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Essential Patents and Standard Dynamics

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Abstract: *Information and Communication Technology (ICT) standards face a permanent tension between keeping up with technological progress and 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 the existence of 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 partly explain the effect of patents on the rate of replacement. Nevertheless, we also find empirical evidence that essential patents induce a slowdown in standard replacement which is independent from the effect of standard upgrades. This effect could be the result of frictions and vested interests among standard setting firms.*

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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 a 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

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".[2] 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 implementers of the technology incur the opportunity cost of not using the best technology available.

The socially optimal rate of introducing new technologies 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

[2] 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)

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.

Lock-in of installed technologies does however not necessarily prohibit technological progress. An installed technology is usually subject to continuous incremental progress along a technological trajectory. These trajectories are defined by the technological paradigms of the underlying technological basis (Dosi, 1985). 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. In comparison 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.

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. 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[3]. This process can take place more or less frequently, and the technological progress incorporated in a new standard can be more or less important.

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

The economic literature has addressed the issue of inertia and momentum in standard replacement mainly for the case of uncoordinated adoption decisions[4]. 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.

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

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

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, 2009; 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*"[5]. 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.

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.

[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).

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.

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

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"*[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 safety requirements*[8]*"*. 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

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

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[9].

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

[9] 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)

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)[10], 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.

[10] 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%).

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[11]. 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.

[11] 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

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.

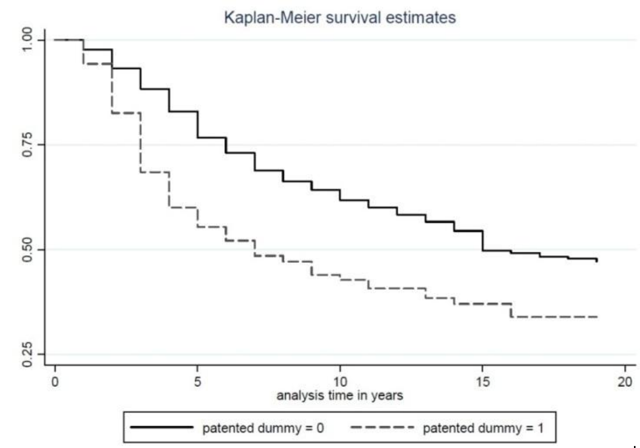

Figure 2a: *Survival estimates of standard versions, including and not including patents*

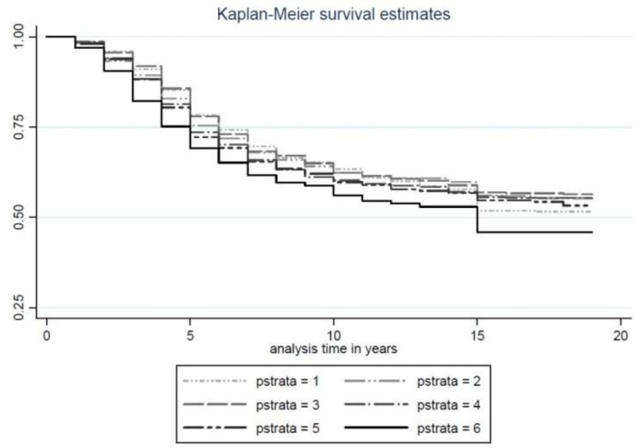

Figure 2b: *Survival estimates of standard versions, by strata*

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[12]. Significant differences are observed

[12] 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.

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:	391	350	3	14	47	57	79	150
	Exp:	*225.50*	*192.20*	*3.20*	*9.55*	*17.16*	*21.25*	*39.07*	*101,98*
Non-patented	Obs:	5147	2131	421	473	392	349	250	246
	Exp:	*5312.50*	*2288.80*	*420.80*	*477.45*	*421.84*	*384.75*	*289.93*	*294,02*
Chi2		140,75	167.29	0.01	2.29	58.30	67.73	48.91	32.70
Pr>chi2		0,0000	0.0000	0.9076	0.1304	0.0000	0.0000	0.0000	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). 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.

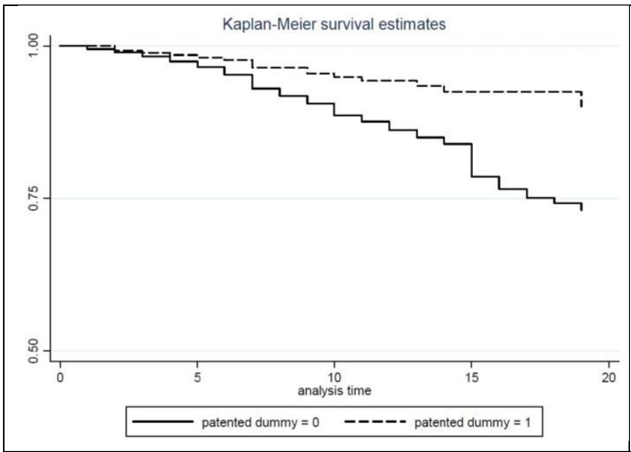

Figure 2a: *Survival estimates of standards, including and not including patents*

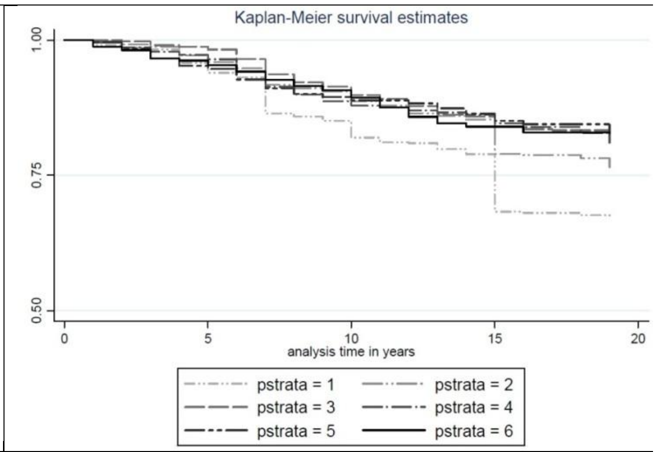

Figure 2b: *Survival estimates of standards, by strata*

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:	22	21	2	0	2	5	3	9
	Exp:	*66.92*	*41.89*	*1.17*	*2.61*	*3.25*	*4.73*	*9.93*	*20.21*
Non-patented	Obs:	1864	714	201	150	108	99	85	71
	Exp:	*1819.08*	*693.11*	*201.83*	*147.39*	*106.75*	*99.27*	*78.07*	*59,79*
Chi2		32.87	12.41	0.61	2.67	0.49	0.02	5.48	8.34
Pr>chi2		0.0000	0.0004	0.4349	0.1021	0.4818	0.8985	0.0193	0.0039

Table 1: *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.

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[13].

[13] 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

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). 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): 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:

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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).

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

$h_0(t)$ 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 or second version etc).

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[14]. 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:

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

[14] 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	
	Model 1	Model 2	Model 3	Model 4	Model 5
Variable name	Cox Regression	Competing risk Cox	Logit	Cox regression	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.*

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[15], while controlling for the baseline age effect.

[15] 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.

However, controlling for standard upgrades only slightly reduces the magnitude and significance of the effect of essential patents on standard replacement (model 5).

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 can use the number of references made to the standard by more recent standards as indicators of technological investment building upon the technological basis incorporated into the standard. 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.

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.

References

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

Arora, A., Ceccagnoli, M., Cohen, W. M. (2008): R&D and the patent premium, *International Journal of Industrial Organization*, Volume 26, Issue 5, 1153-1179.

Arthur, W.B. (1989): Competing Technologies, Increasing Returns, and Lock-In by Historical Events, *Economic Journal* 99, 116-131.

Balcer, Y., Lippman, S. (1984): Technological expectations and adoption of improved technology, *Journal of Economic Theory*, 34(2), pp. 292–318.

Baron, J., Ménière, Y., Pohlmann, T. (2011): R&D Coordination in Standard Setting Organizations: the Role of Consortia, *Proceedings of the Standardization and Innovation in Information Technology Conference 2011.*

Bekkers, R. (2001): Mobile Telecommunications Standards: GSM, UMTS, TETRA and ERMES. Boston, MA: Artech House.

Bekkers, R., Bongard, R., Nuvolari, A. (2011): An empirical study on the determinants of essential patent claims in compatibility standards, *Research Policy*, 40(7), pp. 1001–1015.

Bekkers, R., Catalini, C., Martinelli, A., Simcoe, T. (2012): Intellectual Property Disclosure in Standards Development, *Conference Proceedings of the NBER conference on Standards, Patents & Innovation.*

Bekkers, R., Martinelli, A. (2012): Knowledge positions in high-tech markets: Trajectories, standards, strategies and true innovators, *Technol. Forecast. Soc. Change* (in print).

Bessen, J. (2002): Estimates of patent rents from firm market value, *Research Policy*, 38, 1604–1616.

Blind, K. (2007): Factors Influencing the Lifetime of Telecommunication and Information Technology Standards, *Journal of IT Standards & Standardization Research*, 5(1), 1-24, January-June 2007 1.

Blind, K.; Bekkers, R.; Dietrich, Y.; Iversen, E.; Müller, B.; Pohlmann, T.; Verweijen, J. (2011): EU Study on the Interplay between Standards and Intellectual Property Rights (IPR), commissioned by the DG Enterprise and Industry.

Blind, K., Egyedi, T. (2008): The Dynamics of Standards, Edward Elgar Publishing.

Bresnahan, T., Greenstein, S. (1999). Technological Competition and the Structure of the Computer Industry, *Journal of Industrial Economics*, 47(1), pp. 1-40.

Caliendo, M., Kopeinig, S. (2008): Some Practical Guidance for the Implementation of Propensity Score Matching, *Journal of Economic Surveys*, Vol. 22, Issue 1, pp. 31-72.

Chiao, B., Lerner, J., Tirole, J. (2007): The Rules of Standard Setting Organizations: An Empirical Analysis, *RAND Journal of Economics*, 38(4), pp. 905–930.

Christensen, C. M., Bower, J. L. (1996): Customer Power, Strategic Investment, and the Failure of Leading Firms, *Strategic Management Journal*, 17-3, 197-218.

Christensen, C. M., Suárez, F. F., Utterback, J. M. (1998): Strategies for Survival in Fast-Changing Industries, *Management Science*, 44-12, 207-220.

Clements, M. (2005): Inefficient Standard Adoption: Inertia and Momentum Revisited, *Economic Inquiry*, Vol. 43, July 2005, 507-518.

Cusumano, M., Gawer, A. (2002): The elements of platform leadership, *MIT Sloan Management Review*, Vol. 43, pp. 51-58.

De Bijl, P., Goyal, S. (1995): Technological change in market with network externalities, International *Journal of Industrial Organization*, Vol. 12, Issue 3, pp. 307-325.

Dosi, G. (1982): Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change, *Research Policy*, Volume 11-3, 147–162.

Egyedi, T.; Heijnen, P. (2005): Scale of Standards Dynamics: Change in formal, international IT standards – The Standards Edge: Future Generation, Bolin, S. (ed.): Bolin Communications.

Farrell, J., Klemperer, P. (2007): Coordination and Lock-In: Competition with Switching Costs and Network Effects, *Handbook of Industrial Organization*, 3, pp. 1967–2072.

Farrell, J., Saloner, G. (1985): Standardization, Compatibility and Innovation, *RAND Journal of Economics*, 16(1), pp. 70-83.

Farrell, J., Saloner, G. (1986): Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation, *American Economic Review*, 76(5), pp. 940-955.

Farrell, J., Saloner, G. (1988): Coordination through Committees and Marekts, *RAND Journal of Economics*, 19(2), pp. 235-252.

Farrell, J., Simcoe, T. (2009): Choosing the Rules for Consensus Standardization, *Working Paper*. Available at SSRN: http://ssrn.com/abstract=1396330

Fontana, R., Nuvolari, A,, Verspagen, B. (2009): Mapping Technological Trajectories as Patent Citation Networks. An Application to Data Communication Standards. *Economics of Innovation and New Technology*, 18, pp. 311-336.

Garud, R., Jain, S., Kumaraswamy, A. (2002): Institutional Entrepreneurship in the Sponsorship of Common Technological Standards: The Case of Sun Microsystems and Java, *The Academy of Management Journal*, 45- 1, 196-214.

Ganglmair, B., Tarantino, E. (2012): Patent Disclosure in Standard Setting, *Conference Proceedings of the NBER conference on Standards, Patents & Innovation.*

Hall, B. H., Jaffe, A. B., Trajtenberg, M. (2000): Market Value and Patent Citations: A First Look, NBER Working Paper No. 7741.

Katz, M., Shapiro, C. (1986): Technology Adoption in the Presence of Network Externalities, *Journal of Political Economy* , 94(4), pp. 822-841.

Katz, M., Shapiro, C. (1992): Product Introduction with Network Externalities, *Journal of Industrial Economics*, 40(1), pp. 55-84.

Kindleberger, C. P. (1983): Standards as public, collective, and private goods, Kyklos Vol. 36, pp. 377-397.

Kitch, E. (1977), The Nature and Function of the Patent System, *Journal of Law and Economics*, 20(2), pp. 265-290 .

Kristiansen, E (1998): R&D in the presence of network externalities: timing and compatibility, *RAND Journal of Economics*, 29, pp. 531-547.

Leiponen, A., (2008): Competing Through Cooperation: The Organization of Standard Setting in Wireless Telecommunications, *Management Science*, 54(11), pp. 1904-1919.

Lemley, M., Shapiro, C. (2006): Patent Holdup and Royalty Stacking, Texas Law Review 81, pp. 1991-2044.

Liebowitz, S., Margolis, S. (2005): Path Dependence, Lock-In and History, *Journal of Law, Economics and Organization*, 11(1), pp. 205-26

McGrath, G., Nerkar, A. (2004): Real options reasoning and a new look at the R&D investment strategies of pharmaceutical firms, *Strategic Management Journal*, 25: 1–21.

Park, G., Park, Y. (2006): On the measurement of patent stock as knowledge indicators, *Technological Forecasting and Social Change*, 73, pp. 793-812.

Rosenbaum, P. (1987): The Role of a Second Control Group in an Observational Study, *Statistical Science* , 2(3), pp. 292-306.

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

Shapiro, C. (2001): Navigating the Patent Thicket: Cross Licenses, Patents Pools, and Standard Setting. In: A Jaffe, J Lerner et S, Stern (Eds), *Innovation Policy and the Economy*, vol. 1. MIT Press.

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

Suarez, F. (2005): Network Effects Revisited: The Role of Strong Ties in Technology Selection, *The Academy of Management Journal*, Vol. 48, No. 4 (Aug., 2005), pp. 710-720.

Tassey, G. (2000): Standardization in technology-based markets, *Research Policy*, 29(4-5), pp. 587-602

Trajtenberg, M. (1990): A penny for your quotes: patent citations and the value of innovations, *RAND Journal of Economics*, 21(1), pp. 171-187.

Weitzel, T., Beimborn, D., König, W. (2006): A unified economic model of standard diffusion: The impact of standardization cost, network effects and network topology, *MIS Quarterly, 30, Special Issue, pp. 489-514*

West, J. (2003): How Open is Open Enough? Melding Proprietary and Open Source Platform Strategies, *Research Policy,* 32(7), pp. 1259-1285.

West, J., Dedrick, J. (2000): Innovation and Control in Standards Architectures: The Rise and Fall of Japan's PC-98, *Information Systems Research*, 11(2), pp. 197-216.

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