].

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% (estimated hazard rates). However, it can be argued that standards which are more important or which are more widely adopted have a higher likelihood of upgrades and at the same time a higher likelihood of being subject to standard essential patents. Our specification does not include any measures of standards' importance or standard adoption rates. Since a standard's importance or adoption rate could drive both effects (the survival rate of standard updates as well as the possibility of standard essential patents), our results might be subject to endogeinity.

	M1	M2	M3	M4
Model/ Variable Name	Cox Regression	Cox Regression	Cox Regression	Cox Regression
Patented	0.344***	-0.084	0.395*	-0.104
Dummy	(0.095)	(0.263)	(0.211)	(0.26)
HHI SEP		0.837***		0.839***
per Firm		(0.237)		(0.232)
HHI Standard Related			0.335*	

[12] 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)

Patent Portfolios			(0.191)	
Dummy for at least two		0.247	-0.197	0.188
Firms with SEPs		(0.255)	(0.204)	(0.252)
Technology Focus				1.905**
Insider				(0.773)
Patents	0.002	0.002	0.002	0.001
Cumulative	(0.002)	(0.002)	(0.002)	(0.001)
Innovation	1.11	1.071	1.054	1.063
Intensity	(0.834)	(0.834)	(0.831)	(0.833)
Innovation	-0.016	-0.018	-0.014	-0.018
Intensity*Age	(0.131)	(0.131)	(0.131)	(0.131)
Technology	-0.733*	-0.725*	-0.713*	-0.720*
Gap	(0.4)	(0.401)	(0.4)	(0.4)
Technology	0.097*	0.098*	0.096*	0.097*
Gap*Age	(0.053)	(0.053)	(0.053)	(0.053)
log(Forward	0.191***	0.185***	0.185***	0.178***
References)	(0.036)	(0.036)	(0.036)	(0.036)
Year	-0.032***	-0.032***	-0.032***	-0.032***
	(0.011)	(0.011)	(0.011)	(0.011)
Change of Referenced	0.014	0.013	0.014	0.012
Standard	(0.052)	(0.052)	(0.052)	(0.052)
Change of Referenced	0.060***	0.060***	0.060***	0.061***
Standard*Age	(0.012)	(0.012)	(0.012)	(0.012)
log(Backward	-0.096***	-0.099***	-0.098***	-0.099***
References)	(0.031)	(0.031)	(0.031)	(0.031)
N	36179	36179	36179	36179
Subjects	4768	4768	4768	4768
Failures	1709	1709	1709	1709
Chi2	217.91	243.15	245.10	235.01
Log-likelihood	-5343.917	-5337.421	-5340.901	-5334.62
Proportional Hazard	Chi2: 16.35	Chi2: 19.51	Chi2: 19.29	Chi2: 19.99
Test	Pr:0.1285	Pr:0.1082	Pr:0.1144	Pr:0.1305

Table 3: *Results of the multivariate panel analysis.*

We therefore include variables that account for the distribution of standard essential patents and the concentration of standard related patents in a firm's patent portfolios. We further include a variable that measures a firm's technology focus on the standard in question by relating standard relevant and standard non relevant patents of a firm's patent portfolio. Our results confirm Hypothesis 2: a higher concentration of standard essential patents per firm as well as a higher concentration of standard related patents per firms increases the likelihood a standard upgrade (model 2 and 3). When standard setting participants have a higher technology focus on the particular standard, we also estimate a positive effect on standard upgrade (model 4). The effect of concentration of standard essential patents on standard upgrade remains significant and positive in model 4. When we include our concentration measures, the effect of our patented dummy is only significant in model 3. However, due to the creation of our database, concentration variables can only be calculated when at least one standard essential patent exists. Since it can be argued that the distribution of patents does not depend on a standard's importance or adoption rate, our results provide some evidence for a causal relationship of patents and standard upgrades.

We then analyze the survival rate of standard versions distinguishing between the two competing risks of standard upgrade and replacement (table 4). 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 5). Both of these effects however decrease with the age of the standard version. We then directly model the choice between upgrade and replacement (model 6). Conditional upon a standard being modified, the inclusion of essential patents significantly increases the likelihood of standard upgrade. Essential patents lead to withdrawing standard versions more often, but also increasing the likelihood of choosing standard upgrade rather than replacement. In order to obtain the resulting net effect of patents on standard replacement, we estimate a hazard model of standard replacement and confirm Hypothesis 3: Essential patents reduce the likelihood of standard replacement (model 7). 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 % (estimated hazard rate). 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 1-5 have confirmed that the inclusion of essential patents increases the rate of standard upgrades. Model 8 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[13], 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 8).

	M5	M6	M7	M8
Specification	Version Survival	Standard vs. Version	Standard Survival	Standard Survival
Model/ Variable Name	Competing Risk Cox Regression	Logit Regression	Cox Regression	Cox Regression
Patented	1.310***	-1.270***	-0.925**	-0.832**
	(0.198)	(0.486)	(0.416)	(0.417)
Patented* Upgrade	-3.776***			
	(0.645)			
Patented*Re-placement	-0.076*			
	(0.041)			
Patented* Upgrade*Age	0.294***			
	(0.08)			

13 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.

Patented*Re-Placement*Age	0.002 (0.002)			
Patents Cumulative	1.310*** (0.198)	-0.025 (0.034)	-0.012 (0.017)	-0.013 (0.017)
Technology Gap	-0.654* (0.392)	-0.124 (0.182)	-0.112 (0.22)	-0.456 (0.466)
Technology Gap*Age	0.088* (0.052)		0.047** (0.023)	0.007 (0.055)
Innovation Intensity	1.056 (0.824)	1.341* (0.738)	-1.785 (1.193)	-0.874 (1.353)
Innovation Intensity*Age	-0.009 (0.13)		0.526*** (0.169)	0.594*** (0.185)
log(Backward references)	-0.095*** (0.032)	-0.049 (0.079)	-0.153* (0.081)	-0.141* (0.08)
Change of Referenced standard	0.014 (0.051)	0.200*** (0.061)	0.459*** (0.062)	0.476*** (0.06)
log(Forward references)	0.196*** (0.036)	-0.506*** (0.093)	-0.229** (0.104)	-0.250** (0.109)
Ulterior Accreditations		0.139 (0.09)	0.170*** (0.054)	0.154*** (0.057)
Accreditations* Age		-0.023** (0.009)	-0.023*** (0.008)	-0.020** (0.008)
Number of Pages		-0.002** (0.001)		
ICS Width		0.899** (0.454)		
Year	-0.031*** (0.01)	-0.007 (0.023)	0.04 (0.031)	0.046 (0.03)
Version Age		0.305*** (0.086)		0.893*** (0.208)
Version Age_Sq				-0.027*** (0.01)
Version number		-0.02 (0.114)		1.893** (0.795)
Version number_Sq				-0.340** (0.169)
Subjects	9342	Cons: 10.064	3551	3551
Failures	1709	Obs: 1399	367	367
chi2	372.84	267.00	119.28	155.61
Log-likelihood	-6422.0711	R2:0.3152	-1014.5515	-1005.7632
Proportional Hazard test	Chi2: 13.76 Pr:0.4681		Chi2: 12.92 Pr:0.3751	Chi2: 19.20 Pr:0.2585

Table 4: *Results of the multivariate panel analysis.*

Discussion

The results show that the inclusion of essential patents increases the rate of standard upgrades, but reduces the rate of standard replacement. Essential patent holders have an incentive to regularly invest in further improvements of the standard. This incentive is stronger in situations where the concentration of patents among patent owners is high. Fragmented IP ownership may result in double marginalization and transaction costs which decrease the return from subsequent innovation. Fragmented ownership furthermore encourages free-riding, decreasing investment incentives of standard setters. A single owner of essential patents is better able to internalize returns from essential patents, acting as a platform leader to promote and sponsor a standard. These results are contradictory to recent evidence of a negative effect of IPR on subsequent technological progress in the field of genetic engineering (Murray and Stern, 2007; Huang and Murray, 2009; Murray et al., 2008; Williams, 2013). Our research however focuses on ICT technologies. These are more complex and technology components often indispensably work together. Furthermore, in contrast to the existing literature, we distinguish between continuous (standard upgrade) and discontinuous (standard replacement) technological change. Our results contribute to the current literature by providing differentiated evidence for the effect of patents on ex-post innovation incentives.

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. This is especially true when the ownership of patents is not fragmented and a single firm holds a high concentration of patents. However, our results show that increasing standard upgrades only accounts for a small part of the observable effect of essential patents on the rate of standard replacement.

These findings indicate that standard essential patents contribute to reduce the rate of standard replacement also through other mechanisms. Simcoe (2012) shows 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. Essential patents 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 spite of widespread concerns about the negative effects of patent thickets, we do however not find that the standard replacement is affected by the number of standard essential patents. 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 strongly increases the likelihood of choosing standard upgrade rather than standard replacement. 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. 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 induce frictions in standard development. 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 however not sufficient to explain why standards including essential patents are less likely to be replaced.

Nevertheless, we would not argue based upon the presented evidence that standard essential patents lead to an inefficient lock-in of outdated standards. Indeed, essential patents have a strong 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. Standard 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 standard 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. Our measures of patent concentration even further qualify this finding, showing that high concentration levels of patent ownership increase the positive effect of standard essential patents on the rate of standard upgrades.

These findings have important implications for management and policy. For standard adopters, 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. This is especially the case for situations where one firm holds a high share of standard essential patents and may act as a platform leader to coordinate technological improvement of a standard. Furthermore, essential patents reduce the risk of standard replacement, thereby avoiding the loss of sunk investment in standard implementation. These beneficial effects could compensate the 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 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 standard 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
HHI SEP per Firm	Computed Herfindahl–Hirschman Index on the distribution of standard essential patents on standard setting firms.	Time-variant
HHI Standard Related Patent Portfolios	Computed Herfindahl–Hirschman Index on the distribution of standard relevant patents on standard setting firms' patent portfolios.	Time-variant
Technology Focus Insider	Relation of the number of standard relevant to non-relevant patents in a standard setting firm's patent portfolio.	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 5: *Definition of variables*

Appendix 2

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

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

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 8: *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 9: *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 10: *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 11: *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 12: *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, control s	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 13 *Log rank test of equality of version survival with multiple control groups*