Essential Patents and Standard Dynamics

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Abstract

This paper examines the impact of essential patents on standardization and in particular the influence of patents on the rate of standard replacement. We investigate whether essential patents contribute to a "lock in" of outdated standards, or rather encourage investment and increase the pace of standardization. Building upon a comprehensive dataset of over 6.000 different standards and nearly 20.000 standard versions in the field of ICT, we evidence essential patents to reduce the likelihood of standard replacement. We further show that this effect takes place in the first years when the standard is issued. On the other hand declarations of essential patents increase the likelihood of version replacement. We argue that these version upgrades do not entail replacement of standard components. The effect on versions rather represents the rate of a firm's investment in standardization, while a longer standard survival in early years reflects a stabilizing effect of patents to agree on a common technology.

Keywords: standard dynamics, essential patents, excess inertia and excess momentum

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1. Introduction

The number of patents declared essential to technological standards has sharply increased over the last years (Simcoe, 2005). Essential patents are patents that are necessarily infringed by any implementation of the standard. Owners of essential patents therefore have property rights that allow them to impede the adoption of a standard. The rise in the number of these essential patents may thus have a direct impact on standardization and its main objectives, for instance to encourage the wide adoption of a technology and to create a common, generalized technological interface.

While there have been several recent contributions shedding light on the driving factors of the increasing number of essential patents (Simcoe, 2005; Baron & Pohlmann, 2010), there have been less advances on the consequences of this evolution for standardization. Several contributions raise the concern that the high number of patents could hamper standardization processes (Shapiro, 2001) and slow down issuance of new standards. Nevertheless, it is important to also see the potential benefits of essential patents in addressing inefficiencies in the collective investment into a standard. Allowing standard setting firms to include their proprietary technology into technological standards may indeed be an important incentive for firms to increase their investment in standardization. As a result, essential patents may actually accelerate the pace of standardization. It is the aim of this article to have a more comprehensive understanding of these mechanisms.

We examine empirically the effect of patents on standard replacement. We thereby build upon the nascent literature on the dynamics of standards (Egyedi and Heijnen 2005, Blind 2007, Blind and Egyedi 2008). In our analysis, standard dynamics face a tension between responding to an advancing state of the art, subject to innovation, and ensuring the main function of standardization, which is to fix a stable technological basis for implementation and new applications.

Standard replacement induces costs for standardizing firms (standardization costs) and for users of the standard (switching cost for implementers of the new standard, loss of network effects for users of the old standard), but is likely to improve the technology incorporated in the standard. In many cases, standardizing firms can choose between replacement and upgrade of the standard. While a standard upgrade only adds technological components to an existing standard, standard replacement also replaces existing components. Only replacement allows fully integrating the advances in the state of the art, while standard upgrades are less costly for standard users. Based upon these insights, we investigate the rates of upgrade and replacement of standards including essential patents, as compared to other standards.

We rely upon a comprehensive database of ICT[4] standards released from 1992 to 2010 obtained from the international standards database PERINORM[5]. The database is limited to formal, international standards issued according to a comparable set of rules[6]. This dataset includes over 6.000 different standards and nearly 20.000 standard versions. These observations are richly informed in technical characteristics. We match the standards in our sample to a comprehensive database of patents declared essential. We furthermore match ICS classes of standards to IPC[7] classes based upon the declared essential patents[8] and inform for each standard class the speed at which the state of the art evolves, as measured by the number of patent files in the field.

We estimate the survival rate of standard versions with tools of time-to-event analysis. We focus upon two types of events: standard replacement and standard upgrade (replacement of a standard version by a new version of the same standard). Standards including essential patents have a higher hazard rate of standard upgrade, but a lower hazard rate of standard replacement. We interpret the first findings as indicating higher investment into the standard. Standardizing firms invest more in the standard if they own essential patents, as they internalize larger parts of the incremental benefits of standard upgrading. Consistently, the positive effect of essential patents increases with the number of patents. The second finding indicates that essential patents increase inertia in standardization.

The remainder of this article is organized as follows. In the second section, we sketch a simple analytical framework of standard dynamics. In the third and fourth section, we present our empirical methodology and sampling methods. In the fifth part, we present the results of a descriptive analysis of the database; and the sixth part includes the results from econometric analysis. The seventh part sketches the paths for further research and concludes.

[4] According to the ICS (international classification of standards) standards classified as 33 (telecommunications, audio and video engineering) and 35 (information technology, office machines) represent all standards of ICT (information and telecommunication) technologies. As to Baron and Pohlmann (2011) 98 % of all essential patents can be found in ICT standards (ICS classes 33 and 35).

[5] PERINORM is a bibliographic database of formal standards and is updated by DIN, AFNOR and BSI.

[6] We used standards issued by all SSOs (Standard Setting Organizations) that are compliant with a general set of rules and publish their standards in the international standards database PERINORM. SSOs: ISO, IEC, JTC1, ISO, IEC, CEN/CENELEC, ITU-T, ITU-R, and IEEE.

[7] International Patent Classification

[8] Companies declare their essential IPR to public available databases of the relevant SSO. We captured over 8.000 patent declarations and matched them to the relevant standards of our sample.

2. Analytical Framework

We propose an analytical framework, in which we sketch some basic arguments on the driving forces of standard dynamics. We conceptualize standard dynamics as the timing of standard renewal. Standard renewal is costly, as it generates costs for standardizing firms and for implementers. Nevertheless, technological progress generates new opportunities, and the existing standard may not allow for fully exploiting these opportunities. Efficient standard dynamics thus strike the balance between the discrete costs of standard renewal and the opportunity cost of using outdated technology.

Standard renewal can take the form of an upgrade, which is the replacement of a standard version by a new version of the same standard. In this case, new technological components are added to the standard without replacing the existing ones. Furthermore, the different versions of the same standard are generally compatible among each other. Therefore, even though costly for standardizing firms, standard upgrades do not generate substantial implementation costs. Nevertheless, standard upgrades may not be able to fully integrate the advantages of new technological innovations. Therefore, standard renewal can take the form of standard replacement. When a standard is replaced, existing technological components of a standard are replaced by new technologies. Standard replacement may generate substantial costs for implementers, especially as the new standard may not be fully compatible with the old standard. Users of the former standard may thus be forced to implement the new standard in order to avoid the loss of network effects (stranding). If standard replacement occurs too frequently, it deteriorates the welfare of standard users.

Essential patents can have an impact on these standard dynamics for various reasons. For instance, we focus upon three distinct theoretical arguments. First, we argue that standardization is a costly private investment in a public good and therefore entails free riding by standard takers. Due to this externality, standard makers invest too little in standardization and consequently renew standards less frequently than what would be socially optimal. Strong IPR on standardized technology can help overcoming this inertia, as patent holders have a stronger private interest in renewing the standard version if they can recoup the standardization cost through licensing fees. The incentive to regularly upgrade a standard is particularly strong for owners of essential patents when the technological evolution in the sector generates pressure for standard renewal. In order to avoid standard replacement and the loss of exclusionary power over the standard, owners of essential patents can regularly invest in improving the standard through upgrades, which add technological components without replacing the existing ones.

Second, essential patents on formal standards can generate conflicts between standard makers regarding the shares of proprietary technology covered by the standard. In the literature on vested interests (Farrell and Simcoe, 2009; Simcoe 2011), it is argued that because of patent protection, standardizing firms have a stronger preference for their own preferred technological solution. Therefore essential patents can lead to a time-consuming « war of attrition » in building consensus on a new standard. If standardizing firms need to build consensus for a standard replacing an existing one, they will furthermore face a conflict of interests between sponsors of the existing standard and owners of patents on technological components to be included. "Winners" of a standard replacement need to compensate the "losers", who have otherwise a strong power to impede or at least delay standard renewal. Such a bail-out might be particularly difficult when the turnover in essential technology is high and when the contacts between standard makers are loose.

Thirdly, innovation in network industries can generally generate excessive inertia (lock in of existing technologies) or excessive momentum (too frequent replacement, generating welfare losses for standard users forced to implement the new versions in order to stay in a network). For instance, network effects can generate inertia when users of a technology fail to coordinate on switching to a superior vintage. The pace of standardization has been analyzed from the angle of excess inertia or excess momentum with respect to the social optimum (Farrell and Saloner, 1986). For example Clements (2005) finds that the incentives of an owner of a proprietary standard to have its standard adopted deviate from what would be socially optimal. The problem of excessive momentum may be particularly severe when a standard is embedded in a network of standards. If other standards or more generally new technologies are built upon an existing standard, the social cost of replacing the central standard increases. It is therefore important for a standard to be perceived as a stable technological basis in order to encourage implementation and downstream investment. In this case, essential patents can signal the stability of a standard vintage and encourage standard implementation.

3. Empirical methodology

We implement our analytical framework using a comprehensive database of international ICT standards drawn from PERINORM. We chose to include in our sample all ICT standards (ICS classes 33, 35, and 37) issued by the main formal international SSOs (CEN, CENELEC, ITU-R, ITU-T, IEEE, ISO, IEC, JTC1). We did not include ETSI or informal SSOs, in order to concentrate upon standards issued according to comparable rules. We restrict the analysis to standards issued from 1990 to 2006, and we observe these standards until 2010. Standard versions that are still valid in 2010 are therefore right-censored. Draft standards, amendments and errata documents are excluded from the quantitative analysis. Overall, our sample comprises 6.296 standards, 18.476 standard versions and 50.883 version-year observations (47.931 observations for finalized standards).

For every standard version, the database gives precise dates of release and drawback. We can thus easily obtain the survival time, and the survival rate period by period, of standard versions. PERINORM also informs whether a standard version is replaced by a new version of the same standard, whether the standard is replaced by a new standard, or whether the standard is withdrawn without a direct successor. We have thus three different events: standard upgrade (replacement by a new version), standard replacement (replacement by a new standard), and standard phase-out (drawback without replacement). A standard version is at any time under competing risk of upgrade, replacement or phase-out. We can investigate the effects of our explanatory variables on the hazard rates of the different events using duration analysis. In this first simple analysis, we will proceed in two steps. In a first step, we investigate the hazard rate of any kind of drawback of a standard version. In a second step, we investigate the hazard rate of a standard replacement, i.e. the replacement of a standard version by a different standard. We thus analyze the lifetime of a standard version, beginning with release, and ending with replacement by either a new version, or a different standard (or not ending at all during the time of observation).

The standards in our sample are matched to the database of essential patents in order to obtain the explanatory variable. First, we identify the almost 700 formal standards for which there has been at least one declaration of essential patents. Overall, there are more than 8.000 patent declarations for the standards included in our sample. We can infer from our declaration data the number of patents claimed to be essential for the different standards in our sample. The patent declaration database generally informs the date of declaration, so that we can match each essential patent to its relevant standard at any time from the year of declaration. Patent declarations for which the date could not be informed have not been taken into account.

As explained in our analytical framework, we expect that standard renewals are determined by an evolving state of the art on one hand, and substantial discrete standardization and adoption costs on the other hand. We approximate the evolution of the state of the art using information drawn from essential patents. Building upon Baron and Pohlmann (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 (International Classification of Standards) classes. Thus we can inform for each standard on a relatively disaggregate level the speed at which the state of the art evolves. In future analysis, the robustness of this matching and the sensibility of results to the use of different matching methodologies will have to be analyzed.

From PERINORM, we can furthermore draw a broad range of variables regarding standard characteristics. We use information on the issuing SSO, the technology as indicated through the ICS classification, the breadth of the technological scope, approximated through the number of ICS classifications, the number of pages, standard modifications, references among standards and accreditations of standards by other SSOs, including but not restricted to the major international SSOs we use in our analysis. We inform also accreditations of the standard that have taken place before standard release (backward accreditations), when the standard has not been first issued by one of the SSOs we observe (for example if a national standard is accredited on international level). Just as for patent declarations, standard modifications, references from other standards (forward references) and accreditations by other SSOs (forward accreditations) are matched to the panel cumulatively for each time after occurrence. References to earlier standards (backward references) and backward accreditations are constant over the life-time of a standard version.

We include these variables in order to control for key factors of standardization dynamics. The SSO of issuance is important for standardization procedures, and it has an impact on the cost of standardization. We do not want to impose that the effect of the issuing SSO is linear over time. Therefore, all our results are based upon stratified analysis, estimating the baseline hazard rate individually for each SSO. We also expect the cost of standardization to depend upon the amount of codified technological content, approximated through the number of pages (Blind, 2007). Adoption costs faced by implementers are heavily dependent upon the technological field, so that controlling for ICS classes is important. Once again, we allow for non-linear effects using stratified analysis. Forward references and accreditations also are likely to increase the cost of standard renewal, as changes in the central standard can require changes in the refereeing standard, and the accreditations need to be renewed.

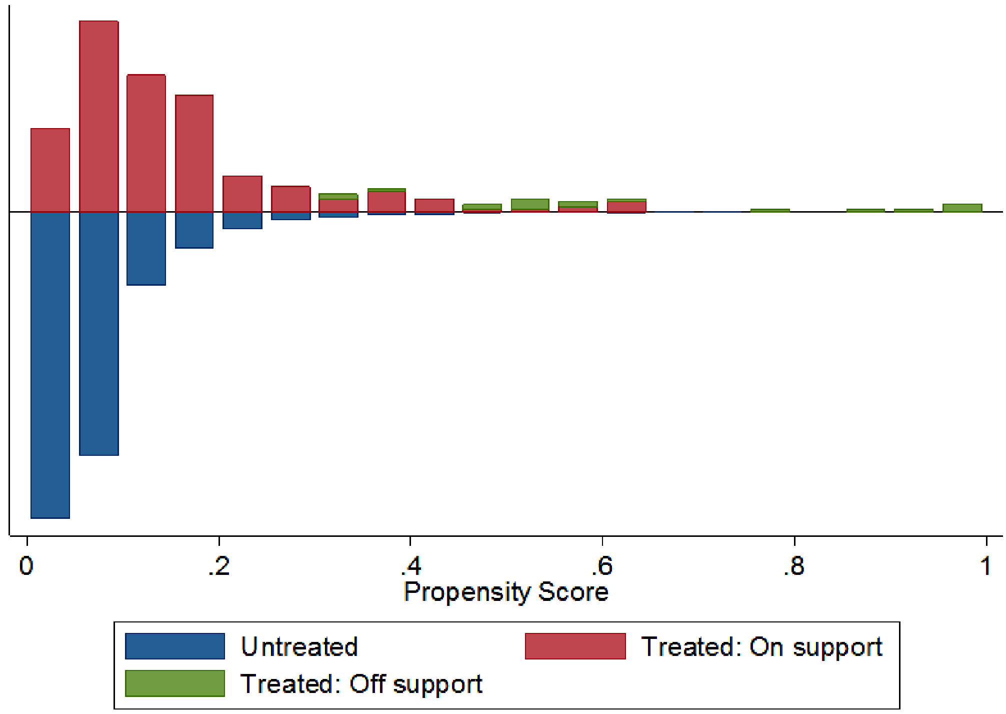
On the other hand, the pressure for renewal presumably increases with standard modifications, references to earlier standards, earlier accreditations and the technological scope. Standard modifications evidence shortcomings of the standard or the occurrence of technological or economic events requiring an adaptation of the standard to its technological environment. References to earlier standards are important for standard renewal, as each renewal of a referenced standard induces pressure for renewing also the refereeing standard. This is the same argument for which we suppose that forward references increase the social cost of standard renewal. Similarly, the number of earlier accreditations indicates the number of SSOs that are likely to produce changes to the standard. Finally, the likelihood of a drastic innovation on a standardized technology increases with the breadth of the technological scope.

4. Sampling

It is the objective of our analysis to compare standards including essential patents with the other standards. However, essential patents are not randomly distributed over the standards in ICT. For instance, essential patents play a much greater role in some technological fields than in others. Furthermore, it can be argued that institutional factors relating to the issuing SSO can encourage or inhibit declarations of essential patents. But also the year of issuance, the size, the technological scope, the international dimension and the novelty of the technological content of the standard are all likely to play a role in explaining which standards include proprietary technology. Many of these factors are also likely to have an impact on the duration until standard upgrade and replacement.

We therefore have to be careful when comparing standards including essential patents with the remainder of the sample. Any differences in the hazard rate between these groups of standards can be either due to a consequence of patents, or to characteristics of standards that more likely include essential patents. In order to disentangle these two sources of difference, we carry through a propensity score matching based upon a broad range of observable standard characteristics. We apply a very strict matching restricted to the next neighbors in propensity score. We impose a maximum propensity score difference of 0.03, thus also eliminating some observations of standards including essential patents. Figure 1 sketches the distribution of propensity scores in the samples of standards with and without essential patents and indicates the observations eliminated because of the absence of a sufficiently close neighbor.

Figure 1:



We can thus construct a sample of standards that have, based upon observable characteristics, the same propensity to include essential patents than those that actually include such patents. If standards including patents behave differently than the standards in this control sample, this difference is not due to observable factors such as the characteristics of a technological field or SSO policies. We can on the other hand not rule out that there is an unobservable common factor affecting the likelihood of a standard to include essential patents and the survival of this standard and its versions. This is particularly true for the various aspects relating to the commercial relevance of a standard. Our interpretation of the findings will have to take this limitation into account.

Table 1 provides descriptive statistics on the main standard characteristics in the samples of standards including and not including essential patents; both before and after propensity score matching. We can see that there are significant differences between the samples of standards with and without patents, most importantly with respect to the technological field (ICS class) and the issuing SSO. After propensity score matching, there are no remaining significant differences between characteristics of the standards in the two samples.

Table 1: Sample statistics

Variable	Sample	Mean Treated	Mean Control	%bias	%reduct |bias|	t-test t	t-test p>|t|
patented	Unmatched	1	0	.		.	.
	Matched	1	0	.	.	.	.
backwardci~s	Unmatched	7.4306	6.7001	7.5		1.14	0.254
	Matched	7.3333	8.5376	-12.3	-64.9	-1.31	0.191
backwardci~g	Unmatched	32.394	30.26	3.7		0.53	0.596
	Matched	31.863	39.556	-13.3	-260.4	-1.42	0.157
older_family	Unmatched	.13523	.1341	0.3		0.05	0.962
	Matched	.1362	.1147	5.2	-1802.1	0.60	0.548
numberpages	Unmatched	106.27	54.742	41.0		8.19	0.000
	Matched	99.419	116.6	-13.7	66.7	-1.28	0.200
icswidth	Unmatched	2.0961	2.1571	-2.3		-0.36	0.719
	Matched	2.1004	2.1434	-1.6	29.5	-0.19	0.853
iec	Unmatched	.03203	.13583	-38.1		-5.02	0.000
	Matched	.03226	.02509	2.6	93.1	0.51	0.613
ieee	Unmatched	.14235	.06273	26.4		5.09	0.000
	Matched	.1362	.14695	-3.6	86.5	-0.36	0.716
iso	Unmatched	.08541	.09151	-2.1		-0.34	0.732
	Matched	.08602	.09319	-2.5	-17.5	-0.30	0.767
itur	Unmatched	0	0	.		.	.
	Matched	0	0	.	.	.	.
itut	Unmatched	.5089	.4354	14.7		2.39	0.017
	Matched	.51254	.47312	7.9	46.4	0.93	0.353
jtc1	Unmatched	.23132	.27453	-9.9		-1.57	0.117
	Matched	.23297	.26165	-6.6	33.6	-0.78	0.433
ics33020	Unmatched	.02491	.05065	-13.5		-1.93	0.054
	Matched	.02509	.01792	3.8	72.1	0.58	0.560
ics33040	Unmatched	.21352	.21583	-0.6		-0.09	0.928
	Matched	.21505	.20789	1.7	-211.1	0.21	0.836
ics33050	Unmatched	.01068	.01237	-1.6		-0.25	0.803
	Matched	.01075	.01792	-6.7	-322.2	-0.71	0.477
ics33060	Unmatched	.02491	.00835	13.0		2.74	0.006
	Matched	.02509	.02151	2.8	78.4	0.28	0.779
ics33080	Unmatched	.09253	.11942	-8.7		-1.35	0.178
	Matched	.09319	.06452	9.3	-6.6	1.26	0.210
ics33160	Unmatched	.07829	.03827	17.1		3.25	0.001
	Matched	.07885	.10394	-10.7	37.3	-1.03	0.305
ics33170	Unmatched	.02847	.01842	6.6		1.18	0.237
	Matched	.02867	.03584	-4.7	28.7	-0.48	0.633
ics33180	Unmatched	.02491	.0895	-28.1		-3.75	0.000
	Matched	.02509	.02151	1.6	94.5	0.28	0.779
ics35040	Unmatched	.19929	.16604	8.6		1.43	0.152
	Matched	.20072	.22581	-6.5	24.5	-0.72	0.470
ics35060	Unmatched	.01779	.01381	3.2		0.54	0.586
	Matched	.01792	.02867	-8.6	-170.1	-0.84	0.401
ics35080	Unmatched	.00356	.00662	-4.3		-0.62	0.536
	Matched	.00358	.01075	-10.1	-134.3	-1.00	0.316
ics35100	Unmatched	.06406	.09468	-11.3		-1.71	0.088
	Matched	.06093	.05376	2.7	76.6	0.36	0.716
ics35110	Unmatched	.08897	.08201	2.5		0.41	0.684
	Matched	.08244	.08961	-2.6	-3.1	-0.30	0.763
ics35140	Unmatched	.00712	.00374	4.6		0.86	0.388
	Matched	.00717	0	9.7	-112.3	1.42	0.157
ics35160	Unmatched	.02491	.03194	-4.2		-0.65	0.516
	Matched	.02509	.01434	6.5	-52.9	0.91	0.362
ics35180	Unmatched	.02491	.00374	17.9		4.70	0.000
	Matched	.02509	.00717	15.1	15.3	1.68	0.093
ics35200	Unmatched	.07829	.05755	8.2		1.42	0.156
	Matched	.07885	.06093	7.1	13.6	0.83	0.407
ics35220	Unmatched	.00712	.0023	7.0		1.51	0.132
	Matched	.00717	0	10.5	-48.9	1.42	0.157
ics35240	Unmatched	.20641	.15942	12.2		2.05	0.040
	Matched	.20789	.1828	6.5	46.6	0.75	0.456
ics37060	Unmatched	.02135	.00115	19.2		6.35	0.000
	Matched	.02151	.02151	0.0	100.0	0.00	1.000
newfirstre~e	Unmatched	14470	13903	28.2		4.45	0.000
	Matched	14472	14791	-15.9	43.7	-2.00	0.046

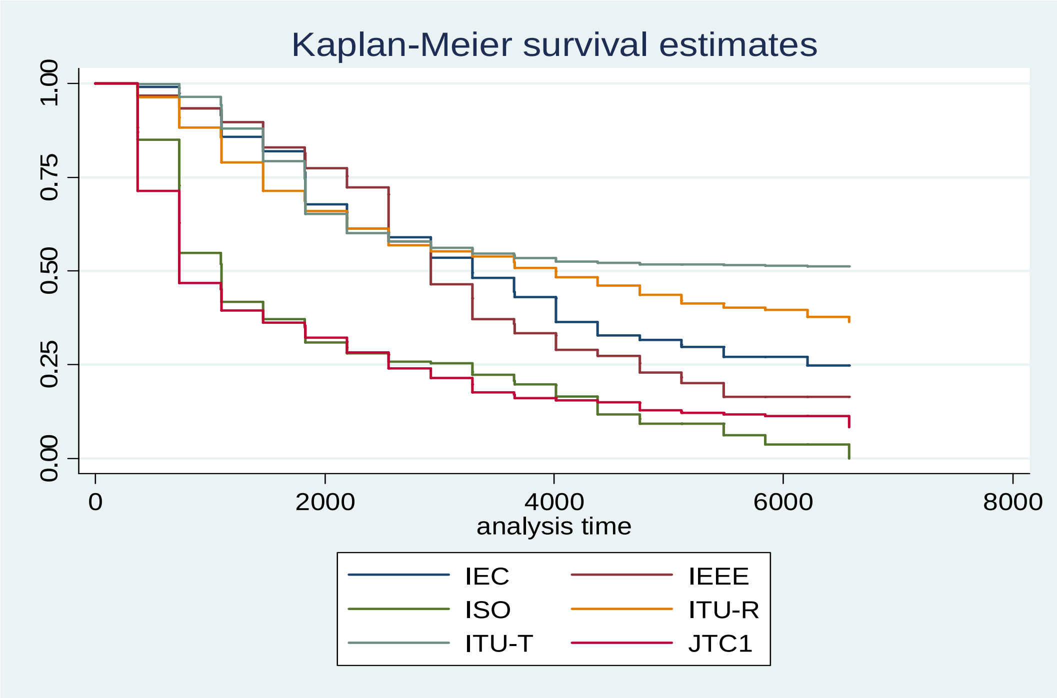
The average standard version is active for 3.5 years. The average standard lasts just a bit longer, 3.72 years. It has to be noticed that this information is right-censored. This information has been retrieved in November 2010; standards still active at that time are not considered for calculating the average survival time. While 11.047 standard versions have been withdrawn, only 8.336 of these versions belong to standards that have been replaced. As the period of observation is relatively short, average survival times are not informative, especially with respect to the survival of the whole standard. Even for a first descriptive analysis of standard replacement, it is therefore preferable to rely upon the tools of duration analysis.

We will thus present stylized facts on the dynamics of standard and version replacements in our samples. We further present statistics on version replacement, i.e. the replacement of a version by another document, either a new version of the same standard, or a different standard.

5. Descriptive Analysis

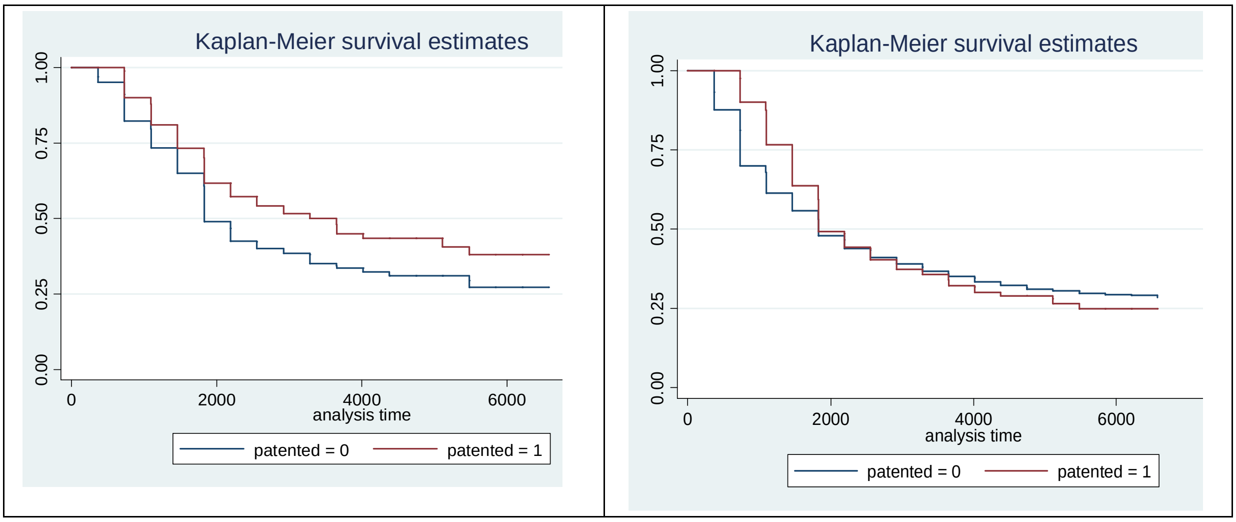
Figure 2 presents the survival estimates of standard versions by SSOs. Survival estimates are the likelihood that an observation will "survive" for a specific time. At each time, only observations that have been observed are taken into account. The following statistics are therefore not subject to truncation problems. These survival estimates furthermore only take into account finalized standards, and exclude drafts, errata and modifications. Version survival rates differ strongly between the different SSOs. For example, less than half of the JTC1 standard versions are active for more than 3 years, while this is true for well above 90% of ITU-T standard versions. These differences need to be explicitly addressed in the following econometric analysis.

Figure 2:



The following figure 3 shows the evolution of the survival rate of version replacement over time, comparing standards including patents with appropriate matches (Figure 3a) and with the overall sample (Figure 3b). The survival rate is the likelihood that a limiting event, such as replacement in our case, has not yet occurred at a certain point in time. Figure 3a shows that the survival rate of standard versions is higher for standards including patents than comparable matches at any time, but that the hazard rate evolves similarly over time for both groups of standards. Figure 3b shows that, in comparison with the overall sample of ICT standards, versions of standards including essential patents have first a higher, and then a lower survival rate. This indicates that the likelihood of an early replacement is lower for this group, but that the likelihood of a replacement occurring in a relatively long time span (about ten years) is higher than for other ICT standards.

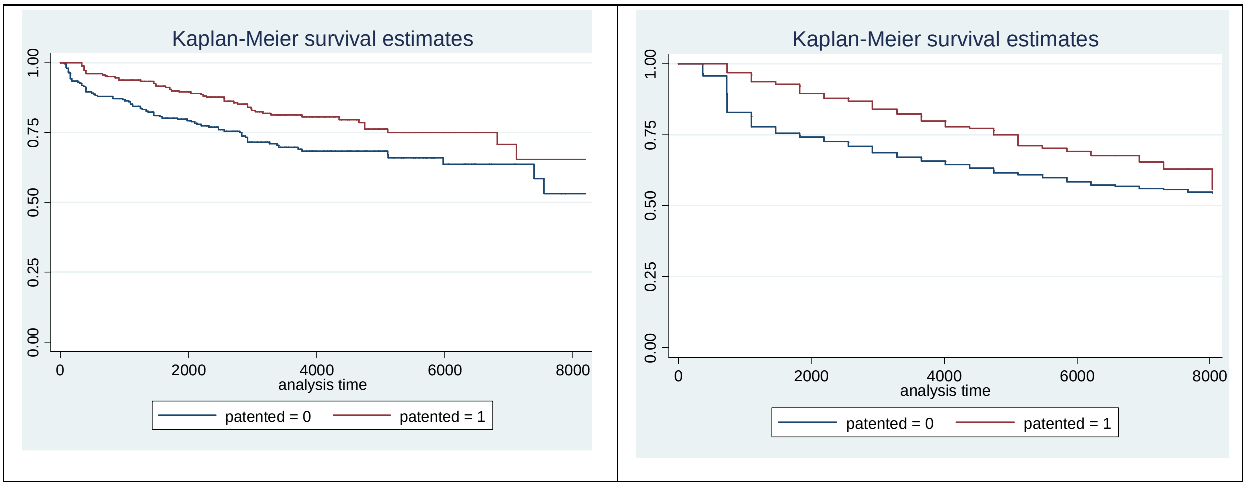
Figure 3:



As discussed in the methodological section, we have aggregated standard versions to standard observations. We can also run survival analysis on these standard observations, considering that standard survival is the time until a standard is replaced by a different standard. Replacement of a standard version by a newer version of the same standard is thus not considered as a limiting event in this statistical analysis. We argued that it is very important to distinguish between a standard upgrade, whereby a version is replaced by an ulterior version of the same standard, and a standard replacement, whereby a standard version is replaced by a different standard. We suppose in our analysis that standard upgrade only adds technological components to an existing standard and never generates costs for implementers, as standard users can continue using the old version without loss of compatibility. By contrast, in a standard replacement, technological components of a standard are replaced, i.e. they are no longer essential for the new standard. Furthermore, standard replacement can be costly for standard users, as the new and the old standard are not fully compatible. Therefore, standard users may be forced to implement the new standard, even though the technological improvements do not justify the adoption costs.

Figure 4 shows the time estimated for a standard to last until standard replacement. The curve is extremely flat in the tail. Therefore, the risk of standard replacement is highest during the first years after the release of a standard version. Only standards issued by ISO and IEEE face a sustained risk of replacement up to 15 years after release. Comparing standards including essential patents with appropriate matches, but also with all ICT standards in our sample, reveals that standards including patents have a higher survival rate. This difference arises in the first years of the lifetime of a standard, and does not cancel out over time. This difference is particularly striking when comparing standards including patents with the overall sample. Indeed, an important number of standards (around 25%) is withdrawn during the first three years after release. This pattern is not verified for standards including patents, and it is less strong for matched standards. Nevertheless, the hazard rate of standard replacement does not seem to be significantly different between the different samples after this initial period.

Figure 4:



In the following Table 2, we corroborate the graphical analysis using statistical tools. For instance, we check whether differences between the different samples of standards are statistically significant and robust to different specifications. For instance, we wish to make sure that standards including patents do not behave differently only because they are mainly issued by specific SDOs, or because they are concentrated in specific technological sectors. Therefore we test for the statistical significance of the differences between the samples also in a stratified analysis, whereby we compare only standards issued by the same SDO or classified into the same ICS class.

Table 2:

	Standard survival				Version survival			
	Comparison with sample		Comparison with PSM matches		Comparison with sample		Comparison with PSM matches	
	Events observed	Events expected	Events observed	Events expected	Events observed	Events expected	Events observed	Events expected
Patented	Log-rank test for equality of survivor function							
0	1901	1850,33	77	60.30	3544	3536,59	184	160,44
1	78	128,67	50	66,70	294	301,41	115	138,56
Chi2/Pr>chi2	22,19	0,0000	8,84	0,0029	0,21	0,6433	8,09	0,0045
Patented	Wilcoxon (Breslow) test for equality of survivor functions							
0	1901	1850,33	77	60,30	3544	3536,59	184	160,44
1	78	128,67	50	66,70	294	301,41	115	138,56
Chi2/Pr>chi2	37,46	0,0000	11,65	0,0006	8,17	0,0043	10,58	0,0011
Patented	Log-rank test, stratified by SDO							
0	1901	1858,17	77	63,35	3544	3577,15	184	168,41
1	78	120,83	50	63,65	294	260,85	115	130,59
Chi2/Pr>chi2	18,25	0,0000	6,31	0,0120	5,32	0,0211	4,05	0,0443
Patented	Log-rank test, stratified by ICS class							
0	1901	1844,33	77	67,67	3544	3538,18	184	173,77
1	78	1347,67	50	59,33	294	299,82	115	125,23
Chi2/Pr>chi2	36,53	0,0000	5,26	0,0219	0,19	0,6611	2,85	0,0915

The statistical tests confirm the graphical analysis. Comparing standards including essential patents with appropriate matches, we notice strongly significant differences in both version and standard survival. Both standards and standard versions including patents face a lower risk of replacement than matched standards. In a comparison with the overall sample, standards including patents also have a higher survival rate. Standard versions have, depending upon the test specification, a higher, a lower or a statistically non-significantly different survival rate.

This descriptive analysis already provides evidence for an impact of essential patents on the survival rate and replacement probabilities of standards and standard versions. It is based upon the hypothesis that standards including essential patents generally face different hazard rates of upgrade or replacement than other standards. In the following multivariate analysis, we will adopt a slightly different approach. We have organized the data into a panel dataset, and information is tracked over time. Most importantly, patents are allowed to have an impact on standard dynamics only after they have been declared. We can therefore estimate how a patent declaration impacts the hazard rate of upgrade or replacement over time. Furthermore, we can now not only distinguish between standards including essential patents and the other standards, but test for the effect of the number of patents declared.

6. Econometric Analysis

It is the aim of this section to evidence an effect of essential patent declarations on the survival of standard versions. We will therefore rely upon semi-parametric survival analysis, using a Cox model. In this methodology, the likelihood of drawback is estimated year by year, conditional upon the fact that the version has not already been withdrawn. The model infers from the data a baseline hazard rate of renewal. This baseline hazard rate is multiplied by the explanatory variables and controls, and the coefficients are estimated in order to match the observed renewal rate. As described in our methodological section, our data are in panel form, meaning that the explained variables, and for instance patent declarations, are fed into the model over time.

We carry through two types of controls. First, we introduce control variables for technological characteristics of the standard, and for instance for the variables mentioned in the methodological part. We therefore construct a large panel of references among standards and accreditations of standards by different SSOs, and feed in the count of references and accreditations over time. Time-invariant standard version characteristics, such as IPC classification, breadth of classification, number of pages, backward references prior accreditations are also taken into account.

Second, we wish to make sure that we really adequately control for two crucial factors: standard renewal dynamics are likely to vary from one SSO to the other, and among technological fields. Introducing dummy variables is not likely to adequately control for these differences: control variables in a Cox model are only allowed to have a linear effect on the survival rate. This means that a control variable can control the idiosyncratic effect of a technological field or SSO when the likelihood of standard renewal is higher or lower by a given coefficient *at any time*. Our descriptive analysis has revealed that renewal rates at some

SSOs (for instance ISO and JTC1) are very high in the first years, and low in the following years. In order to control for this non-linear effect, we propose stratified survival analysis. In stratified survival analysis, the baseline hazard rate is allowed to vary among the strata, but the effect of the explanatory variables is the same in all strata. We stratify alternatively by SSO and ICS class, respectively introducing linear controls for the other factor.

Model 1: Duration analysis of version replacement
Model 2: Duration analysis of version replacement, stratified by ICS class
Model 3: Duration analysis of version replacement, stratified by SSO
Model 4: Duration analysis of standard replacement
Model 5: Duration analysis of standard replacement, stratified by ICS class
Model 6: Duration analysis of standard replacement, stratified by SSO

Table 3:

Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Patent declarations	1.00526 3,58 ***	1.00486 2.50 *	1.00497 3.36 ***	0.95488 -1,37	0. 90231 -2.15 *	0.95707 -1.38
Technology gap	1.02813 1,03	1.01617 0.37	1.01469 0.51	1.06759 1,72	1. 00716 0.12	1.05432 1.34
Backward references	0.99195 -2,15 *	0.99681 -0,76	0.99324 -1.77	0.99085 -1,69	0. 99260 -1.35	0.99132 -1.57
Prior accreditations	1.27398 4,61 ***	1.26894 3.77 ***	1.26152 4.29 ***	1.29090 3.36 ***	1. 23035 2.60 **	1.26028 2.95 **
Breadth of scope (ICS classes)	1.65131 6,15 ***		1.69935 6.32 ***	1.89982 5.54 ***		2.04718 6.14 ***
Number of modifications	1.06301 1.37	1.05608 1.08	1.05969 1.33	0.96388 -0.25	0. 98538 -0.11	0.98394 -0.10
Number of pages	1.00066 2.93 **	1.00015 0.53	1.00066 2.90 **	1.00049 1.83	1.00006 0.20	1.00038 1.40
Forward references	0.99773 -0.90	1.00011 0.03	1.00064 0.23	0.97402 -2.10 *	0. 96266 -2.34 *	0.98016 -1.62
Ulterior accreditations	0.96560 -2.65 **	0.94258 -3.67***	0.96243 -2.84 **	0.91023 -3.82***	0. 84889 -5.86***	0.91574 -3.56***
Year	1.05774 3.68 ***	1.04640 2.49 **	1.06119 3.83 ***	1.00141 0.06	0.97902 -0.71	1.01641 0.63
Standard age	0.99983 -1,22	0.99972 -1.58	0.99989 -0.75	1.00051 2.50 *	1.00020 0.87	1.00057 2.73 **
Standard age squared	1 3,68 ***	1 3.49 ***	1 3.07 ***	1 -2.17 *	1 -0.78	1 -2.37 *
SDO control	YES	YES	n./a.	YES	YES	n./a.
ICS class and	YES	n./a.	YES	YES	n./a.	YES
Position controls	YES	YES	YES	YES	YES	YES
Observations	15386	15386	15386	15386	15386	15386
No. of Subjects	2166	2166	2166	2166	2166	2166
No. of Failures	1054	1054	1054	555	555	555
Log Likelihood	-6933,67		-5460,06	-3402,95	-1914.35	-2734.64
LR chi2	714,68		479,33	954,21	568.87	614.32

On the one hand, the econometric results seem to confirm one of our descriptive findings. Essential patents seem to reduce the likelihood of standard replacement, even though this result is statistically significant only in one of the three models. We have exposed two different theoretical arguments that could explain this finding. In contrast to standard upgrades, standard replacements involve changes that can exclude technological components from a standard. Based upon this argument, we can argue that essential patents on a standard raise the standardizing firms' resistance to radical changes to the standard. This argument is in line with the low rate of standard replacement during the fifteen years following release of a standard version including essential patents, and it seems to corroborate suspicions that essential patents increase inertia of technological standards.

Nevertheless, this increased inertia is potentially beneficial for standard users, as it reduces the cost of implementation. If this argument is true, essential patents could provide a signal to standard users that a standard is less likely to be replaced, and therefore provide important incentives to invest in sunk costs derived from implementation. It is important to notice that the difference between standards including essential patents and the other standards mainly arises in the first years after standard release, and does not increase over time. Essential patents do not seem to lock-in standards for a very long time after release.

On the other hand, we do not corroborate our descriptive finding that standard versions including essential patents have a higher survival rate. Taking into account the timing of patent declaration, and the number of patents declared, declarations of essential patents increase the likelihood of version replacement. We can interpret this result in light of our theoretical analysis. Regular standard upgrades are costly for standardizing firms. Firms are more inclined to accelerate the rhythm of standard upgrade and therefore to reduce the life-time of single standard versions, when the standard involves important commercial stakes. Essential patents could be an additional incentive for firms to invest in standardization, or they can indicate a higher commercial relevance of the respective standard.

The analysis of the control variables reveals that our model is able capture key aspects of our analytical framework. Downstream investment building upon a standard for instance, delays the replacement of a standard version. The accreditation of a standard version by a different SSO significantly delays both version and standard replacement. References from ulterior standards only delay standard replacement. These findings match well our analytical framework and corroborate our hypotheses on the difference between version and standard replacement. While every version replacement is costly for SSOs having accredited a standard (as the new version needs to be accredited again), only standard replacement is problematic for referencing standards building upon a standard, as the referenced technological content remains unchanged in a version replacement. Variables capturing the size and scope of the standard (such as the number of ICS classes and the number of pages), are significantly and positively associated with a higher likelihood of version replacement. The likelihood of replacement also increases with the number of prior accreditations. As discussed, we argue that these variables are related to the number of potential technological events that can require standard replacement.

The highly significant and high coefficients on these variables are however somehow puzzling, as other variables more directly associated to relevant technological changes do not exhibit significant effects. While the effect of the technology gap (the cumulative number of patents filed in the field since the last release, normalized by field and year[9]) on the likelihood of replacement is positive, it is not significant in any model. Also the number of modifications of a standard does not have a statistically significant effect on the likelihood of standard replacement. The results reveal that the driving factors of standard replacement are at this stage not yet very well understood. While our contribution has made some progress on this understanding, robust results on the effects of patents on standard dynamics will also depend upon a solid theoretical and empirical modeling of standard replacement.

7. Conclusion

We have presented an empirical analysis of the effects of essential patents on the duration of standard version activity until replacement. Essential patents reduce the likelihood of standard replacement. A standard including essential patents is therefore less likely to be replaced by a different standard. This effect is consistent with several hypotheses on the effect of patents on standard dynamics. For instance, we have argued that owners of essential patents oppose to changes in the standard that exclude their IPR from the standard.

Nevertheless, we did not find evidence that essential patents induce excessive inertia in standardization. While standard versions including essential patents also have a higher survival rate than other standards, econometric analysis suggests that this difference is not due to a causal effect. Indeed, essential patents seem to have a positive effect on the rate of

[9] We counted all patent files per year and per standard relevant IPC using the EPO Worldwide Patent Statistical Database (PATSTAT).

standard upgrades. We have argued that these standard upgrades do not entail replacement of standard components. This finding suggests that essential patents not only induce standardizing firms to substitute standard upgrades for standard replacements, but also to accelerate the rhythm of standardization. The latter part of the finding can be explained by the cost of standardization: standard changes are costly for standardizing firms, who are unable to internalize all the benefits of the improved standard. Essential patents generate licensing revenue that is dependent upon the value of the standard. They therefore provide incentives for at least some standardizing firms to regularly invest into the standard. Furthermore, regular standard upgrades can be a means of avoiding standard replacement. Indeed, by adding technological components to a standard, owners of essential patents can reduce the competitive pressure from new, alternative technologies.

The descriptive analysis seems not to support concerns of excessive inertia, as the effect of essential patents on standard replacement takes place over the first years after the release of the standard version. Rather than locking in outdated standards, essential patents therefore appear to stabilize standards in an early period, and may even reduce socially inefficient excessive momentum.

As long as essential patents do not lock in standards for an inefficiently long time, these effects are potentially beneficial for standard users. Indeed, only standard replacement, and not standard upgrades, seems to be problematic for downstream investment building upon a standard. Consistently, references from ulterior standards reduce the likelihood of standard replacement, but have no incidence on version replacement.

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