The Private and Social Value of Patents in Discrete and Cumulative Innovation

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Abstract

This article analyzes the relationship between private and social value of patents, comparing discrete and cumulative innovation. Indicators of the social value of patents are known to be less correlated with measures of private value in technological fields where innovation is more cumulative. We test whether this is because the link between private and social value is weaker, or because the indicators are less informative of the underlying concepts of value. Furthermore we analyze whether these differences between technological fields are really due to cumulativeness. We observe cumulative innovation by making use of databases of patents declared essential for technological standards. Using factor analysis and a set of patent quality indicators, we test the relevance of social value for predicting the private value of a patent measured by renewal and litigation. Whereas we establish a robust and significant link for discrete technologies; neither common factors nor any indicator of social value allows predicting the private value of essential, very cumulative patents. Nevertheless, this result cannot be generalized to whole technological classes identified as "complex" by the literature.

JEL Codes: O31, O34, D23
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Introduction

Patents play an important role in modern economies, especially in the growing sector of Information and Communication Technologies (ICT). At the same time, ICT patents are seen with increasing suspicion. One important source of concern is the importance of cumulative innovation in ICT. For the purpose of this inquiry, cumulative innovation is defined as a process whereby various strongly complementary inventions need to be bundled together for any commercial application. In technological fields where cumulative innovation is dominant, patents do not provide their owner with a monopoly right over a marketable invention, but rather with a blocking power over a jointly controlled technology. This could explain why the economic literature has evidenced different patenting strategies in technological fields such as ICT or software than in other technologies (Cohen et al., 2000). For instance, recent research highlights the importance of strategic patenting in these technological fields (Bessen and Hunt, 2003; Noel and Schankerman, 2006). It is a widely shared belief that an important share of the numerous patents filed in these fields is of questionable value (Jaffe and Lerner, 2004). Furthermore, there is skepticism about the contribution of these numerous patents to technological progress (Bessen and Maskin, 2006). Many scholars raise concerns that cumulative innovation in ICT might be stifled in a dense "patent thicket" [3] (Shapiro, 2001) with many low quality patents having a blocking capacity.

For many economists, the patent thicket problem weakens innovation incentives by reducing returns on significant innovations through patent inflation and litigation, while allowing litigious firms to earn much on patents of dubious technological significance (Shapiro, 2001; Bessen, 2003). The core prediction of this theory is thus that the link between the social value and the private value of the patent for its owner erodes. Social value of a patent designates the contribution of the underlying invention to social welfare[4], including both future technological developments and the value of current commercial applications. As opposed to social value, the private value only encompasses the value of a patent for its owner.

The link between the private and social value of patents is important for the capacity of the patent system to reward innovators for socially desirable innovations. If the link is weakened, the patent system is at risk to encourage strategic patenting on incremental contributions rather than inventive efforts and significant innovations. We will therefore address the crucial issue of the link between private and social value of patents with a special focus on cumulative technologies.

Probably one of the most prominent examples of cumulative technologies is ICT standardization. Standards are means of ensuring compatibility between complementary

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[3] Patent thickets can be defined as: "a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology." (Shapiro, 2001)

[4] The earlier literature often refers to a broader concept of "patent quality". Nevertheless, the concept of patent quality lacks a clear definition. We will therefore stick to the better defined concept of patent value, and rely upon the traditional distinction between private and social value of inventions. This distinction dates back at least to Arrow (1962).

technological components. Standardization is thus a crucial feature of cumulative innovation. Standard setting has evolved to an original form of joint development of common technological platforms in highly profitable markets such as mobile telephony, wireless communication, digital data processing and consumer electronics. The question whether the patent system is able to appropriately reward innovators for their contributions to this cumulative technological innovation is a crucial policy issue. This is evidenced by the debates around sharing of royalty surplus between the owners of patents included into standards (Swanson and Baumol, 2005; Salant, 2009). Therefore, standardization is a perfect way to identify patents on cumulative inventions, even though not all cumulative sectors are subject to standardization.

Going beyond the narrowly defined, yet extremely important, technology markets around formal standardization, there are attempts in the literature to identify broader technological fields in which technology is more cumulative. Many authors have relied upon the technological classification of patents by patent examiners, proposing a categorization in discrete and complex technology classes. In this definition, the difference between complex and discrete technological classes is that a complex class is characterized by stronger cumulativeness[5]. Even though the concrete classification varies from study to study, ICT technologies are consistently classified as complex. ICT is indeed characterized by high citation rates among patents, indicating strong cumulativeness of research (Nagaoka, 2005), and it concentrates the majority of mutually blocking patent rights (Von Graevenitz et al. 2009).

In several empirical studies[6] on the capacity of indicators of the social value of patents to predict private value, electronics and other "complex" technological fields have revealed a low link between measures of private and social value. Nevertheless, these studies do not reveal whether the capacity of social value indicators to predict measures of private value is weaker because the link between private and social value is weaker, or because the indicators are themselves less informative of the underlying concepts of value. Furthermore, none of these studies has clearly established whether cumulativeness per se is driving this apparently lower link between indicators of the social and private value of patents, or whether other specificities of technological classes classified as "complex" could be the reason for these results.

It is an important contribution of the present study to disentangle these issues. First, we analyze whether the observed differences in the relationship between measures of private and social value are due to differences in the performance of indicators to measure the underlying concept, or in the link between the concepts themselves. Therefore, in this study we will use a broad range of indicators to measure the social value of patents: forward citations, backward citations, number of claims, family size, and originality and generality indices. We observe

[5] See for instance Cohen et al. (2000), p. 19: "[…], the key difference between a complex and a discrete technology is whether a new, commercializable product or process is comprised of numerous separately patentable elements versus relatively few"
[6] E.g. Hall et al. (2005) and Lanjouw and Schankerman (1999), for a more detailed literature review, see Part I.

the private value of patents by predicting the likelihood of renewal after 4, 8 and 12 years of patent terms and check the robustness of our results by using litigation data as alternative measure of private value[7]. We are thus able to disentangle the link between private and social value from the performance of indicators.

Second, we analyze whether these differences between patents in complex and discrete technology classes are due to the cumulativeness of research. For this purpose, we compare random complex technology patents to patents that are essential to technological standards and thus perfect examples of cumulative innovation. We will therefore study three different samples of patents. The first sample consists of patents declared as essential to technological standards, and allows testing directly the characteristics of cumulative innovation. In order to analyze whether these effects can be generalized to the broader technological field, we compare our sample of essential patents with a control sample of sibling patents from the same technological classes as the essential patents, classified as complex by the related literature. Finally, we introduce a third sample of patents with the same application years as our two other samples, but randomly drawn from patent classes that are consistently classified as discrete by the related literature. We then compare the link between the private and social value of patents from sample to sample.

The remainder of this article is organized as follows. Part I summarizes the literature and sketches our main contributions to the state of the art. Part II describes the data and discusses the construction of the samples. Part III summarizes the results of the factor analysis. In Part IV, we will describe how the quality factor performs in predicting patent value as measured through patent renewals. Part V discusses the implications of our results for policy and research methodology.

I. Analytical framework

It is the aim of this part to provide an overview over the literature and to sketch our main contributions to the state of the art. In the first part, we summarize the economic literature on the measurement of the social value of patents, and in particular the use of patent indicators. In the second part, we discuss results of previous studies using these indicators to analyze the relationship between private and social value. In both parts we focus particularly on the distinction between discrete and cumulative innovation. In the third part, we show how the present study goes beyond and complements the previous findings.

I.1 Measuring the social value of patents: the literature on patent indicators

There is a longstanding tradition in economic research to measure the output of innovative activity with patent data. Nevertheless, patents are very heterogeneous, as some patents are

[7] for a discussion of these measures of patent private value, see Lanjouw and Schankerman, 1999 and Bessen, 2006

very important, while many patents are never used. As this heterogeneity of patents reduces the significance of patent counts as measure of innovation output, empirical research seeks for ways to weight patent counts by measures of the social value of the patents.

Various strategies exist to compare the social value of patents: the literature has used e.g. expert rankings, case studies, or survey analysis. Nevertheless, these strategies are not available for studies of broad technological sectors with a very high number of relevant patents. Therefore the economic literature systematically relies upon indicators of patent quality. Indicators are quantitative patent characteristics that are easily observable and are thought to reflect their social value.

The most commonly used indicators are the number of citations a patent receives by posterior patents (so-called forward citations), the number of claims, and the size of the patent family (i.e. the number of international patent files with the same priority patent) (Griliches, 1990). Other indicators of social value include the number of backward citations, i.e. the number of patents cited as prior art and the patent’s generality index (measuring the dispersion of prior art over technology classes) and originality index (measuring the dispersion of citing patents over technology classes). Table 1 summarizes the main indicators used in the literature.

INSERT TABLE 1 HERE

These indicators are often used indiscriminately in different sectors and to measure a vague and little defined social value of patents. However, the indicators capture at best heterogeneous phenomena associated with this social value. For example, the number of claims could indicate the breadth of a patent whereas forward citations measure technological significance for further research. These specific phenomena could be, according to the field and the aim of the study, more or less relevant. Thus, these indicators may be, according to the sector, considered as more or less suited to a study of a specific situation. Consequently, assessing the reliability of social value indicators is crucial.

For instance, the performance of the forward citations indicator has been repeatedly assessed and confirmed. Trajtenberg (1990-1) shows on a sample of computed tomography patents that more highly cited patents contribute more to consumer and producer welfare, Harhoff and al. (1999) show that patent holders value higher those of their patents that receive more citations, and Giummo (2003) finds that patents more often cited are more likely to be licensed. It has furthermore been shown that patents cited more frequently are more likely to be litigated (Lanjouw and Schankerman, 1999) or to be included into technological standards (Rysman and Simcoe, 2008). In a different approach, Lanjouw and Schankerman (2004) carry through a factor analysis on four indicators of social value and identify a strong common variability with one single common factor capturing an important part of the variance in the data. They argue that patent “quality” is the only underlying factor that could be thought of to jointly affect the number of claims, forward and backward citations and the size of the families. They furthermore argue that using a common underlying factor of various indicators rather than a single indicator allows reducing the noise and improves the capacities of indicators to approximate patent “quality”.

Probably, the most important challenge to the general use of patent indicators is the heterogeneity of the patent population. The functions and the mechanisms of patents can vary very much according to external factors, such as the type of assignee, the grant year and especially the field of technology. It is important in our context to make sure that for instance cumulativeness does not affect the capacity of indicators to measure the social value adequately.

For several reasons the cumulativeness of a technological field could have an impact on the measures used as indicators of social value of patents. For instance, the cumulativeness of innovation mechanically affects the average number of forward citations (Nagaoka, 2005). Indeed, a patent has a higher chance of being cited in a technological field where technological inventions strongly build upon each other. For the same reason, a patent in such a dense web will have to cite more previous art than a comparable patent in another technological field.

Also patenting strategies are different from discrete to cumulative innovation, which could have an impact on specific indicators. For instance, in cumulative innovation, not all complementary parts of a technology need to be patented in every single office in order to exclude potential imitation. Therefore patent families are larger in discrete than in cumulative innovation. Furthermore, the existence of overlapping patents in cumulative innovation could provide incentives to raise the number of claims, as increasing the number of claims increases the chances of the patent to be relevant to future developments of a jointly held technology (Berger and al., 2012).

The fact that the indicators are driven upwards or downwards by the cumulativeness of innovation in a particular technological field does not impede that variance inside a sample of patents from this technological field indicates differences in the social value of patents. For instance, Lanjouw and Schankerman (2004) in their factor analysis of four indicators over samples of patents from different technological fields identify a “quality” factor that is roughly consistent over technological differences. Nevertheless, the common variability of the indicators captured by this factor is lower in electronics, and the relative weights of the different indicators included in the factor are different. These results could indicate that even though the indicators still evidence a common “quality” factor in complex technology classes, they yield less consistent results in these sectors where innovation is more cumulative.

The reviewed literature provides several arguments why patent indicators perform differently well in measuring the social value of patents in discrete and cumulative innovation. It is therefore important to test the consistency of patent indicators across different technological fields before analyzing differences in the link between the social and private value of patents.

I.2 The link between private and social value of patents: cumulative vs. discrete innovation

Economic research draws a clear distinction between private and social value of inventions (Arrow, 1962; Trajtenberg 1990-2). As mentioned before, the social value represents the total net value created by the patent for social welfare. The concept of private value takes into account only the value added of the patent for its owner: it can thus be defined as the depreciated sum of expected cash flows or the contribution of the patent to the market value of the owning firm. The private value can also be expressed as the social value minus all positive[8] and negative externalities[9] (Bloom et al., 2010). The social value is thus a causal determinant of the private value of the patent. Private value is furthermore determined by the ability of the owner to appropriate the value generated by the patent and to exclude the generation of positive externalities (Trajtenberg et al., 1997). On the other hand the private value can also exceed the social value of patents, if additionally to reaping the added value of the protected technology they allow leveraging on related innovations, for instance in the case of patent thickets.

In a very complete review of the literature, Van Zeebroeck and Van Pottelsberghe de la Potterie (2011) highlight the conceptual difference between determinants and indicators of patent value. Indeed, the empirical literature relies upon statistical patent indicators as measures of private patent value. As discussed, the same patent characteristics are as well used to measure the social value of patents. As such, they are often determinants rather than indicators of private patent value. The use of a specific variable as indicator of private or social value of patents depends upon the research setting. Recent research (Lanjouw and Schankerman, 2004; Bessen, 2006) focuses upon patent renewal and litigation decisions as measures of private value, as costly renewal and litigation decisions reveal a minimal threshold value of the patent to its owner. Thus, the private value of patents is measured indirectly, through the observation of the behaviour of the agents, which reveals the value that they attribute to their patent. The remaining observable characteristics, such as technological significance as measured by citations, the breadth of the patent as measured by the number of claims, and application strategies such as family size, are used to represent the social value of patents. Assuming a correlation between social and private value, these indicators can thus be analyzed as causal determinants of private value.

An increasing strand of empirical literature has studied the link between private and social value of patents. Hall et al. (2005) and Nagaoka (2005) analyze the correlation between patent indicators reflecting the social value of patents and the market value of the patent owner, and Lanjouw and Schankerman (1999) and Thomas (1999) analyze the impact of patent "quality" indicators on the probability that a patent is renewed. Consistently, all studies evidence a strong link between private and social value, but there is also evidence for strong differences across technological fields.

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[8] such as for consumers, intermediaries, and follow-up inventors

[9] such as the effect on the profits of a competitor

Many arguments pointing to a divergence between the private and social value of patents relate to the cumulativeness of research. Different strands of research have established that firm strategies with respect to patents differ from cumulative to discrete technologies. In cumulative technologies, many firms use patents for other reasons than excluding their rivals from the use of their technology (Cohen et al., 2000). Most notably, many firms active in cumulative technologies rely heavily on cross-licensing agreements to cut their way through patent thickets (Shapiro, 2001) and engage into patent portfolio races (Hall and Ziedonis, 2001). Hereby patent portfolios play an important role as "mass of negotiation".

Thus, the way how patents create value could be different from discrete to cumulative technological fields. According to this argument, the value is not only derived from the use of the technology, but from the possibility to use the patent as a threat of exclusion and mass of negotiation. The possibility to use patents as bargaining chips has two implications on the private value of patents: first, there is an incremental value to holding a patent in cumulative innovation which is independent of the social value of the underlying invention. In line with this hypothesis, Liu et al. (2008) find that patents relating to sequential innovation held by the same owner are more valuable. Second, in cases of cumulative innovation, the private value of the patent for its holder is less determined by the intrinsic significance of the underlying invention. For instance, Noel and Schankerman (2006) find evidence that the contribution of software patents to firm value depends upon fragmentation of patents in patent thickets and upon strategic patenting by competitors. In very cumulative innovation, and most notably in the realm of telecommunication standards, the perceived disconnection between the social value of patents and the royalty revenue that they generate for their owner has spurred a long series of litigation and regulatory efforts[10].

Consistently with these arguments, several empirical findings highlight weaker links between indicators of private and social value of patents in "complex" technological classes, where cumulative innovation is assumed to be more important. These contributions build upon the idea that technologies can be categorized into complex and discrete technologies, whereby complex technologies are characterized by a dominance of cumulative innovation and a strong incidence of patent thickets[11]. This distinction originates in a paper of Levin et al. from 1987 and has by now been studied by an extensive body of research[12].

Lanjouw and Schankerman (1999) use a compound factor of "quality" indicators (claims, forward citations, family size and backward citations) to predict patent litigation and renewal as measure of private value. They emphasize a strong link between patents' private value and indicators of "quality"; but this link is less obvious for the electronics sector. Hall et al. (2005) underline that the impact of citations on the contribution of patents to the firms' market value

[10] There is an increasingly precise regulatory framework for licensing patents in these very cumulative technologies, as it is not clear that market mechanisms will yield prices that are in adequate proportion to the technological contribution of the patent. A recent example is the drastically extended chapter on standardization in the draft guidelines on the applicability of European Competition Law to Horizontal Cooperation Agreements, see http://ec.europa.eu/competition/consultations/2010_horizontals/guidelines_en.pdf

11 Harhoff et al. (2008)

12 Levin et al. (1987), Merges and Nelson (1990), Cohen et al. (2000)

differs according to the type of technology. They especially highlight that the impact of patent citations on market value is over 50% higher for drugs than the average effect. This effect is lower for computers than that for the other sectors. They explain this difference by the cumulativeness of innovation: "*Computers and Communications is a group of complex product industries where any particular product may rely on various technologies embodied in several patents held by different firms. In this industry patents are largely valued for negotiating cross-licensing agreements, so their individual quality is not as important, although having them is*". On the other hand, Nagaoka (2005) finds that forward citations are more correlated with firm market value in ICT and other industries where innovation is cumulative.

I.3 Our contribution to the state of the art

The empirical literature has repeatedly found differences in the link between indicators of private and social value of patents between technological classes. These differences have been widely attributed to implications of more or less cumulative innovation, as theoretical arguments predict a weaker link between private and social value of patents when innovation is cumulative. However, the empirical validation of this hypothesis faces two methodological challenges. First, it is necessary to make sure that the measurement of private and social value is consistent throughout the samples to be compared. In previous studies, differences between discrete and cumulative innovation have been either attributed to measurement issues, regarding the performance of indicators (e.g. Lanjouw and Schankerman, 1999), or to economic differences in the link between private and social value (e.g. Hall et al. 2005). Second, it is not straightforward to identify cumulativeness of innovation. Previous studies have relied upon patent classification into complex and discrete patent classes, but it is unclear to what extent technological classes can capture higher or lower degrees of cumulativeness[13]. It is the main contribution of our paper to jointly resolve these two methodological challenges.

We address the first point running a factor analysis to identify the common variance of patent indicators. We can thus test in a first stage the consistency of patent indicators in the different samples, and use the underlying factors rather than single indicators as measures of social value. With respect to previous studies, we enlarge the set of indicators, by adding generality and originality indices to the traditional indicators. In the factor analysis, we will allow for two rather than one common factor, in order to capture a broad concept of social value.

[13] Indeed, the notion of complex technology fields seems problematic in light of e.g. recent evolutions in the field of biotechnology. Biotechnology comprises a set of technological advancements in the field of medical drugs, plant breeding and crops. These technological fields are traditionally classified as discrete. Biotechnology itself however is characterized by an important degree of cumulativeness, with strong incidence of patent thickets and cross-licensing. This example shows that processes of strongly cumulative innovation can occur also in "discrete" technological fields. On the other hand, also in complex technology fields there are inventions that can individually be commercialized. For this reason, it is important to directly identify cumulative technologies, and to assess to what respect technological classification is able to capture the effects of cumulativeness.

We have defined social value as the contribution of a patent or the underlying invention to social welfare. The first aspect of the social value of a patent is thus the impact of the underlying invention on current welfare and future technological progress. Nevertheless, we argue that when inventions are cumulative, it is unclear whether it is possible to assess their individual social value in terms of impact. Indeed, the idea of cumulativeness implies that each single invention is necessary to allow the bundle of inventions to have an impact. In order to capture differences in the significance and social value of single inventions relating to a cumulative research effort, we thus believe that it is necessary to allow for aspects of social value other than direct measures of impact.

Second, in order to identify cumulativeness, we introduce a sample of patents that are declared essential for technological standards. This sample reveals the effects of cumulativeness, as standardization is a pure case of cumulative innovation. We will compare a sample of (complex) patents declared as essential to technological standards with a control sample of patents from exactly the same (complex) technology classes, and another control sample of patents classified as discrete. This methodology allows us to establish whether particularities of patents classified in "complex" technology classes are really due to cumulativeness, and to disentangle the effects of cumulativeness from the technological class a patent belongs to.

We now turn to a description of the construction of the database and provide descriptive statistics for the various samples.

II. Data and Descriptive statistics

II.1 Construction of the samples and variables

Our objective is to analyze the way cumulativeness impacts the link between private and social value of patents. As discussed, we make use of two different strategies in order to identify cumulative innovation: first, we use data on patents essential for technological standards as a pure case of cumulative innovation. Second, we will use a sample of random patents classified in the same technological classes as the essential patents. These technological classes are consistently classified as "complex" classes in the relevant literature.

As data are most constrained for standard-essential patents, we first constituted a database of US patents that are essential to technological standards (Sample 1). This database is derived from patent disclosures at 8 standard setting organizations (SSOs) collected by Rysman and Simcoe[14] and from the websites of seven different patent pools (lists of SSOs and patent pools can be found in the appendix 3). It comprises overall 3343 essential patents[15].

[14] Data available online at http://www.ssopatents.org/
[15] 993 of these patents are part of a patent pool

By merging these patent lists with the NBER patent database, we inform the technology classes of 3128 patents and verify that the patents in our database cover technology classes that are classified as "complex" according to previous literature[16]. The concrete classification of technological classes into complex or discrete is still subject to debate. In our analysis, we will concentrate on clear cut cases of classes classified as complex or discrete according to several methodologies[17]. Details on our selection of classes can be found in appendix 4.

Based on the remaining patents, we construct a sample of siblings. These are US patents with the same application year and the same technology class randomly chosen from the NBER patent database. This second sample is what we will call in the following the group of complex, non-essential patents (Sample 2).

Finally, we build up a third sample of discrete patents (Sample 3). These are patents with the same application years as the patents in the other two samples, randomly chosen from a large range of discrete technology classes in the NBER patent database. The detailed, three-digit technology classes of both the complex and the discrete patent samples can be consulted in appendix.

Overall, we have 9255 patent observations. The NBER patent database yields information on citation flows and other important variables. We inform the number of *forward citations* (including and excluding self-citations), *backward citations* as well as the *generality* and *originality* indice**s**, both building upon citation data. We furthermore retrieve the number of *claims*, the *application year* and the *grant year*. We complete this information on patents using the website of the European Patent Office www.espacenet.com, where we retrieve the *size of the patent families* and indications on *renewals*.

Finally, using the Stanford IP litigation database (www.lexmachina.org), we generate a dummy variable - *litigated* - which gives 1 if the patent has been cited in at least one law suit in the database.

II.2 Descriptive statistics

In this section, we will use the comprehensive database to provide first descriptive statistics. In a first step, we will provide statistics on the average scores of indicators in the different samples (Table 2). While these statistics do not inform about the linkages between indicators, they corroborate several arguments on factors affecting the performance of single indicators in the comparison between discrete and cumulative innovation. For instance, we confirm earlier findings that citation rates are higher in complex technology classes and that patent families are larger in discrete technology classes: both backward and forward cite rates are significantly higher in Samples 1 and 2 than in Sample 3 whereas the scores for claims are not significantly different, and family size is much bigger in Sample 3 than in Sample 2. These

[16] See von Harhoff et al. (2008) or Cohen et al. (2000)

[17] For instance, we rely upon the classifications used by von Graevenitz et al. (2009) and Cohen et al. (2000)

differences of indicator levels in the different samples provide a further justification for our use of composite indicators to measure social value.

Regarding measures of private value, we confirm previous findings that the litigation rate is indeed higher in complex than in discrete industries (1.4 compared to 1 %)[18]. Furthermore, higher renewal rates in Samples 1 and 2 provide further evidence that less patents are of low value to their owners in complex technologies. Essential patents in Sample 1 are clearly found to be of a higher value to their owners, as indicated by much higher renewal and litigation rates.

Patents in Sample 1 score high on all the quality indicators and on renewal and litigation rate. This provides evidence that we are confronted with a selection effect: essential patents are not only more strongly cumulative, but also more valuable than average patents from their technological field. This bias can result from the fact that standard setting organizations often choose between different technological options and select the best technologies for inclusion into the standard. In the remainder of the analysis, we will have to control for this selection effect. We want to make sure that our findings on the link between private and social value in the sample of essential patents can be attributed to the strongly cumulative nature of these patents, and not to their high private and social value.

INSERT TABLE 2 HERE

III. The quality indicators relevant for different types of technologies: the principal factor analysis

The aim of this part is to compare the consistency of indicators among the three different samples of patents using factor analysis. Factor analysis is a way to relate common variability among observed variables to a smaller number of underlying variables, called factors. Factor analysis estimates how much of the variability of the observed variables is due to common underlying factors. Thus, the factor analysis uses a large number of observations and reveals common patterns underlying the variables[19]. In this part we will use the factor analysis for our three samples: Sample 1 (essential, very cumulative patents), Sample 2 (complex technology classes) and Sample 3 (discrete technology classes). The objective is to study the consistency of the different indicators and to analyze if a common pattern exists among the samples.

[18] This could hint to the fact that patents are indeed used in a slightly more "litigious" way in complex industries, and corroborates the argument that patents generate value in a different way from complex to discrete technological fields.

[19] In economics, factor analysis is used when capturing a common phenomenon is more interesting than analyzing individual variables. Lanjouw and Schankerman (2004) first used the principal factor analysis to identify an overall patent "quality" factor through four indicators.

We first want to make sure that our samples are comparable to those used in earlier analyses, and especially Lanjouw and Schankerman (2004). We therefore reproduce the earlier methodology and run a factor analysis on the four indicators most frequently used to assess the social value of a patent, namely the number of forward citations, the number of claims, the number of backward citations and the family size of the patent. We only make the comparison for Samples 2 and 3. Our results on this first factor analysis (presented in annex 1) are very close to the previous results using the same methodology. We highlight that the impact of forward citations on the common factor 1 is more important in Sample 3 than in Sample 2. Inversely, the impact of the number of claims is more important in Sample 2. We can also highlight that the common variability explained by factor 1 is less important in Sample 2.

We then implement our methodological innovations discussed above. First, we introduce our Sample 1 of essential patents, and second we include two additional indicators: the originality and the generality of the patent. The generality and originality, measured by the number of forward or backward citations between the patent and patents from other technological classes, indicate the patents' interest for broader technological applications (Hall et al., 2001). We do not restrict the number of common factors in order to allow for various aspects of the social value of patents. The notion of the social value of a patent indeed incorporates various complementary aspects, such as the contribution of an invention to social welfare, or the inventive step of a patented invention with respect to the state of the art. The following table summarizes the factor loadings for each sample.

INSERT TABLE 3 HERE

Table 3 highlights that there are two main factors underlying these indicators. A first factor is mainly correlated to the number of forward citations, claims and to some extent backward citations and family size. This first factor has already been discussed in the literature (Lanjouw and Schankerman, 2004) and named "quality". In order to reflect the idea that these indicators measure the social impact of the underlying invention, we will call this factor "social value – impact". Table 3 also stresses the existence of a second factor, having an important impact on the indicators' common variability in all the samples. This second factor is mainly linked to the generality and the originality of the patent. In samples 1 and 2, this second factor also has significant loadings on the citation indicators. A plausible interpretation would be that this factor discriminates between fundamental and incremental innovations; which could be the reason why it is particularly linked to the generality and originality of the patent but also with the number of citations in the case of complex technologies. Trajtenberg et al. (1997) have examined the generality and originality indices and argue that these indicators measure the "basicness" of a patent. In order to refer to this concept, we will speak of "social value – basicness". For the sample of essential patents, the common variability of social value indicators is mainly driven by the social value – basicness factor.

This result implies that especially in the case of very cumulative innovation, it is important to take various aspects of social value into account. As we have argued above, when innovation is cumulative, it is unclear whether it is possible to assess the social value of patents in terms of impact. The idea of cumulativeness implies that not each single invention, but only all cumulative inventions taken together have an impact. The result on the social value -- basicness factor confirms that there exist other aspects to rank the social value of cumulative patents. The aspect highlighted by our basicness factor is the place of an invention in the innovation chain discriminating between some inventions being fundamental, and others being narrow and incremental contributions.

In spite of the presence of a second factor that is especially important in samples of cumulative patents, we identify a social value - impact factor that is roughly consistent across the samples. In all three samples, this factor is driven by a positive correlation between forward citations, claims and family size. Nevertheless, the loadings of indicators are slightly different between complex and discrete technologies. The number of claims seems to have more impact than the number of forward citations on the social value - impact factor for Sample 2. It is exactly the opposite in Sample 3, where the most important indicator is the number of forward citations. Backward citations are important and stable components of the social value – impact factor for both Samples 2 and 3, but do not have any importance for Sample 1 of essential, highly cumulative patents.

Another important difference is the variance explained by the social value - impact factor between the complex and discrete sample. Indeed, we can underline that this factor explains almost fifty percent of the common variability of the indicators for Sample 3. However, in the Sample 1 and 2, this factor only explains one fourth of the common variability of the indicators.

For the social value - basicness factor, we argue that it captures the fundamentality of the patent, i.e. its place in a chain of cumulative innovation. This factor is orthogonal to the impact factor of the individual patent, and takes into account the relationship between this patent and complementary patents. This factor is thus useful for discriminating between fundamental, early-stage patents, and incremental patents in a later stage of a cumulative innovation effort. Consistently with this interpretation, this factor is more important in the samples of complex technology patents, and especially in the sample of strongly cumulative essential patents. Indeed, the social value - basicness factor captures almost 50 % of the common variability of patent indicators in this particular sample of very cumulative patents. We use data on the timing of declaration or introduction of patents into standard setting organizations and patent pools to corroborate our interpretation. The results are presented in table 4 (appendix 4). They show that both factors are related to being a founding patent. The results stress that being a founding patent of a pool or being declared early in a standardization project is significantly linked to a high score on the social value - basicness factor[20]. The social value - impact factor is also significantly associated with the likelihood of being a founding patent.

To sum up our main conclusions, we can say that the factor analysis underlines the existence of two factors driving the common variability of the indicators. The first one, mainly linked to the traditional indicators of "quality", has already been studied in the literature. The second one is mainly driven by the generality and originality of the patent. We call it the social value - basicness factor and give some evidence corroborating our interpretation. For Sample 1, this basicness factor explains almost half of the common variability of the indicators. This is the first time that these different aspects of the social value of patents are discussed and empirically related to the private value of patents. While in the case of discrete technology patents (Sample 3), one single factor seems sufficient to capture a large part of the common variability of indicators of social value, in the case of cumulative innovation, allowing for our second factor strongly increases the part of the variability of the indicators captured by the underlying factors.

The traditional "quality" factor, which we call social value – impact factor, seems to remain stable (with some minor changes on claims and forward citations) across our three different samples except for the importance of the backward citations. Indeed, there is a stable covariance of forward citations, claims and family size across the samples. Nevertheless, this factor captures a lower part of the common variability of indicators in Samples 1 and 2. This factor is however not less important in Sample 1 than in Sample 2. If there is thus a difference in the capacity of patent indicators to measure the social value of patents, this difference affects only the comparison of complex and discrete technology patents. The patent indicators do not seem to perform worse in capturing the social value in the case of the very cumulative essential patents.

In the next section, we will look at the ability of these factors to predict the private value of the patents. In order to assess the private value of a patent, we will use data on renewals and litigations. To take into account the instability of backward citations in the social value - impact factor, we will use a common factor compound of forward citations, claims and family size. Results for the single indicators can be consulted in the appendix.

IV. The link between private and social value of patents in discrete and cumulative innovation

As discussed in part I, we expect that the link between indicators of private and social value of patents is weakened when innovation is cumulative. We will analyze whether this link is

[20] This confirms our interpretation that this factor discriminates between fundamental and incremental innovations.

weaker for random patents in complex technology classes than for patents in discrete technology classes, and whether this link is weaker for essential, very cumulative patents than for patents randomly drawn from the same (complex) technology classes.

Specifically, we will estimate the private value of patents in an ordered logistic regression estimation of patent renewals 4, 8 and 12 years after grant. First proposed by Lanjouw et al. (1998), patent renewals are by now a well-established indicator of the private value of a patent (Bessen, 2006). As every renewal is costly and the cost of patent renewal is increasing over time, patent renewal decisions reveal the willingness to pay of the patent holder for patent protection. Comparing samples of complex and discrete technology patents, we will test whether the common social value factors are less explanatory of patent value in complex technologies. We also analyze whether the mere fact of holding a patent is more valuable in cumulative innovation, i.e. whether patents in cumulative innovation have a higher private value than patents in discrete technologies of the same social value[21].

We have two means to test for the effects of cumulativeness. First, we test for the effect of a patent being classified in a "complex" rather than a "discrete" technology class. Complex technologies are thought of in the literature as being characterized by a more cumulative type of innovation. Second, we use a sample of patents declared essential for standards. As explained above, standardization is a procedure to ensure compatibility between complementary technologies and therefore a perfect example of cumulative innovation. We have thus argued that if cumulative innovation weakens the link between patent quality and patent value, this should clearly be seen in the case of essential patents.

We thus estimate the following baseline equation:

$$V = \alpha \cdot Q + C + \delta \cdot X + \varepsilon \qquad \textbf{(1)}$$

where V represents private value, measured through an ordered logistic regression of the probability of patent renewal. Q represents social value, measured by the two different social value factors established in part III.1. X is a vector of control variables, including application year and assignee dummies. These control variables have been chosen in agreement with the literature on the subject[22]. C is a constant and ε is a stochastic error term.

We introduce dummies for complex technologies and essential patents. Both dummies are interacted with the social value of patents.

$$\boldsymbol{V = \alpha \cdot Q + [\beta \cdot Pc + \gamma \cdot Pc \times Q] + [\beta' \cdot Ps + \gamma' \cdot Ps \times Q] + \delta \cdot X + C + \varepsilon} \qquad \textbf{(2)}$$

[21] See for instance Liu et al. (2008)
[22] see for instance Hall et al. (2001) on the variables that have an impact on the number of citations

Hypothesis 1:

$\beta > 0$ and $\beta' > 0$, there is a premium for patents in cumulative innovation, therefore patents in complex technologies (respectively essential patents) are more valuable to their owners than patents of the same social value in discrete innovation. This hypothesis predicts that cumulativeness has an impact on the level of private value of patents.

Hypothesis 2:

$\gamma < 0$ and $\gamma' < 0$, social value has a lower impact on private value in cumulative innovation. This hypothesis predicts that cumulativeness has an impact on the link between private and social value.

INSERT TABLE 4 HERE

Table 4 allows underlining a couple of results. First of all, only the social value – impact factor is significant for the definition of the private value of a patent. The coefficient for the social value - impact factor is positive and significant for our two models. The link between private value and a compound factor of traditional "quality" indicators is verified in our case. On the other hand, even though important for establishing the social value of a patent, the social value – basicness factor does not have any significant effect on the private value of patents in any of the samples. Fundamental patents are no more valuable to their owners than incremental patents of the same social value – impact.

Hypothesis 1 is verified, there is a premium for patents in cumulative innovations. Thus, a patent in cumulative innovation is more valuable to its owner than a patent of the same social value in discrete technologies. This result is confirmed for both patents classified in complex technology classes, and for very cumulative essential patents. This finding relates to earlier research finding that patents that are part of sequential innovation are more valuable to their holders (Liu et al., 2008). Furthermore, we can infer from this result that a patent in cumulative innovation generates value for its owner even when it has a very low social value. This is in line with the theoretical argument that holding a patent in cumulative innovation is valuable per se, as patents can be used e.g. as mass of negotiation.

Hypothesis 2 is verified only for very cumulative patents. The coefficient on the interaction term *interaction_impact_essential* is negative and significant. Therefore, the social value - impact is significantly less important for the definition of private patent value for cumulative innovation (i.e. the link between private and social value is less obvious for this type of very cumulative innovation). But hypothesis 2 is not verified for Sample 2 of random "complex" technology class patents. Therefore, the social value of a patent is not less important for determining the private value of patents in complex than in discrete technology classes. This result casts doubts on the hypothesis that the link between private and social value of patents is weaker in whole "complex" technology classes than for patents classified in discrete technology classes.

The social value - impact factor predicts renewal in Samples 2 and 3, but not in our Sample 1 of essential, very cumulative patents. We verify that this is not due to a selection effect. Indeed, one could argue that patent indicators are less informative of patent value in a sample of essential patents, as all these patents are selected and their private and social value is above average[23]. There is no evidence for non-linear effects of social on private patent value in any sample, and our results hold under all the different control strategies[24]. As we can rule out that our results are driven by a selection effect, we argue that it is clearly cumulativeness that alters the way how patents generate value. Nevertheless, this cumulativeness is rather unrelated to technological classes, as Sample 2 does not exhibit any weakened link between private and social value of patents.

Table 7 (appendix 5) allows refining the previous results. We run the same regression as in Table 4 for each patent indicator individually. For model 1, we use in the same regression all the indicators together as explanatory variables. The coefficients therefore allow assessing the indicators' impact holding other patent characteristics constant. Model 2 reports the coefficients for each indicator used individually as explanatory variable. In order to check the sensitivity of our results to our indicator of private patent value, we also introduce patent litigation as an alternative indicator (Lanjouw and Schankerman, 1999).

Table 7 confirms that indicators of social value, especially forward citations, claims and family size are good predictors of the private value of patents (measured by litigation or renewal) for discrete and complex non-essential technologies. The main result is that no indicator of social value predicts the private value of essential, very cumulative, patents. This is in line with our hypothesis that cumulativeness disrupts the link between private and social value due to the different use of patents in the two types of innovation.

However, the traditional indicators of "patent quality" are significant predictors of patent value for other patents in the same technology classes. While cumulativeness therefore has an impact on the link between patent quality and value, the real difference is not between complex and discrete technological classes, but between the narrow sample of very cumulative essential patents and the remainder of the patent population.

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[23] We control for selection effects by excluding all patents from the analysis that have never been renewed, by restricting the samples to patents that have been litigated, by dropping all patents from the sample that have a social value – impact factor score below average, and by introducing the square of the social value factors to control for non-linear effects.
[24] The results are available upon request from the authors.

V. Conclusion: Implications for policy and research methodology

We have highlighted two aspects of social value of patents that can be related to two common factors driving the common variability of measurable patent characteristics. Besides a social value – impact factor, mainly related to traditional indicators of patent "quality", we evidence a social value – basicness factor, which is particularly predominant in the case of very cumulative innovation. This is the first analysis to discuss and evidence the importance of this second aspect of social value of patents.

We have demonstrated a very significant and robust relationship between the social value – impact factor and the private value of patents classified in discrete and complex technology classes. Traditional "quality" indicators work well in predicting the private value of patents. Nevertheless, this robust relationship completely disappears in highly cumulative innovation, as demonstrated using a sample of patents declared essential to technological standards. While these patents have both a higher social and private value than control patents, none of the two aspects of social value plays any role for explaining differences in private value inside the sample of essential, highly cumulative patents. Nevertheless, these results cannot be generalized to whole "complex" technological classes. This finding casts doubts on the hypothesis that theses classes are generally dominated by cumulative innovation.

On the one hand, we have found that in the case of highly cumulative innovation, the private value of each patent is generally high, but independent of measures of social value. This has strong implications for patent filing incentives and innovation strategies. If there is no link between the private value of a patent and the social value of the underlying invention, innovators have incentives not to pursue social value, as long as they can achieve patentability. This finding helps to revisit the patent portfolio theory (Parchomovsky and Wagner, 2005), according to which holding patents is valuable as such, independently of the value of the underlying inventions. We thus provide support to those who see the surge in patenting in highly cumulative technological sectors with some worries.

In order for the patent system to provide socially efficient innovation incentives, there must be some link between the private and social value of patents. We have discussed and shown in the data that the notion of social value is a concept which incorporates different aspects. In the case of very cumulative innovation, the traditional aspect regarding the impact of a single invention seems to be less relevant than another aspect, reflecting the basicness of the invention in the cumulative research effort. We have shown that there are indicators that can be used to measure this basicness, but that they do not display any significant link to measures of private value. This absence of link between private and social value could explain the importance of strategic patenting and litigation surrounding cumulative innovation, such as ICT standardization. This is especially worrying, as many of the most important current technological evolutions are characterized by strong cumulativeness.

On the other hand, our results suggest that the link between private and social value is robust in the remainder of the patent population and stable across technology classes. Indeed, our Sample 2 of complex technology patents drawn from exactly the same classes as the essential patents in Sample 1 does not exhibit a weakened link between private and social value. This latter finding is important for appreciating the implications for research methodology. Indeed, we find no evidence that indicators of social value of patents are less informative in complex than in discrete technological classes. In spite of the lower common variability of indicators, the social value factors predict renewal decisions and litigation even more accurately for (randomly chosen) "complex" technology patents in Sample 2 than for "discrete" technology patents in Sample 3. This suggests that the link between private and social value is affected only in narrow, yet highly relevant technological fields. Technological classification of patents seems unable to capture this phenomenon.

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Tables and Figures

Name of the Indicator	Description	Justification
Forward citations	Number of citations received by posterior patents	Indicates the relevance of the patent for further research
Backward citations	Number of citations made to previous patents	Indicates the extent to which the patent makes use of the existing prior art
Number of claims	The number of priority claims made in the patent	Indicates the breadth of the technology claimed by the patent holder
Family size	The number of international patents filed for the same priority patent	Indicates that a patent is important on an international scale, and that the validity of the patent has been certified by various patent offices
Generality	Dispersion of cited patents over technology classes	Indicates that the patent draws from various sources, increases the likelihood that the patent is a fundamental rather then incremental innovation
Originality	Dispersion of citing patents over technology classes	Indicates that the patent has been important for a broad field of further research

Table 1: Patent quality indicators

	Complete sample		**Sample 1** : Essential, very cumulative patents		**Sample 2** : Complex technology classes		**Sample 3** : Discrete technology classes	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Allnscites	23,35	42,76	40,15	57,86	20,93	36,66	8,58	15,42
Backward citations	9,30	14,12	11,72	16,18	8,87	15,38	7,28	9,67
Claims	16,85	15,09	19,66	17,54	15,77	12,92	15,19	14,07
Family size	15,66	46,33	24,75	62,67	6,51	17,88	13,64	40,15
Generality	0,35	0,37	0,43	0,35	0,39	0,37	0,22	0,34
Originality	0,23	0,24	0,25	0,22	0,26	0,25	0,14	0,22
Renewal at 8	0,73	0,44	0,95	0,21	0,73	0,44	0,59	0,49
Renewal at 12	0,57	0,50	0,92	0,27	0,55	0,50	0,37	0,48
Litigated	0,03	0,17	0,07	0,25	0,01	0,12	0,01	0,10

Table 2: Descriptive statistics of indicators

	Sample 1 : Essential, very cumulative patents		**Sample 2** : Complex technology classes		**Sample 3** : Discrete technology classes	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
Variance	0.47470	0.28419	0.26113	0.24636	0.48807	0.24936
Forward citations	0.2139	0.3903	0.3029	0.1377	0.4532	0.0021
Backward citations	-0.0722	0.0685	0.4036	-0.0143	0.3549	0.0762
Claims	0.0563	0.3745	0.4197	0.0469	0.2383	-0.0049
Originality	0.4441	0.0759	-0.0286	0.3467	-0.0794	0.3629
Generality	0.3828	0.1426	0.1113	0.3276	0.0370	0.3662
Family size	-0.0677	0.1463	0.2102	0.0289	0.4174	-0.0950
Number of observations	3191		3004		3139	

Table 3: Loadings factor analysis six indicators

	Ordered logistic Regression renewals		Ordered logistic Regression renewals	
	Coef.	Odds ratios	Coef.	Odds ratios
Impact factor	1.07511*** (0.267)	2.930*** (0.781)	1.09445*** (0.273)	2.988*** (0.814)
Basicness factor			-0.01812 (0.157)	0.982 (0.154)
Dummy essential	1.7190671*** (0.287)	5.579*** (1.604)	1.74413*** (0.342)	5.721*** (1.956)
Dummy complex	0.47798*** (0.133)	1.613*** (0.214)	0.55548*** (0.144)	1.743*** (0.251)
Interaction Impact_essential	-1.46111** (0.563)	0.232** (0.131)	-1.45623* (0.615)	0.233** (0.143)
Interaction Impact_complex	0.57896 (0.363)	1.784 (0.649)	0.69004 (0.376)	1.994 (0.749)
Interaction Basicness_essential			-0.31799 (0.743)	0.727 (0.540)
Interaction Basicness_complex			-0.27421 (0.238)	0.760 (0.181)
Grant year	-0.05839 (0.060)	0.943 (0.057)	-0.06079 (0.060)	0.941 (0.057)
Control appyear dummy	Y		Y	
Control assignee dummy	Y		Y	
Number of obs	1637		1637	
Log pseudolikelihood	-1753.59		-1751.81	
Wald chi2	290.41		288.62	
Prob > chi2	0.0000		0.0000	
Pseudo R2	0.0988		0.0998	

Table 4: The link between quality and value for cumulative and discrete innovation

Appendix 1

The following table summarizes the results of a principal factor analysis of the four main indicators of patent quality used by Lanjouw and Schankerman (2004)

	Complex technologies Sample 2		**Discrete technologies Sample 3**	
Variance	0.31715	0.23077	0.52903	0.07807
allnscites	0.3053	0.1541	0.4456	0.1267
cmade	0.2875	0.3087	0.3543	0.1614
claims	0.3462	0.1783	0.2311	0.1825
familysize	0.1464	0.2827	0.3893	0.0518
Number of observations	*3004*		*3139*	

Table 5: Factor analysis four indicators

Appendix 2

List 1 : list of discrete technology classes

19	Textiles: Fiber Preparation
26	Textiles: Cloth Finishing
28	Textiles: Manufacturing
29	Metal Working
38	Textiles: Ironing or Smoothing
44	Fuel and Related Compositions
57	Textiles: Spinning, Twisting, and Twining
66	Textiles: Knitting
68	Textiles: Fluid Treating Apparatus
71	Chemistry: Fertilizers
75	Specialized Metallurgical Processes, Compositions for Use Therein, Consolidated Metal Powder Compositions, and Loose Metal Particulate Mixtures
76	Metal Tools and Implements, Making
87	Textiles: Braiding, Netting, and Lace Making
99	Foods and Beverages: Apparatus
100	Presses
101	Printing
135	Tent, Canopy, Umbrella, or Cane
139	Textiles: Weaving
148	Metal Treatment
162	Paper Making and Fiber Liberation
164	Metal Founding
228	Metal Fusion Bonding
229	Envelopes, Wrappers, and Paperboard Boxes
423	Chemistry of Inorganic Compounds
424	Drug, Bio-Affecting and Body Treating Compositions
429	Chemistry: Electrical Current Producing Apparatus, Product, and Process
435	Chemistry: Molecular Biology and Microbiology
436	Chemistry: Analytical and Immunological Testing
514	Drug, Bio-Affecting and Body Treating Compositions
518	Chemistry: Fischer-Tropsch Processes; or Purification or Recovery of Products Thereof
585	Chemistry of Hydrocarbon Compounds

List 2: list of technology classes of essential patents

Class	Description of the class	Discrete	Complex
8	Bleaching and Dyeing; Treatment of Textiles and Fibers	1	0
16	Miscellaneous Hardware	1	0
29	Metal Working	1	0
36	Boots, Shoes, and Leggings	1	0
40	Card, Picture, or Sign Exhibiting	0	1
73	Measuring and Testing	0	2
75	Specialized Metallurgical Processes	1	0
84	Music	2	0
105	Railway Rolling Stock	1	0
119	Animal Husbandry	1	0
169	Fire Extinguishers	1	0
174	Electricity: Conductors and Insulators	0	3
178	Telegraphy	0	1
188	Brakes	1	0
211	Supports: Racks	1	0
235	Registers	0	14
250	Radiant Energy	0	1
257	Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)	1	0
264	Plastic and Nonmetallic Article Shaping or Treating: Processes	1	0
283	Printed Matter	1	0
315	Electric Lamp and Discharge Devices: Systems	1	0
324	Electricity: Measuring and Testing	0	7
326	Electronic Digital Logic Circuitry	0	4
327	Miscellaneous Active Electrical Nonlinear Devices, Circuits, and Systems	0	1
329	Demodulators	0	1
330	Amplifiers	0	7
331	Oscillators	0	3
332	Modulators	0	1
333	Wave Transmission Lines and Networks	0	2
335	Electricity: Magnetically Operated Switches, Magnets, and Electromagnets	0	1
340	Communications: Electrical	0	73
341	Coded Data Generation or Conversion	0	48
342	Communications: Directive Radio Wave Systems and Devices (e.g., Radar)	0	51
343	Communications: Radio Wave Antennas	0	1
345	Computer Graphics Processing, Operator Interface Processing …	0	13
346	Recorders	0	1
347	Incremental Printing of Symbolic Information	3	0
348	Television	0	102
351	Optics: Eye Examining, Vision Testing and Correcting	0	1
358	Facsimile and Static Presentation Processing	0	99
359	Optics: Systems (Including Communication) and Elements	0	17
360	Dynamic Magnetic Information Storage or Retrieval	0	9
361	Electricity: Electrical Systems and Devices	0	2
362	Illumination	2	0
365	Static Information Storage and Retrieval	0	4
367	Communications, Electrical: Acoustic Wave Systems and Devices	0	1
369	Dynamic Information Storage or Retrieval	0	278
370	Multiplex Communications	0	588
375	Pulse or Digital Communications	0	333
379	Telephonic Communications	0	85
380	Cryptography	0	109
381	Electrical Audio Signal Processing Systems and Devices	0	19
382	Image Analysis	0	87
385	Optical Waveguides	0	4
386	Television Signal Processing for Dynamic Recording or Reproducing	0	225

395	Information Processing System Organization	0	120
401	Coating Implements with Material Supply	1	0
423	Chemistry of Inorganic Compounds	1	0
428	Stock Material or Miscellaneous Articles	6	0
430	Radiation Imagery Chemistry: Process, Composition, or Product Thereof	4	0
434	Education and Demonstration	1	0
435	Chemistry: Molecular Biology and Microbiology	1	0
436	Chemistry: Analytical and Immunological Testing	2	0
438	Semiconductor Device Manufacturing: Process	0	1
439	Electrical Connectors	0	13
455	Telecommunications	0	307
473	Games Using Tangible Projectile	0	1
514	Drug, Bio-Affecting and Body Treating Compositions	2	0
524	Synthetic Resins or Natural Rubbers -- Part of the Class 520 Series	1	0
568	Organic Compounds -- Part of the Class 532-570 Series	1	0
604	Surgery	0	1
606	Surgery	0	1
700	Data Processing: Generic Control Systems or Specific Applications	0	2
701	Data Processing: Vehicles, Navigation, and Relative Location	0	4
702	Data Processing: Measuring, Calibrating, or Testing	0	7
704	Data Processing: Linguistics, Audio Compression/Decompression	0	64
705	Data Processing: Financial, Business Practice, Management	0	1
707	Data Processing: Database and File Management, Data Structures	0	16
708	Electrical Computers: Arithmetic Processing and Calculating	0	4
709	Electrical Computers and Digital Processing Systems: Multiple Computer	0	41
710	Electrical Computers and Digital Data Processing Systems: Input/Output	0	11
711	Electrical Computers and Digital Processing Systems: Memory	0	12
713	Electrical Computers and Digital Processing Systems: Support	0	24
714	Error Detection/Correction and Fault Detection/Recovery	0	75
		41	2904

Appendix 3

List 3: list of patent pools in our sample

- 1394
- DVD 6C
- MPEG 2
- MPEG 4 Systems
- MPEG 4 Visual
- AVC
- DVB-T

List 4: list of Standard Development Organizations in our sample

- American National Standard Institute
- Alliance for Telecommunications Industry Standards
- European Telecommunications Standards Institute
- Institute for Electrical and Electronic Engineering
- Internet Engineering Task Force,
- International Organization for Standards International Electrotechnical Commission
- International Telecommunications Union
- Telecommunications Industry Association

Appendix 4

We inform the concrete technological standard that 1.509 patents are essential to and the dates of disclosure. If one patent is disclosed as essential to several standards, we retain only the standard of the first disclosure. For every standard, we calculate the mean of the disclosure dates of all essential patents. For every patent, we generate an *age_of_disclosure* variable, defined as the difference between the disclosure date and the mean disclosure date for this particular standard. For the 993 pool patents, we use an earlier database including an *age_of_input* variable, defined as the difference between the date of input of a given patent and the date of input of the first patent in the pool. Even though differently constructed, age_of_disclosure and age_of_input both allow studying the chronological order of patents that are essential for the same technology.

We created two new variables, *founding patent pool*, which equals 1 if the patent is a pool founding patent and *founding_patent_sso* which equals 1 if the patent was disclosed before the average age of patent disclosure to the respective standard. These variables allow us to discriminate between fundamental and incremental innovations. The underlying assumption is that founding patents of a pool or a standardization project are more fundamental. We run a regression with the two variables *founding patent pool* and *founding_patent_sso* as explained variable and the factors highlighted in section III as the explanatory variables.

Probit	Founding patent SSO	Founding patent pool
Basicness factor	0.24172*** (0.127)	0.25693* (0.127)
Impact factor	0.53371*** (0.196)	0.50440** (0.196)
Age effect	0.08696* (0.094)	0.16499 (0.094)
Dummy Assignee control	Y	Y
_cons	-173.9146* (187.164)	- 327.8643 (187.164)
Number of obs	*2601*	*369*
Wald chi2(22)	*217.33*	*86.89*
Prob > chi2	*0*	*0*

legend: * p<0.05; ** p<0.01; *** p<0.001
Robust standard erros in parentheses

Table 6: Interpretation basicness factor

Appendix 5

	Sample 1 : Essential, very cumulative patents				Sample 2 : Complex technology classes				Sample 3 : Discrete technology classes			
	Litigated		Renewed after 8 years		Litigated		Renewed after 8 years		Litigated		Renewed after 8 years	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Forward citations	-0,001 (0.001)	-0,001 (0.001)	-0,001 (0.001)	-0,001 (0.001)	0,005*** (0.001)	0.005*** (0.0636)	0,006*** (0.002)	0.005** (0.0154)	0.008* (0.003)	0.009*** (0.0293)	0.007** (0.002)	0.011*** (0.0120)
Backward citations	-0,003 (0.004)	-0,003 (0.004)	-0,003 (0.004)	-0,003 (0.004)	0,010* (0.004)	0.008** (0.0382)	-0,004 (0.003)	0.002 (0.0003)	-0.013 (0.008)	-0.004 (0.0105)	-0.005 (0.003)	0.003 (0.0003)
Claims	0,005 (0.004)	0,005 (0.004)	0,005 (0.004)	0,005 (0.004)	0,001 (0.008)	0.013** (0.0361)	0,012** (0.004)	0.014** (0.0114)	0.005 (0.006)	0.006 (0.0099)	0.007 (0.003)	0.008** (0.0037)
Originality	0,889* (0.352)	0,889* (0.352)	0,889* (0.352)	0,889* (0.352)	0,770 (0.513)	0.571 (0.0234)	-0,010 (0.008)	-0.113 (0.0004)	-0.708 (0.539)	-0.240 (0.0242)	-0.286 (0.136)	-0.173 (0.0007)
Generality	0,026 (0.229)	0,026 (0.229)	0,026 (0.229)	0,026 (0.229)	0,668 (0.568)	0.506* (0.0224)	-0,116 (0.101)	0.109 (0.0007)	0.211 (0.290)	0.229 (0.0128)	0.233 (0.093)	0.300** (0.0057)
Family size	0,001 (0.001)	0,001 (0.001)	0,001 (0.001)	0,001 (0.001)	0,004 (0.002)	0.006* (0.0365)	0,023** (0.015)	0.014 (0.0078)	0.001 (0.001)	0.001* (0.0098)	0.007* (0.002)	0.012*** (0.0147)
Age control	Y	Y	Y	Y	Y	Y			Y	Y		
Control Assignee	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Number of observations	3191	3191	3191	3191	3004	3004	3004	3004	2853	2853	2853	2853

legend: * p<0.05; ** p<0.01; *** p<0.001
Robust standard errors in parentheses

Table 7: The impact of single patent quality indicators on patent value, as measured by litigation and renewal