Essential Patents and Standard Dynamics

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Abstract: *We analyze the rate and direction of technological progress of standards subject to declared standard-essential patents (SEP). We observe continuous and discontinuous changes in a sample of 3,500 ICT standards. Standards including SEPs change significantly more often than other standards. This difference is particularly pronounced if ownership over patents is concentrated. Furthermore, standards subject to SEPs are characterized by a more continuous pattern of technological progress. While the existence of SEPs is correlated with a significantly higher number of continuous standard upgrades, standards subject to SEPs are much less likely to experience discontinuous standard replacements. In particular, standards are less likely to be replaced if the owners of the SEPs are relatively more specialized on the technological field of the standard.*

Keywords: technology standards, standard-essential patents, cumulative innovation, disruptive innovation, incremental innovation, complex technologies

Introduction

An increasing number of patents are declared to be essential to technology standards (Bekkers et al., 2012). A standard-essential patent (SEP) is a patent that is necessarily infringed by any implementation of a standard. The effect of SEPs on the technological and commercial success of technology standards is subject to lively debates. It is often alleged that SEPs discourage standard adoption, because standard users fear to be faced with litigation and exorbitant requests for royalties (Lemley and Shapiro, 2006; Lerner and Tirole, 2015). In addition, a high number of complementary patents owned by different firms may lead to patent thickets and hamper technological innovation (Shapiro, 2001).

These potential threats have received considerable attention and motivated initiatives for binding regulatory action or more restrictive SSO policies on SEPs.[1] Many observers however complain that concerns regarding SEPs are insufficiently supported by empirical evidence (Geradin et al., 2008; Sidak, 2009; Galetovic et al., 2015). Given the importance of patents and technology standards for innovation, it is urgent that public policy with respect to SEPs is put on a more solid empirical foundation. In particular, while the current discussion largely focuses on potential risks and costs associated with SEPs for implementers of standards, it is important to consider the role of SEPs for innovation in technology standards.

In this paper, we analyze continuous and discontinuous technological progress of technology standards, and compare standards subject to SEPs with other standards. We analyze declarations of SEPs to six formal SSOs, and use the standard designations in these declarations to match declared SEPs to standard documents. We use rich bibliographical information on standards to study their technological evolution. SSOs can withdraw outdated standards, or publish a revised version of the same standard. Following Yorukoglu (1998), we call these two options respectively the *replacement* and *upgrade* of existing standards,[2] whereas we use the term *revision* to refer to both these events. While a standard upgrade incrementally changes and improves upon an existing standard, standard replacement indicates a discontinuous change in the underlying technology.

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[1] The U.S. Department of Justice, Antitrust Division (DOJ), and the U.S. Patent & Trademark Office (USPTO), published in January 2013 a position paper (available under: http://www.justice.gov/atr/public/guidelines/290994.pdf) that discusses the role of SEPs. A particularly controversial SSO policy change was approved in 2015 at IEEE: https://standards.ieee.org/develop/policies/bylaws/approved-changes.pdf For a critical discussion of the recent policy change, see Teece (2015)

[2] In Yorukoglu (1998), *replacement* means "junking" the existing technology and the associated capital stock, whereas *upgrade* is an improvement of the existing technology. While an upgrade preserves the existing capital stock, it is less effective in integrating new technological developments.

We find that standards including SEPs are revised significantly more frequently than other standards. This significant difference decreases with fragmentation of patent ownership. While standards including SEPs are upgraded significantly more often than other standards, they are subject to significantly lower rates of discontinuous standard replacements. In particular, the likelihood of discontinuous change is lower if SEP owners specialize on the technological field related to the standard including their technology. This statistical analysis of standards subject to declared SEPs is a first step towards a better understanding of the role of SEPs for standards' development, and a necessary complement to the existing analysis focusing on strategic behavior with respect to SEPs, and potential downstream costs of SEPs for implementers.

The remainder of this article is organized as follows. Section 2 reviews the existing literature and summarizes the public policy debate. In Section 3, we present our data and discuss the research methodology. Section 4 provides results from a comparative analysis comparing standards including SEPs with appropriate control observations. In Section 5, we discuss the results of a multivariate panel analysis. Section 6 concludes and discusses policy implications.

1. Literature review

SEPs may generate substantial economic returns, e.g. through licensing.[3] The value of a patent may substantially increase if the underlying invention is declared essential to a technology standard (Rysman and Simcoe, 2008). Pohlmann et al. (2015) and Hussinger and Schwiebacher (2013) find that SEPs contribute more significantly than other patents to firm revenue and value. There is however only very limited evidence on the consequences of SEPs for standardization and the technical progress of standards.

SEPs have the potential to exacerbate conflicts of interest in SSOs. The development of standards within SSOs is often characterized by diverging interests between participating firms (Garud et al., 2002). Vested interests in standardization due to commercial stakes can reduce the speed at which standards are developed (Farrell and Simcoe, 2012; Simcoe, 2012). In addition to these concerns regarding the efficiency of standard development, SEPs could produce transaction costs or internalization effects that affect the rate of improvement of existing technology standards.

Transaction costs and internalization effects have also been highlighted by a more general literature on the effect of patents on follow-up innovation (Williams, 2013). Bessen and Maskin (2009) predict that in the presence of transaction costs, patent protection could deter potential follow-up innovators. Follow-up innovators making sunk investments in the improvement of an existing patented technology are at risk of

[3] C.f. Stasik, Eric(2010),

being held up by the owner of the original patent. The risk of patent hold-up is viewed as particularly worrisome for SEPs subject to vague licensing commitments and ex-post negotiations (Lemley and Shapiro, 2006; Farrell et al., 2007; Shapiro, 2010). There is however to date no evidence that the theoretical possibility of patent hold-up is empirically relevant and detrimentally affects the technological evolution or commercial viability of standards subject to SEPs (Galetovic et al., 2015).

Patents can also reduce transaction costs and facilitate follow-up innovation. Spulber (2015) argues that patents facilitate transactions in the market for inventions. The other important implication of patents for follow-up innovation is an internalization effect. Kitch (1977) argues that patents allow a firm to internalize the benefits from further developing the patented technology. More recent empirical findings confirm that patents reduce uncertainty in investments that are complementary to a specific technology (McGrath and Nerkar, 2004, Arora et al. 2008). SEPs may incentivize their owners to invest in the further improvement and promotion of a standard. The cost of these efforts is usually borne by some private actors, while the benefits accrue to all standard users (Kindleberger, 1983).

The existing literature thus supports arguments both pointing to a positive or to a negative effect of patents on the rate of follow-up innovation. Galasso and Schankerman (2015) study the effect of patents on follow-up innovation in various technological fields, and find a negative effect only in Information and Communication Technologies (ICT). They argue that this negative effect is due to the fact that ICT are characterized by highly fragmented patent ownership.

Fragmentation of patent ownership over multiple firms is of particular concern with respect to ICT standards, which are often subject to large numbers of SEPs owned by different firms. Transaction costs may be exacerbated because potential users of the standard need to negotiate many different licensing contract. Consistently, Simcoe et al. (2009) document an increase in patent litigation after patents are included into technology standards. Galasso and Schankerman (2010), however, find that ownership fragmentation reduces the stakes of each patent owner in the technology, and can reduce rather than increase delays in negotiating licensing agreements. Lemley and Shapiro (2006) warn that standards including SEPs from different owners are subject to royalty stacking and reduced transparency. Llanes and Trento (2012) find that the accumulation of patents owned by different firms reduces ex-post innovation incentives.

The inclusion of SEPs may affect not only the *rate*, but also the direction of the technological progress of standards. Patents may provide their owners with incentives to invest in the further development of their technology, but discourage them to develop new, alternative technologies (Arrow, 1962). The distinction between continuous progress and discontinuous technological change is crucial to the analysis of technology standards (Farrell and Saloner 1985, 1986). Katz and Shapiro (1992) find that resistance to change can be overcome if new standards are subject to property rights. Furthermore, the resistance to discontinuous standard replacement depends upon the ability of incumbent firms to take advantage of technological change. Ranganathan and Rosenkopf (2014) for instance find that SSO members with strong R&D connections to other SSO members are less likely to oppose to changes in standards.

We contribute to this literature the first statistical analysis of the technological progress of standards subject to SEPs. Unlike previous empirical studies, we directly observe patent ownership fragmentation, and can distinguish between continuous and discontinuous technological progress.

2. Empirical Methodology

2.1. Using standard upgrades and replacements to analyze the technological progress of standards

We analyze standard revisions in a comprehensive database of international ICT standards drawn from PERINORM. PERINORM is a database with bibliographic information on technology standards issued by more than 200 SSOs in 23 countries.[4] We include all ICT standards (International Classes of Standards 33 – telecommunications - and 35 – office machines) issued by six important international SSOs: International Organization of Standardization (ISO), International Electrotechnical Commission (IEC), the ISO/IEC Joint Technical Committee 1 (JTC1), two bodies of the International Telecommunications Union (ITU-R and ITU-T), and the Institute of Electric and Electrotechnical Engineers (IEEE).

The selected SSOs have similar policies regarding SEPs, and account for an important share of SEP declarations studied e.g. by Bekkers et al. (2012).[5] We include standards released from 1988 to 2008, and we observe these standards until 2010. We exclude draft standards, amendments, errata, technical reports and other non-standard documentation produced by SSOs. We restrict the sample to specific technological classes in which at least one standard includes SEPs. Furthermore, we exclude standards with incomplete information. The resulting 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 were withdrawn during the observation period.

[4] More information on PERINORM can be found at www.perinorm.com.
[5] Other SSOs with large numbers of declared SEPs are the 3rd Generation Partnership Project (3GPP), the European Telecommunication Standards Institute (ETSI), and the Internet Engineering Task Force (IETF). These SSOs are either not included in PERINORM, or declared SEPs cannot be matched to specific standards documents.

For every standard version, the database includes the dates of release and withdrawal. SSOs regularly revise their standards to keep up with technological progress.[6] During the revision, „*a majority of the members of the TC* [Technical Committee] *decides whether the standard should be confirmed, revised or withdrawn"*.[7] We can observe the withdrawal of standard documents in PERINORM, and identify new versions of the same standard using PERINORM information on the version history of a standard. We call a case where a standard version is replaced by a more recent version a *standard upgrade*. Standard upgrades reflect continuous technological progress.

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 and audio and video coding standards currently coexist. Nevertheless, evolution and deployment of new generations eventually lead to the earlier standard being withdrawn: "*Several factors combine to render a standard out of date: technological evolution, new methods and materials, new quality and safety requirements."*[8] Baron and Delcamp (2015) analyze SEPs included in various patent pools related to three succeeding generations of MPEG video coding standards. The overlap of SEPs in these different pools is less than 10%. We thus conclude that when a standard is replaced, patents that are essential to the old standard would often not be essential for the new standard.

Earlier research corroborates our use of standard revisions to indicate technological change. Blind (2007) documents a correlation between standard withdrawal and innovation in the related technological field. Baron and Schmidt (2014) find that new versions of existing standards induce lower long-run productivity gains than entirely new standards. In contrast to new versions of existing standards, new standards induce a short-run productivity decline. We conclude that a *standard replacement* is a discontinuous technical change that may render existing technology obsolete.

We then 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 from release of the first standard version to standard replacement (withdrawal of the last version).

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[6] ISO e.g. states: „ISO standards represent, by an international consensus among experts in the technology concerned, the state of the art. To ensure that ISO standards retain this lead, they are reviewed at least every five years after their publication. The technical experts then decide whether the standard is still valid, or whether it should be withdrawn or updated. In some fields, the pace of development is such that when an ISO standard is published, the experts who developed it are already thinking about the next version!" (http://www.iso.org/iso/home/faqs/faqs_standards.htm, last consulted in May 2015).
[7] http://www.iso.org/iso/standards_development/processes_and_procedures/stages_description.htm
[8] http://www.iso.org/iso/standards_development/processes_and_procedures/how_are_standards_developed.

2.2. Matching declared SEPs to standard documents

We downloaded declarations of SEPs from the websites of the SSOs in March 2010. The declaration of patent essentiality is made by owners of the patents, and no external validation of this essentiality claim is made. There is furthermore no guarantee that all SEPs are accurately declared. The literature has nevertheless used declared SEPs as a proxy for actual SEPs (e.g. Rysman and Simcoe, 2008). In the following, we will speak of SEPs, and use declared SEPs as an empirical approximation. We identified more than 8,000 patent declarations for 700 formal standards included in our sample.

The large majority of SEP declarations made to the SSOs in our sample either reference a specific standard, or a specific version of a standard document. We aggregate different versions of the same standard to a single observation, and match SEPs to standards using the date of declaration. Following Rysman and Simcoe (2008), we assume that the SEP is included into the standard at the date of declaration. In the majority of cases, the SEP declaration database includes the date of declaration, so that we can match each SEP to its relevant standard from the date of declaration onwards.[9]

We use the data on SEPs to build explanatory variables. *SEP_dummy* is a dummy variable indicating that a standard includes at least one SEP. *SEP_cumul* indicates the cumulative number of SEP declarations by standard.[10] *Numberfirms_cumul* indicates the cumulative number of firms declaring to own SEPs for the same standard; *secondfirm* and *thirdfirm* are dummy variables indicating that a standard is subject to SEPs declared by at least two or three different firms, respectively. We also use the number of SEP declarations by firm to calculate a time-variant Herfindahl–Hirschman Index (HHI) of SEP ownership, *HHI_SEP*. The HHI measures fragmentation of SEP ownership for a specific standard.

Furthermore, following Baron et al. (2014), we use the IPC classification of declared SEPs to identify standard-related technology classes. Using PATSTAT, we analyze the patent applications by the firms who have declared SEPs to one of the standards in our sample, and count the patent applications in the technology classes identified as relevant to each specific standard. We calculate a different HHI index, using the overall number of patents in the standard-relevant IPC classes owned by the firms declaring SEPs instead of the number of declared SEPs (*HHI_rel_patents)*. Second, we measure the importance of the standard-related technological field for the incumbents' patent portfolios. We thus calculate the share of patents related to the standard in the overall portfolio of patents owned by these firms. We call this variable

[9] SEP declarations without declaration dates are matched to standards and considered in the comparative cross-section analysis, but excluded from the multivariate panel analysis.

[10] Declarations are counted as unique combinations of patents and standards. A patent declared essential to multiple standards, and multiple patents declared essential to one standard, are thus both counted as multiple declarations. Blanket declarations are counted as single declarations.

Incumbents_standard_focus. This variable measures the specific stake of the incumbent patent owners in the particular technology currently used by the standard.

2.3. Control variables

We control for the identity of the issuing SSO, the ICS (International Classification of Standards) technology class, the breadth of the technological scope of the standard (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 focal SSO in our sample (*prior accreditations*).[11]

In addition to these time-invariant characteristics of standard documents, we gather data on references from other standards (*forward references*) and accreditations by other SSOs (*ulterior accreditations*). These time-variant variables capture downstream investment building upon the standard. We also observe changes to referenced standards upon which the standard is built (*change of referenced standard*).

When comparing the rates of standard upgrades and replacement over time, we need to control for the general speed of technological progress in the technological field relevant to each standard. We identify the IPC classification of all SEPs declared to all standards in this particular ICS class. We then count all patent applications in these IPC classes, and refer to this variable as "*innovation intensity*". The yearly patent files in the related field indicate the flow of standard-related inventions. Following Hall et al. (2000) and Bessen (2009)[12] we accumulate 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. The technology gap measures the difference between the current state of technology and the state of technology when the standard was developed. We assume that a new standard release integrates the advances in technology, so that the technology gap is set back to zero.

A full list of variable definitions is provided in Appendix A.

3. Comparative Analysis

[11] e.g. if an ISO standard had first been developed by a national SSO not covered by our sample.
[12] According to Park and Park (2006) this is the average depreciation rate of patents in the Electrical machinery and Radio, TV and communication equipment industries.

In this section, we compare the survival rates of standards and standard versions including SEPs with other standards and standard versions.[13]

Figure 1a shows the Kaplan-Meier estimates of survival of standard versions (in years after release). Lower survival rates of standard versions indicate higher rates at which standards are revised. The survival rates of standard versions including SEPs decreases more rapidly than those of other standard versions. Figure 1b presents the likelihood that a standard is fully withdrawn by a certain time (in years after the release of the first standard version). Lower survival time of standards indicates a higher propensity for discontinuous standard replacement. The survival rates of standards including SEPs decrease more slowly than those of other standards. Standards including SEPs thus undergo more frequent revisions, but face a lower likelihood of replacement than other standards.

INSERT FIGURE 1 HERE

The difference in standard version survival rates between standards with and without SEPs is statistically significant at any time horizon of more than two years after release. The difference in the survival rates between standards with and without SEPs is statistically significant at 95% after more than five years after standard release.

Standards in more innovative technological fields may be more likely to include SEPs, and subject to faster changes in the state of the art. Declarations of SEPs could also signal the importance, technological complexity or commercial relevance of a technological standard. In order to address these concerns, we perform a propensity score matching using observable standard characteristics. The number of standard pages is an indicator of the technological complexity of the standard. References from other standards are 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). The ICS classification can account for the characteristics of the technological field. The identity of the issuing SSO can control for institutional factors such as IPR policies. Table 4 (Appendix B) presents the results of the regressions used to calculate the propensity scores.

Appendix C describes the distribution of the propensity scores. Several standards including SEPs have a significantly higher propensity score than any standard without SEPs. We eliminate these standards from

[13] Standards are defined as being subject to SEPs after a first SEP declaration was made. This way, we ensure that our analysis is not affected by survivor bias (which would result if standards were in the control group only because they did not survive long enough to become subject to a SEP declaration).

the comparison.[14] Furthermore, we weight control observations based on their propensity score, i.e. we give a higher weight to standards without SEPs if they have a larger propensity score. As a result of the resampling and weighting, there are no remaining statistically significant differences on observable characteristics between standards with and without SEPs.

Figures 3a and 3b in the Appendix D display the survival rates of standards and standard versions in the modified sample, i.e. comparing standards including SEPs on support with standards without SEPs reweighted based on their propensity score. The differences between standards with and without SEPs remain qualitatively unchanged, but are a little bit less pronounced as compared to the unadjusted sample.

We also use the propensity score for a log-rank test. We divide the sample of standards into six strata of equal size according to their propensity score, and compare the observed survival rate of standards with and without SEPs within strata. The test aggregates the differences within strata to a joint comparison of all observations balanced on propensity scores. The test confirms that the observed differences in standard version survival rates between standards with and without SEPs are globally significant, and significant within each stratum in which we have a sufficient basis for comparison. On the standard version level, the region of common support are the upper three strata. The number of standards is lower than the number of standard versions, and standards have a higher likelihood of including at least one SEP than single standard versions. As a result, the observation that standards including SEPs have a significantly lower likelihood of replacement thus rests on a smaller and less representative sample of 1,141 standards that have a high propensity to include SEPs. Details of the test can be consulted in the tables 4 and 5 in Appendix D.

If revisions of standards subject to SEPs induce revisions in standards that are technologically closely related, our comparison would understate the true difference between standards subject and standards not subject to SEPs. Figure 4 (Appendix E) displays Kaplan-Meier survival rates comparing standards and standard versions subject to SEPs with the two different control groups: standards that are not subject to SEPs, but are technologically related to standards subject to SEPs, and standards entirely unrelated to SEPs.[15] The analysis confirms that standards including SEPs undergo a significantly higher rate of revision, and face a significantly lower risk of replacement, than either control group.

The findings of our comparative analysis do not necessarily reflect a causal effect of SEPs. The propensity score only captures observable variables. Furthermore, the comparative analysis is a cross-section analysis

[14] We apply a maximum caliper distance of 0.02. All our results are qualitatively robust to changes in the caliper distance.

[15] We identify related standards 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 related to IEEE802.11)

and cannot account for time-variant factors, such as technological change, variance in standard adoption and other trends or shocks that simultaneously affect SEP declarations and standard revision. We therefore also conduct a multivariate panel analysis.

4. Multivariate Panel Analysis

We analyze the upgrade and replacement rates of standards using a semi-parametric Cox model. The hazard of withdrawal is estimated year by year, conditional upon the fact that the version or standard has not yet been withdrawn. The estimated hazard is the product of a baseline hazard $h_0(t)$ and the covariates multiplied by constant coefficients:

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

In order to compare only comparable standards, we stratify the observed individual standards i into strata j. The baseline hazard rate is allowed to vary between the strata.

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

We stratify jointly by SSO, ICS class and cohorts of standards released before and after 2001. After testing for violation of the Proportional Hazard assumption, we further stratify by ranges of standard size (number of pages), and standard versions by their position in the series of successive versions. The remainder of the variables is included as covariates $x_{j,t}$ in the Cox model.[16] At the standard level, the tests indicate that the proportional hazard assumption is violated unless we control for standard revisions. We control for standard revisions in Model 15, which confirms our basic findings.

We calculate and report hazard ratios. The hazard ratio is the quantity by which the estimated hazard rate is multiplied if the respective explanatory variable increases by 1. Hazard ratios below 1 imply a negative effect of the explanatory variable on the hazard ratio (rate of withdrawal).

INSERT TABLE 1 HERE

[16] We control for a linear effect of all control variables. We carried out robustness checks testing for non-linear effects of covariates. None of our results are sensitive to the functional form of the control variables, either qualitatively or quantitatively (results available upon request).

We start with a series of models explaining the survival rates of standard versions, i.e. the hazard of standard revision (Models 1-6).[17] We first analyze the difference between standards subject to SEPs and standards not subject to SEPs (M1). Standards including SEPs are revised at a 44% higher rate than other, otherwise comparable standards. Neither the number of declarations (M2), nor the inclusion of SEPs from more than one firm are associated with statistically significant differences in standard revision rates (M3 and M4).

A high number of firms declaring SEPs does not systematically result in significant fragmentation, if one or few firms declare very significant numbers of SEP. In M5, we include the HHI over SEP declarations.[18] A higher HHI is associated with a significantly higher rate of standard revisions. Moving a standard from total fragmentation to fully concentrated ownership is associated with a 95% increase in the rate of revisions. In M6, we include the HHI over patents filed by incumbents in the related technological field. A field with fully concentrated patent ownership is associated with a 50% higher revision rate than a field with fully fragmented ownership.

INSERT TABLE 2 HERE

In the following, we distinguish between standard upgrade and standard replacement. We first focus on the effect of SEPs on the rate of continuous standard upgrades. The risk of standard replacement is a competing risk to the risk of standard upgrade (a standard that is replaced is no longer at risk of being upgraded). In Models 7 to 9, we use a competing risk Cox model to estimate the effect of explanatory variables on the rate of continuous standard upgrades, controlling for the competing risk of discontinuous replacement. The results are qualitatively similar to the results in Models 1 to 6. The relationship between SEPs and standard upgrades is however significantly more pronounced than the relationship between SEPs and standard revisions in general (subhazard ratios are presented in Table 9 in the Appendix F).

We next analyze the choice between standard upgrade and standard replacement using a logit regression. Conditional on a standard being revised, the likelihood of discontinuous replacement is 55 % lower for standards including SEPs (M10).[19] We then analyze the rate of standard replacement in a survival model

[17] Many of the explanatory variables, including the variables related to SEPs, are determined at the level of the standard. We therefore cluster standard errors by standards.
[18] We set this value to zero if the standard does not include SEPs
[19] We report the odds-ratios of the logit regression. Similarly to hazard ratios, odds-ratios of logit regressions can be directly interpreted in terms of magnitude of the effect.

on the standard level, tracking standards from the release of the first to withdrawal of the last version (M11). Standards including SEPs face a risk of replacement that is 51% lower than for other standards.

We next differentiate between standards including SEPs declared by one or by several firms. Standards including SEPs declared by a single patent owner do not differ significantly from standards that are not subject to SEP declarations. SEP declarations by several firms are however associated with an 80% lower risk of standard replacement (M12). The likelihood of standard replacement does however not generally depend on the number of firms declaring to own SEPs (M13). Finally, we include the HHI of declared SEPs, and *insiders_standard_focus*. The latter variable measures the relative weight of the technological field of the standard in the patent portfolio of declaring SEP owners. Standards including SEPs face an even lower risk of standard replacement if SEP holders specialize on the specific technological field related to this standard. The risk of standard replacement decreases by 43% if the share of patents owned by SEP holders classified in the same technological classes as the SEPs increases from 0 to 100%. Concentration of SEP ownership is, however, associated with a much higher rate of standard replacement. This effect as well is statistically significant and quantitatively important.

In Model 15, we control for the number of upgrades and the time elapsed since last standard upgrade. This model thus only measures the relationship between standard replacement rates and the covariates of the model that are not transmitted by more frequent upgrades. The estimated hazard rates do not change substantially, and confirm our previous finding: standards including SEPs are much less likely to be replaced than other standards.

5. Discussion

Our analysis has highlighted empirical regularities that shed a new light on the implications of SEPs for the technological progress of standards.

First, **s**tandards subject to declared SEPs undergo a substantially more pronounced rate of revisions than otherwise comparable standards. Given our stratification strategy, this difference cannot be attributed to characteristics of the SSO or the technological field.

One possible explanation for the significant difference is that the inclusion of SEPs induces an increased rate of technological progress in the standard. In particular, the inclusion of SEPs is likely to incentivize the SEP owner(s) to invest in the further technological progress of the standard, and to bear a part of the substantial cost of standard maintenance.

The correlation between the inclusion of SEPs and a higher rate of progress is open to alternative, non-causal interpretations. SEPs are more likely to be declared to standards of greater commercial importance. Those standards are also more likely to be revised, e.g. because they have to adapt to changes in a larger number of commercial applications. Another interpretation is that SEPs are more common for standard requiring the use of very specific technology. A standard with many SEPs is less flexible in its implementation, and is therefore more likely to require revision in the presence of technological change. We partially control for this effect using the number of normative references to other standards. While SEPs indicate that a patented technology must necessarily be used for the implementation of a standard, a normative reference indicates that a different standard must necessarily be used for any standard implementation. Normative references therefore also indicate that the implementation of a standard requires very specific technologies.

Secondly, we find that standards subject to fragmented SEP ownership undergo fewer revisions than standards subject to concentrated SEP ownership. This difference remains significant when controlling for the number of declared SEPs.

This finding is consistent with the literature on the effect of patents on follow-up innovation (in particular Galasso and Schankerman, 2015). SEP holders have an incentive to invest in further improvements of the standard. This internalization effect is stronger if SEP ownership is highly concentrated. Fragmented IP ownership reduces the internalization benefit of patents. A negative effect of fragmented patent ownership can also result from increased transaction costs, which decrease the return from subsequent innovation. We would however expect that transaction costs increase with the number of firms declaring SEPs for a standard. We however find a significant effect of the HHI of patent ownership, and no significant effect of the number of declaring firms. These findings are more consistent with an explanation based on the internalization of the costs of standard maintenance.

We also find a significant negative correlation between the rate of progress and fragmentation of patent ownership when measuring patent fragmentation using the HHI of patents in the standard-related technological field, instead of patents actually declared to be SEPs. This finding is less likely to be affected by confounding factors such as the commercial or technological importance of the standard.

Thirdly, standards including SEPs face a higher rate of standard upgrades, but a lower rate of standard replacement than other comparable standards. It is plausible that patents have opposite effects on the incentives to further improve the existing technology, or develop a new technological alternative. Our descriptive finding could indicate that SEP owners have an incentive to invest in additional upgrades of the existing standard, but to oppose to discontinuous standard replacements.

It can also be argued that standards which are more important or which are more widely adopted have both a higher likelihood of upgrades and a higher survival rate. At the same time, the importance or success of a standard can correlate with a higher likelihood of being subject to SEPs. We include the number of received references to control for standard success or importance over time. Incoming references from other standards are associated with significantly higher rates of standard upgrades, and significantly lower rates of standard replacement.

In addition, declarations may be rate-dependent. Patent holders may observe the expected residual lifetime of a standard. Firms are more likely to declare SEPs for standards subject to ongoing improvements and facing a lower risk of replacement.

Fourthly, the replacement effect is significantly attenuated if SEP owners are active in different technological fields. If firms own different technological resources that they can contribute to a standard, they may benefit from discontinuous technological change and are less likely to oppose to standard replacement (Rosenkopf et al., 2014). While the general comparison of standards including SEPs with other standards is open to a broad range of interpretations, the observation of more specific factors, in particular the degree of SEP ownership fragmentation and the SEP owners' technological focus, provides an indication of causal effects.

Our analysis captures key aspects of standard dynamics. The likelihood of standard replacement is strongly associated with the "*innovation intensity*" (the flow of new patented inventions in the related technological field) and the "*technology gap*" (the stock of patents filed in the field over the years since the last standard release). In the presence of high rates of related technological progress ("*innovation intensity*"), standard setters tend to choose standard replacement rather than upgrade. Similar to Yorukoglu (1998), this finding indicates that standard upgrades are a less effective means of catching up with a dynamic technological frontier.

We also find strong evidence for interdependence of standards. Backward references to other standards are associated with a lower risk of standard replacement. If a referenced standard is replaced or upgraded, there is however a strongly increased likelihood that the referencing standard is replaced or upgraded as well. Incoming references from other, more recent standards increase the likelihood of a revision, but reduce the likelihood of standard replacement.

6. Conclusion

Our findings shed light on the role of SEPs for the technological progress of standards. While it is widely recognized that SEPs can provide significant incentives to invest in standard-essential inventions, our results suggest that existing SEPs also play an important role for the subsequent progress of standards. In particular, we show that it matters who declares SEPs. More concentrated SEP ownership is associated with a higher rate of technological progress. Standards are less likely to undergo discontinuous technological change if the incumbent SEP owners are highly specialized in the technological area of their SEPs. Taken together, these findings support the hypothesis of an internalization effect of SEPs.

We also contribute to an emerging body of empirical evidence on the effect of patents on subsequent innovation. Using data on technology standards, we observe bundles of inventions that are typically used together, and can therefore directly analyze the implications of ownership fragmentation, which is associated with lower rates of subsequent technological innovation. Technology standards also provide a unique opportunity to study the trade-off between continuous improvements and discontinuous technological change. The economic implications of this trade-off are still insufficiently understood and deserve further investigation.

Finally, while further research is necessary to investigate the differentiated causal effects of SEPs on standard development, our results inform ongoing policy discussions regarding the regulatory framework for the licensing of SEPs. Many of these discussions focus on the royalty burden of SEPs for implementers and static efficiency. The effects of SEPs on the technological evolution of standards deserve more attention of policy makers and SSOs currently working on a reassessment of the rules applying to SEPs in finding the right balance between static and dynamic efficiency.

References

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

Baron, J., Delcamp, H., 2015.: The strategies of patent introduction into patent pools, *Economics of Innovation and New Technology*, 24(8), pp. 776-800

Baron, J., Ménière, Y., Pohlmann, T., 2014. Standards, Consortia and Innovation, *International Journal of Industrial Organization,* 36 pp. 22-35.

Baron, J., Schmidt, J., 2014. Technological Standardization, Endogenous Productivity and Transitory Dynamics, Working Paper

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*.

Bessen, J, Maskin, E., 2009. Sequential innovation, patents, and imitation, *The RAND Journal of Economics,* 40(4), pp. 611–635.

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

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.

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.

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., Hayes, J., Shapiro, C., Sullivan, T (2007): Standard setting, patents, and hold-up, *Antitrust Law Journal*, 74(3), pp. 603-670

Farrell, J., Simcoe, T., 2012. Choosing the Rules for Consensus Standardization, *RAND Journal of Economics*, 43(2), pp. 235-252.

Galasso, A., Schankerman, M., 2010. Patent thickets, courts, and the market for innovation, *The RAND Journal of Economics*, 41(3), pp. 472–503

Galasso, A., Schankerman, M., 2015. Patents and Cumulative Innovation: Causal Evidence from the Courts, *Quarterly Journal of Economics*, 130(1), pp. 317-369.

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.

Geradin, D., Rato, M., 2007. Can Standard-Setting Lead to Exploitative Abuse? A Dissonant View on Patent Hold-up, Royalty-Stacking and the Meaning of FRAND, *European Competition Law Journal*, 101

Gilbert, R., Newbery, D., 1982. Preemptive Patenting and the Persistence of Monopoly, *American Economic Review*, 72(3), pp. 514-526

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.

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.

Layne-Farrar, A., Llobet, G., Padilla, J., 2014. Payments and Participation: The Incentives to Join Cooperative Standard Setting Efforts, *Journal of Economics & Management Strategy*, 23(1), pp. 24-49

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.

Lerner, J., Tirole, J., 2015. Standard-Essential Patents, *Journal of Political Economy*, forthcoming

Llanes, G. and Trento, S., 2012. Patent Policy, Patent Pools, and the Accumulation of Claims in Sequential Innovation, *Economic Theory*, 50(3), pp. 703-725.

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, pp. 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.

Pohlmann, T., Blind, K., Neuhaeusler, P., 2015. Standard essential patents to boost financial returns, *R&D Management*, in print.

Ranganathan, L., Rosenkopf, R., 2014. Do Ties Really Bind? The Effect of Knowledge and Commercialization Networks on Opposition to Standards, *Academy of Management Journal*, 57(2), pp. 515-540.

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.

Shapiro, C., 2010. Injunctions, Hold-Up, and Patent Royalties, *American Law and Economics Review*, 12(2), pp. 280-318

Simcoe, T., Graham, J., Feldman, M., 2009. Competing on Standards? Entrepreneurship, Intellectual Property and Platform Technologies, *Journal of Economics and Management Strategy*, 18(3), pp. 775-816.

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

Spulber, D., 2008. Consumer Coordination in the Small and in the Large: Implications for Antitrust in Markets with Network Effects. *Journal of Competition Law and Economics*, 4(2), pp. 207-262.

Spulber, D, 2015. How Patents Provide the Foundation of the Market for Inventions. *Journal of Competition Law and Economics*, 11(2), forthcoming

Teece, D., 2015. Are the IEEE Proposed Changes to IPR Policy Innovation Friendly? *Working paper*

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

Williams, H., 2013. Intellectual Property Rights and Innovation: Evidence from the Human Genome, *Journal of Political Economy*, 121(1), pp. 1-27

Yorukoglu, M., 1998. The Information Technology Productivity Paradox, *Review of Economic Dynamics*, 1, pp. 551-592

Appendix A

INSERT TABLE 3 HERE

Appendix B

INSERT TABLE 4 HERE

Appendix C

INSERT FIGURE 2 HERE

INSERT TABLE 5 HERE

INSERT TABLE 6 HERE

Appendix D

INSERT FIGURE 3 HERE

INSERT TABLE 7 HERE

INSERT TABLE 8 HERE

Appendix E

INSERT FIGURE 4 HERE

Appendix F

INSERT TABLE 9 HERE

Figure 1

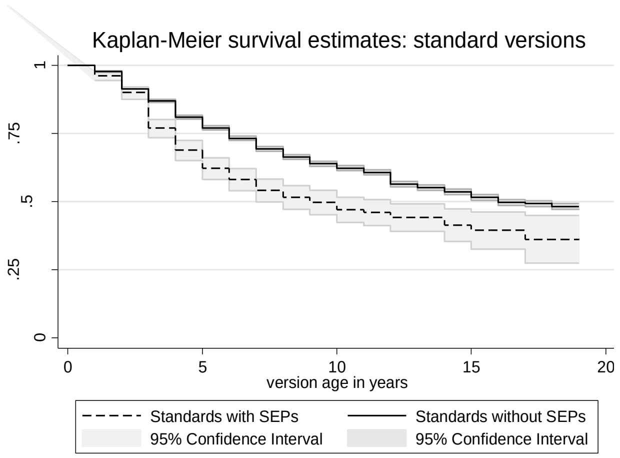

Figure 1a: *Survival estimates of standard versions*

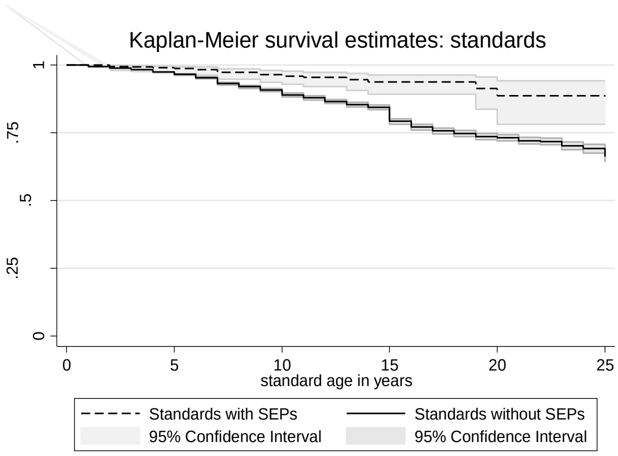

Figure 1b: *Survival estimates of standards*

Figure 2

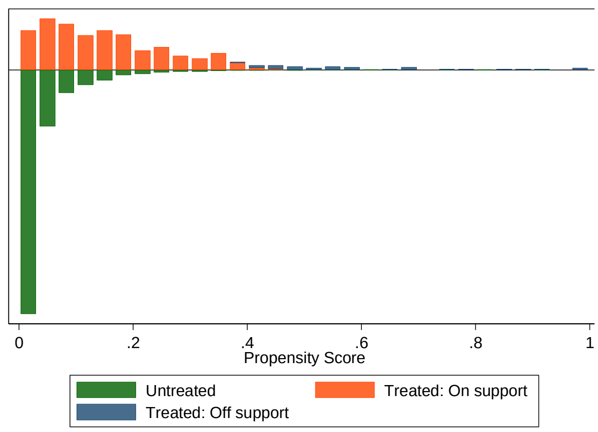

Figure 2a: *Propensity score matching on the verison level*

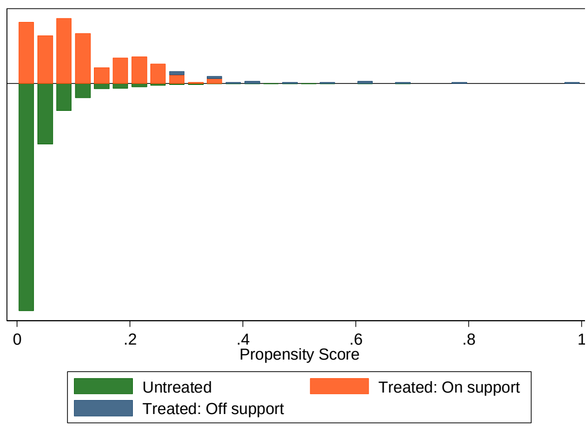

Figure 2b: *Propensity score matching on the standard level*

Figure 3

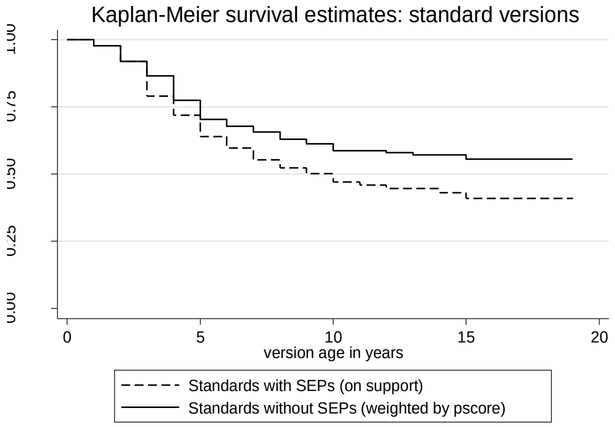

Figure 3a: *Survival estimates of standard versions*

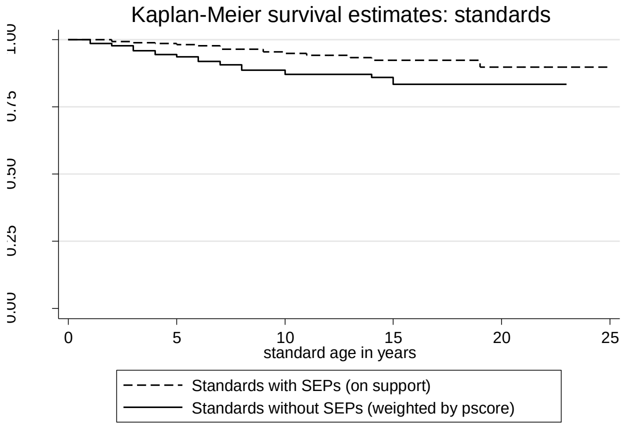

Figure 3b: *Survival estimates of standards*

Figure 4

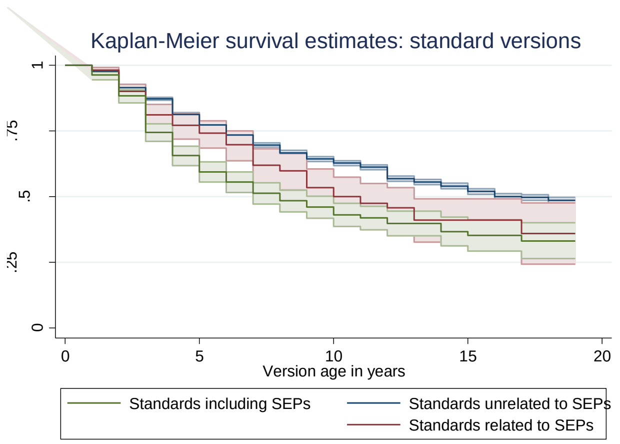

Figure 4a: *Survival estimates of standard versions*

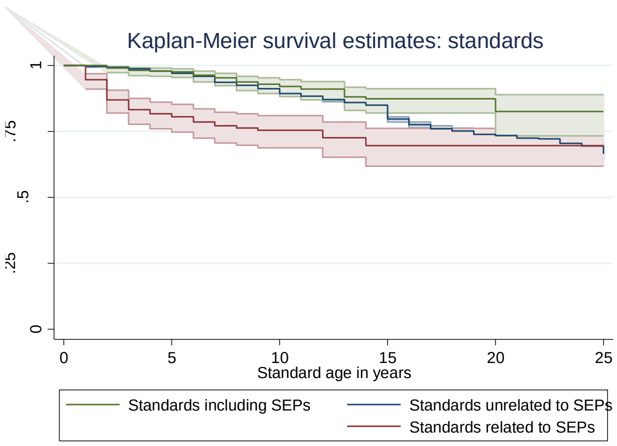

Figure 4b: *Survival estimates of standards*

Table 1

Model/ Variable Name	M1 Cox Regression	M2 Cox Regression	M3 Cox Regression	M4 Cox Regression	M5 Cox Regression	M6 Cox Regression
SEP_ Dummy	1.4893*** (0.1328)	1.4525*** (0.1318)	1.4589*** (0.1486)	1.4317*** (0.1369)	1.1659 (0.1322)	1.2637** (0.1420)
SEP_cumul		1.0024 (0.0017)		1.0019 (0.0021)	1.0028 (0.0018)	1.0027 (0.0018)
Second_firm			1.2846 (0.3000)			
Third_firm			0.7663 (0.1922)			
Numberfirms_cumul				1.0051 (0.0136)		
HHI_SEP					1.9906*** (0.3400)	
HHI_rel_patents						1.5523** (0.2670)
Innovation Intensity	1.4120 (0.5402)	1.4289 (0.5468)	1.4030 (0.5368)	1.4297 (0.5469)	1.3688 (0.5232)	1.3893 (0.5298)
Technology Gap	1.0344 (0.1238)	1.0235 (0.1231)	1.0362 (0.1239)	1.0241 (0.1231)	1.0347 (0.1238)	1.0364 (0.1242)
Forward References	1.0104*** (0.0034)	1.0103*** (0.0034)	1.0104*** (0.0034)	1.0103*** (0.0034)	1.0100*** (0.0033)	1.0668*** (0.0034)
Backward References	0.9884*** (0.0035)	0.9885*** (0.0034)	0.9885*** (0.0035)	0.9885*** (0.0034)	0.9886*** (0.0034)	0.9886*** (0.0034)
Change of referenced standard	1.2731*** (0.0329)	1.2710*** (0.0328)	1.2731*** (0.0331)	1.2713*** (0.0327)	1.2685*** (0.0326)	1.2683*** (0.0325)
Year	0.9633*** (0.0099)	0.9620*** (0.0099)	0.9631*** (0.0099)	0.9620*** (0.0099)	0.9622*** (0.0100)	0.9610*** (0.0099)
N	36,179	36,179	36,179	36,179	36,179	36,179
Subjects	4,671	4,671	4,671	4,671	4,671	4,671
Failures	1,709	1,709	1,709	1,709	1,709	1,709
Wald Chi2	134.21	137.95	133.47	138.96	156.26	147.04
Log-likelihood	-5,361.56	-5,360.31	-5361.07	-5360.23	-5354.47	-5357.80
Proportional Hazard Test †	10.46 (0.1639)	10.54 (0.2293)	13.14 (0.1564)	13.03 (0.1613)	12.07 (0.2092)	11.93 (0.2173)

Robust standard errors (adjusted for 3,551 clusters) in parentheses
Stratified by SSO, ICS class, version number, cohort, prior accreditation, pages range
***, ** and * indicate statistical significance at 1%, 5% and 10% respectively
† chi2 value, confidence level at which the Proportional Hazard assumption is rejected in parentheses

Table 1: *Results (hazard ratios) of the multivariate Cox regressions on the version level*

Table 2

	M10	M11	M12	M13	M14	M15
Model/ Variable Name	Logit Regression‡	Cox Regression	Cox Regression	Cox Regression	Cox Regression	Cox Regression
SEP_ Dummy	0.4291** (0.1670)	0.4815** (0.1499)	0.8207 (0.2622)	0.6603 (0.2613)	0.5777* (0.1871)	0.5038* (0.1861)
Second_firm			0.1938*** (0.1223)			
SEP_cumul	0.9626 (0.0353)			0.9956 (0.0105)	0.9791 (0.0275)	0.9863 (0.0225)
Numberfirms_cumul				0.9308 (0.0847)		
HHI_SEP						5.4216** (3.7481)
Insider_standard_focus						0.5833*** (0.1185)
Innovation Intensity	3.3640* (2.4492)	2.9715 (1.9698)	3.2191* (2.1562)	3.0172* (2.0034)	6.4361** (4.6853)	3.0094* (1.9964)
Technology Gap	0.9912 (0.1742)	1.6707*** (0.1316)	1.6615*** (0.1297)	1.6684*** (0.1303)	1.2022 (0.2079)	1.6808*** (0.1310)
Forward References	0.9424*** (0.0181)	0.9756 (0.0173)	0.9741 (0.0172)	0.9744 (0.0175)	0.9710 (0.0197)	0.9746 (0.0158)
Year	0.9908 (0.0233)	0.9941 (0.0306)	0.9916 (0.0307)	0.9943 (0.0307)	0.9935 (0.0299)	0.9955 (0.0306)
Change of referenced standard	1.2072*** (0.0765)	1.5891*** (0.0976)	1.5987*** (0.0980)	1.5999*** (0.0997)	1.6076*** (0.0958)	1.5998*** (0.0975)
Backward References	0.9899 (0.0081)	0.9846 (0.0125)	0.9867 (0.0122)	0.9846 (0.0126)	0.9850 (0.0122)	0.9855 (0.0123)
Ulterior Accreditations	0.9154** (0.0349)	0.9914 (0.0293)	0.9930 (0.0293)	0.9937 (0.0292)	0.9893 (0.0300)	0.9929 (0.0291)
Version age	1.2342*** (0.0919)				1.3011*** (0.1243)	
Position	0.8735 (0.1050)				1.7702*** (0.2749)	
Number pages	0.9985* (0.0008)					
ICS width	2.1443 (1.0036)					
N	1,399	33,380	33,380	33,380	33,380	33,380
Subjects		3,529	3,529	3,529	3,529	3,529
Failures		345	345	345	345	345
Wald Chi2	266.2	112.71	115.73	113.91	118.99	121.11
Log-likelihood	-538.749	-913.408	-909.991	-911.715	-906.611	-909.764

Proportional Hazard Test †	25.28 (0.0014)	26.02 (0.0020)	29.97 (0.0009)	37.42 (0.0001)	28.94 (0.0023)

Robust standard errors (adjusted for 3,529 clusters) in parentheses
Cox Models are stratified by SSO, ICS class, version number, cohort, prior accreditation, pages range
***, ** and * indicate statistical significance at 1%, 5% and 10% respectively
† chi2 value, confidence level at which the Proportional Hazard assumption is rejected in parentheses
‡ SSO and technology field dummies included but not reported

Table 2: *Results (odds ratios and hazard ratios) of the multivariate Logit and Cox regressions.*

Table 3

SEP_dummy	Indicates that a standard has received at least one patent declaration by this year	Time-variant
SEP_dummy_tinv	Indicates that a standard has received at least one patent declaration up to 2010	Time-invariant
SEP_cumul	Cumulative count of patents declared up to (including) this year	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	Computed Herfindahl–Hirschman Index on the distribution of SEP ownership between firms.	Time-variant
HHI_rel_patents	Computed Herfindahl–Hirschman Index on the distribution of standard relevant patents on standard setting firms' patent portfolios.	Time-variant
Insiders_standard_ Focus	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 standard	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	Dummy variable indicating that Referencesafter4 is bigger than 0	Time invariant
Ulterior accreditations	Cumulative count of the number of accreditations by other SSOs after release of the standard at the sample SSO	Time-variant
Prior accreditations	Count of the accreditations by other SSOs before the release of the standard at the sample SSO	Time-invariant*
National Standard	Indicates that the standard was not first developed at the sample SSO (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 3: *Definition of variables*

Table 4

Probit regression				Number of observations:	8,811
				LR chi2(55):	827.66
				Prob >chi2:	0.0000
Log Likelihood:	-1,268.27			Pseudo R2:	0.2460

Variable	Coef.	Std. Error	Z	Pr>|z|	95% Confidence Interval	
Number pages	0.00235	0.00024	9.80	0.000	0.00188	0.00282
Referenced (after 4 years)	0.52343	0.06893	7.59	0.000	0.38833	0.65852
Number References (after 4 years)	0.00607	0.00153	3.97	0.000	0.00307	0.00907
First release year	0.00461	0.00678	0.68	0.497	-0.00868	0.01789
Release year	0.06507	0.00924	7.04	0.000	0.04696	0.08318
IEC	-2.05309	0.19935	-10.30	0.000	-2.4438	-1.66237
ISO	0.11927	0.13725	0.87	0.385	-0.14973	0.38828
JTC1	-1.03688	0.14080	-7.36	0.000	-1.31285	-0.76091
IEEE	-1.01604	0.11487	-8.85	0.000	-1.24118	-0.79090
ITU-R	0	(omitted)				
ITU-T	0	(omitted)				
Constant	-141.3017	14.07144	-10.04	0.000	-168.881	-113.722

32 ICS-class dummies included not reported

Table 4: *Probit regression model used for calculating the propensity scores (version level)*

Table 5

Pstrata	SEP_dummy_tinv		Total
	0	1	
1	1,467	1	1,468
2	1,462	7	1,469
3	1,455	13	1,468
4	1,434	35	1,469
5	1,390	78	1,468
6	1,185	284	1,469
Total	8,393	418	8,811

Table 5: *Standard versions with and without SEPs, by strata*

Table 6

Pstrata	SEP_dummy_tinv		Total
	0	1	
1	1,140	0	1,140
2	1,130	10	1,140
3	1,126	15	1,141
4	1,113	27	1,140
5	1,092	48	1,140
6	959	182	1,141
Total	6,560	282	6,842

Table 6: *Standards with and without SEPs, by strata*

Table 7

SEP	Events	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5	Strata 6	Total
Y	obs.	1	2	4	16	41	156	220
	exp.	0.11	2.86	5.53	9.56	24.51	98.6	141.18
N	obs.	734	747	578	491	456	417	3,423
	exp.	734.89	746.14	576.47	497.44	472.49	474.4	3,501.82
Chi2		7.7	0.28	0.45	4.64	12.31	43.35	54.07
Prob. Chi2=0		0.0055	0.5968	0.5008	0.0312	0.0005	0	0

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

Table 8

SEP	Events	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5	Strata 6	Total
Y	obs.	.	2	0	1	5	8	16
	exp.	.	2.52	2.23	5.22	4.81	21.13	35.91
N	obs.	348	319	228	196	98	117	1,306
	exp.	348	318.48	225.77	191.78	98.18	103.87	1,286.09
Chi2		0.00	0.11	2.36	3.59	0.01	9.92	12.66
Prob. Chi2=0		.	0.7345	0.1247	0.0582	0.9290	0.0016	0.0004

Table 8: *Log-rank tests of equality of standard survival functions*
Standards including and not including patents, by strata, within strata

Table 9

	M7	M8	M9
Model/ Variable Name	Competing risk Cox Regression	Competing risk Cox Regression	Competing risk Cox Regression
SEP_ Dummy	2.1716*** (0.2072)	1.7723*** (0.2241)	1.8347*** (0.2314)
HHI_SEP		1.7919*** (0.3412)	
HHI_rel_patents			1.6180** (0.3200)
SEP_cumul	1.0027*** (0.0008)	1.0031*** (0.0008)	1.0030*** (0.0008)
Innovation Intensity	0.4738** (0.1395)	0.4794** (0.1408)	0.4754** (0.1404)
Technology Gap	1.1918** (0.0921)	1.1802** (0.0910)	1.1906** (0.0921)
Forward References	1.0109*** (0.0020)	1.0107*** (0.0020)	1.0108*** (0.0020)
Year	1.0038 (0.0131)	1.0040 (0.0131)	1.0035 (0.0131)
Change of cited	1.1550*** (0.0253)	1.1541*** (0.0252)	1.1549*** (0.0252)
Backward References	0.9915** (0.0042)	0.9914** (0.0041)	0.9911** (0.0041)
Accredited	0.9977 (0.1077)	1.0005 (0.1079)	0.9984 (0.1073)
Number pages	1.0013*** (0.0002)	1.0013*** (0.0002)	1.0013*** (0.0002)
ICS_width	1.2143 (0.1694)	1.1898 (0.1666)	1.1931 (0.1664)
N	25,195	25,195	25,195
Subjects	2,979	2,979	2,979
Failures (upgrades)	811	811	811
Comp. events (replacements)	286	286	286
Wald Chi2	307.33	319.61	316.03
Log-likelihood	-6,122.47	-6,117.63	-6,119.09

Robust standard errors (adjusted for 3,551 clusters) in parentheses
Stratified by SSO, ICS class, version number, cohort, prior accreditation, pages range
***, ** and * indicate statistical significance at 1%, 5% and 10% respectively

Table 9 *Results (subhazard ratios) of the competing risk regression*