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par

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Abstract

This thesis addresses the question of a patent value from three different angles. It comprises three papers on the patent valuation methods. The patent valuation issues are well-known to the world of research and practice. However, the debates over what the patent contributes to the business and the economy overall remain open. The main contribution of my dissertation is that I present novel ways of addressing the value of patents from both micro- and macroeconomic perspectives. I bridge the theoretical modeling with real-world estimations, which sheds light on the legitimacy of certain hypothetical assumptions in patent valuation.

In the first paper, I develop a factor model to value patents in a corporate patent portfolio. According to the results, the patent value is determined by five factors, such as forward and backward citations, family size, the number of oppositions received, and the number of claims. I contribute to the literature by introducing an interaction of a quantitative measure of a patent value with its qualitative assessment derived from a survey of patent managers. The results show that model estimates are weakly consistent with an expert opinion on the value of patents.

In the second paper, we collaborate with a large multinational company and analyze internal and highly confidential data on product sales, revenues, and other corporate performance measures by tracing each patent down to its product market. To establish causality, we design a randomized controlled trial together with the management of the company, in which some randomly chosen patents are dropped from the portfolio, while others are kept for the duration of the study. To our knowledge, this is the first study that conducts a randomized controlled trial to measure the real market effect of patent protection.

In the third paper, we study whether the regulator expands production possibilities of the economy by assigning a standard-essential status to patents. As we show, the innovators' risk of losing the standard-setting game ex-ante attenuates the anticipation of a larger market share. Secondly, since the discovery of new technologies is typically slower than the discounting rate for the monopoly profits, standards with a positive contribution to productivity tend to be growth-reducing. Our results have significant policy implications. Regulators impose Fair, Reasonable, And Non-Discriminatory (FRAND) pricing on standard-essential technologies to compensate for the larger market-share the innovators get. We demonstrate how FRAND regulation of mark-ups has an unambiguously negative effect on growth and long-term growth-destroying consequences.

Keywords: Patents, Patent Valuation, Factor Analysis, Randomized Controlled Trial, Standard Essential Patents, Endogenous Growth Model, FRAND Regulation

Résumé

Cette thèse aborde la question de la valeur d'un brevet sous trois angles différents. Elle comprend trois articles sur les méthodes d'évaluation des brevets. Les questions relatives à l'évaluation des brevets sont bien connues du monde de la recherche et de la pratique. Cependant, les débats sur la contribution du brevet à l'entreprise et à l'économie en général restent ouverts. La principale contribution de ma thèse est que je présente de nouvelles façons d'aborder la valeur des brevets dans une perspective à la fois micro et macroéconomique. Je fais le lien entre la modélisation théorique et les estimations du monde réel, ce qui éclaire la légitimité de certaines hypothèses hypothétiques dans l'évaluation des brevets.

Dans le premier article, je développe un modèle factoriel pour évaluer les brevets dans un portefeuille de brevets d'entreprise. Selon les résultats, la valeur des brevets est déterminée par cinq facteurs, tels que les citations en avant et en arrière, la taille de la famille, le nombre d'oppositions reçues et le nombre de revendications. Je contribue à la littérature en introduisant une interaction entre une mesure quantitative de la valeur d'un brevet et son évaluation qualitative dérivée d'une enquête auprès des gestionnaires de brevets. Les résultats montrent que les estimations du modèle sont faiblement cohérentes avec une opinion d'expert sur la valeur des brevets.

Dans le second article, nous collaborons avec une grande multinationale et analysons des données internes et hautement confidentielles sur les ventes de produits, les revenus et d'autres mesures de performance de l'entreprise en remontant jusqu'au marché de chaque brevet. Pour établir la causalité, nous concevons un essai contrôlé randomisé en collaboration avec la direction de l'entreprise, dans lequel certains brevets choisis au hasard sont retirés du portefeuille, tandis que d'autres sont conservés pendant la durée de l'étude. À notre connaissance, il s'agit de la première étude qui effectue un essai contrôlé randomisé pour mesurer l'effet réel de la protection par brevet sur le marché.

Dans le troisième article, nous étudions si le régulateur élargit les possibilités de production de l'économie en attribuant un statut standard essentiel aux brevets. Comme nous le montrons, le risque pour les innovateurs de perdre le jeu normatif ex ante atténue l'anticipation d'une plus grande part de marché. Deuxièmement, étant donné que la découverte de nouvelles technologies est généralement plus lente que le taux d'actualisation des bénéfices des monopoles, les normes qui contribuent positivement à la productivité ont tendance à réduire la croissance. Nos résultats ont des implications politiques importantes. Les régulateurs imposent une tarification équitable, raisonnable et non discriminatoire (FRAND) pour les technologies essentielles aux normes afin de compenser la part de marché plus importante que les innovateurs obtiennent. Nous démontrons comment la réglementation FRAND des marges a un effet négatif sans ambiguïté sur la croissance et des conséquences néfastes à long terme sur la croissance.

Mots-clés : Brevets, évaluation des brevets, analyse factorielle, essai contrôlé randomisé, brevets essentiels standard, modèle de croissance endogène, réglementation FRAND

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Factor Model of Patent Valuation

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Abstract

In this paper, I develop a factor model to value patents in a corporate patent portfolio. According to the results, the patent value is determined by five factors such as IPC scope, forward and backward citations, family size, the number of oppositions received and the number of claims. I contribute to the literature by introducing an interaction of a quantitative measure of a patent value with its qualitative assessment derived from a survey of patent managers. The results show that model estimates are weakly consistent with an expert opinion on the value of patents.

1. Introduction

Perhaps surprisingly, mainstream economic theory has almost completely failed to come to grips with the role of intangibles in creating value (Teece, 2015)

The management of IP in the form of patents ... is now an essential part of the management of innovation (Henkel, 2013)

In the era of the fourth-industrial revolution, a notorious question remains the same: from where do fundamental transformations come from? In 1939, Joseph Schumpeter, within the theory of creative destruction, suggested that innovations drive the development (Schumpeter, 1939). Nowadays, the most successful companies are technology-based giants packed with commercialized inventions. According to estimations by PWC in 1998, intangible assets accounted for almost 78% of the total value of S&P 500 listed companies (Ghafele, 2004). The dominance of intangibles applies not only to technology intensive companies, but it can be observed across various industries. The asset base of manufacturing companies in US has also notably changed. One research shows that in the period from 1978 to 1998 the proportion of physical and non-physical assets has proportionally inverted from 80/20% to 20/80% accordingly (Sullivan Jr, 2000). Intangibles include goodwill, formal and informal forms of intellectual property. Patents represent a formal IP and accounted for a major share of intangible assets.

Many researches propose patent data as a proxy for defining the value of innovative superiority of nations and companies. However, a particular technology field or a specific nationality of the patent sample (Caves, 1991), (Ziedonis, 2001), (Griliches, 1984) limits most of their findings. Undoubtedly, patents have a role beyond being a source of commercial intelligence. Patents are a means of monitoring various sources and flows of technology, which are essential to companies' business. It is an essential part of learning and not just gaining but maintaining a lead in a dynamic technological environment (Schumpeter, 1939). How we can measure such practices? As the saying goes, you cannot manage what you cannot measure.

The issue of valuing patents occupies scientific minds, disturb managerial routines, and challenges policymakers. Trajtenberg (1990) highlights that the body of evidence that has accumulated since Schmookler (1966) indicates fairly clear that simple patent counts are closely associated with the input side of the innovative process, primary with contemporaneous R&D expenditures in the cross-sectional dimension (Griliches, 1984). In the theory of heterogeneous firms Teece (2015) states that ownership (or control) of intangibles and their complements allows innovative firms to differentiate and establish some degree of competitive advantage. The augmentation and orchestration of these assets helps (along with strategy) to generate longer-run enterprise competitive advantage.

This paper aims to give evaluate a structurally diverse but conceptually uniformed patent portfolio of one of the European-based transnational knowledge-intensive companies. Technology intensive entities could prune their R&D portfolios and target markets depending on their relative performance. On the one hand, an objective of this research is to define the actual value of patents, which should facilitate the process of defining and maintaining successful patent strategies for companies. Besides, the absence of a direct quantitative measure of the value of patents complicates communication outside the department. To get support and commitment from senior management and stakeholders, managers should be able to argue on what is the value created by patents for a company. Moreover, if patent litigation or opposition happens, it is vital to monitor the value that is patent-protected and patent-created to compare profit-and-loss form a possible outcome of the conflict and make a risk assessment.

On the other hand, a goal of this paper is to reveal a common practice of measuring the value of corporate patent portfolios, which can be helpful for policy makers to harmonize approaches in addressing patent valuation issues across different fields and define a proper unified measure to compare relative performance of companies in innovation sector.

2. Research Methods and Data Collection

2.1. Theory

To build a framework on the patent valuation, I use mixed-method approach. Mixed research methods, as defined by Johnson & Onwuegbuzie (2004) is the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts, or language into a single study. Mixed methods offer a unique opportunity for researches to ground theory in a flexible and open-minded manner. A combination of different nature approaches aims to enhance complementary strengths and compensate for non-overlapping weaknesses (Turner, 2003). Following Johnson & Onwuegbuzie (2004), I focus on an eight-step process model as a guideline as presented below. It comprises a parallel process of performing research.

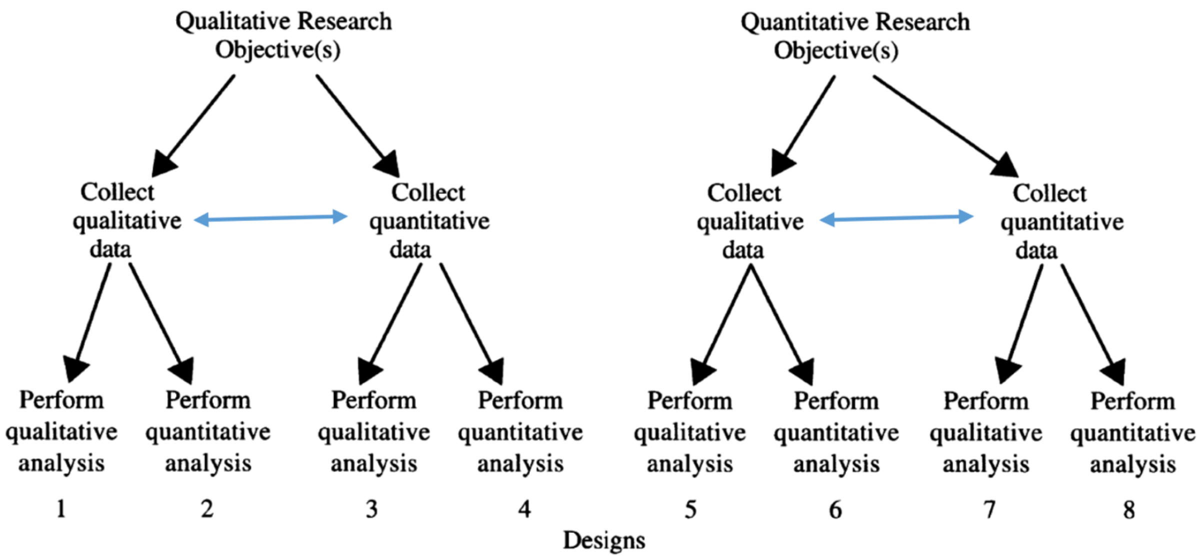

Figure 1 Mixed Methods Approach

In their original model, collections of quantitative and qualitative data are independent processes as displayed in a diagram. In the current study, the collection of data of both types are interrelated. I obtain criteria via interviews and group discussions to check the reliability and completeness of the available data.

2.2. Settings

I construct a unique data set by organizing an inter-party survey. I conduct a survey of 27 patent attorneys in one of the European multi-national company, which holds a diverse patent portfolio across different technological sectors. It allows differentiating the result by controlling the industry sector in the analysis as would expect to have some divergencies in the experts' opinion based not only on their personal biases but also based on inherent specificities of different sectors.

I formulate the systematic process of the study in Figure 2. This approach allows us to iterate steps and have a validation of results and visions by running in parallel modelling for the data analysis and interviews for the data collection.

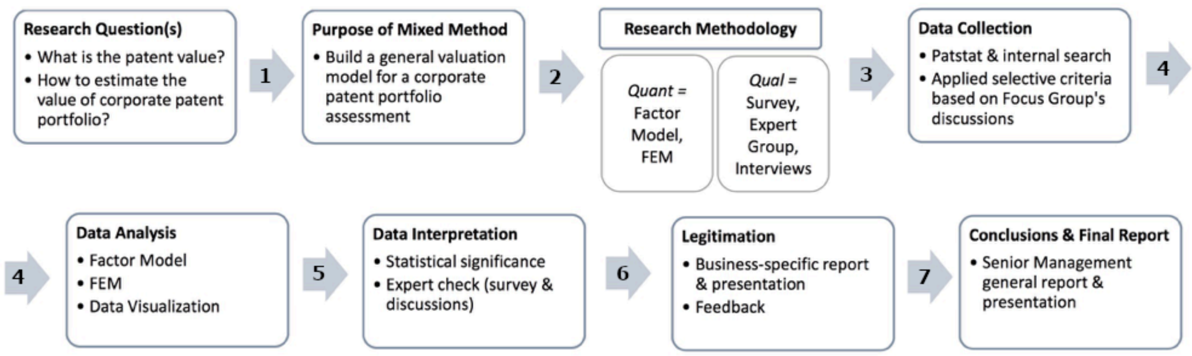

Figure 2 Mixed Methods Process Model

Before the data collection, I mix several methods to obtain criteria to filter the data. I use two primary sources of the patent records – an internal corporate database of patents and an external global database of the universe of patents – Patstat. As the first step, three patent attorneys form the Focus Group. Attorneys come from different business sectors with different scientific background, also they have diverse experience in the company – one of the patent attorneys has spent more than 20 years in different positions, two others are relatively new and worked in a pharma business and private practice as patent attorneys before joining the company. Thus, this diversification allows reducing possibly biased opinion on the patent value.

To reduce biased judgment of the patent families' quality, I made several on-site visits to interview patent attorneys, have discussions with the working group dedicated explicitly for this study before sending them the survey. Additionally, I studied the routine patent management practices.

2.3. Data Collection

The response rate is 96%, i.e., 26 of 27 patent attorneys sent their rates. Each of them received a table with selected his/her live patent families. There are four criteria been used to select families:

1. a patent family should have a "live status", i.e. the family contains at least one live patent that provides active protection for invention;
2. this live family member should be a granted EP or US filing;
3. the age of patent families selected for survey should vary across families – differentiation on the maturity of families allows to check if there is biased perception of a patent value due to relative "obsolesce" of patented technology;
4. preferably, patent families used in survey should belong to an invention/technology that is placed on the market.

However, not all of the attorneys work on patents that end up on the market straight away. Their portfolios consist of patents that relate to nascent technologies/product categories. Based on the criteria mentioned, I construct a sample of 149 patent families. I compare the results with the quality factor score that I assign to each family based on the valuation model.

2.4. Method: Interview and Method Selection

Before the survey, I interview attorneys to familiarize myself with a specific language that they use. During the interview, patent attorneys explained in detail their current practices of grading patents. After having a discussion, attorneys received a guideline with an explanation of a grading scheme to assign a certain "degree" of a patent strength to each of the patent families listed. The scale of quality falls into four categories:

1 = Low 2 = Moderate 3 = High 4 = Excellent

A patent data manager commented later:

"The values are to be updated as required and should be reviewed at least once per year. However, since the size of the portfolio varies from one patent attorney to another, the practices of evaluating and interpreting these strength classes are expert-dependent despite an existing general guideline. It makes it very challenging to have a holistic view of a whole corporate patent portfolio for senior management. Since each specific business-attributed portfolio (each patent attorney is responsible for a particular business area) requires a "personalized" interpretation. Thus, to unite business-portfolios in the unified corporate one is an extremely difficult task."

A Likert scale allows patent attorneys to "rank" families in a homogenous manner, also allows having a "middle" option, which helps better differentiation in a quality assessment above or below average perception:

1 = Poor 2 = Fair 3 = Moderate 4 = Good 5 = Excellent

I use a specific language obtained from interviews to translate numeric ranks into associated descriptive values. Because of the ambiguity of initially suggested scale, patent attorneys gave their interpretations of the scaling ranks to ensure clarity and disambiguate quality values. As attorneys explain:

"It is unclear how we can say that a patent family represents a low-quality invention since a granted patent protects the invention. Thus, it successfully went through the examination process and was qualified as a patentable. However, it is true that every patent office has its expertise and differs in examination procedures. Even if a patentee obtains a grant, under certain circumstances, a granted patent still can be challenged. A patent attorney may doubt the strength of a patent itself because of its weakness in one of the patentability requirements, i.e., in case of a possible patent-ineligible subject matter. In this case, we can consider this patent as a "weak" or "poor" but not "low" in a patentable quality."

With respect to the feedback, I define "1" not as a "low" quality rank, but rather a "poor" inventive quality.

Inherent differences of patent offices in filing processes and data collection is another issue that patent attorneys raised during the interview. Since the participating company based in Europe, most of the patent families contain at least one European filing (EP) under national or international PCT procedure.

Consequentially, instead of valuing each patent separately and aggregating them on a country-level, I choose a patent family as a unit for this study. This is motivated by the working group comment on the composition of a family:

"The practices of allocating patent into families eliminate divergences of the patent offices' examination practices partially when assessing the value based on the components' count by selecting the most reliable family-member as a representative."

Given that "the definition of a family is not defined by law, but by each database producer for their convenience" (Adams, 2006), for this study I choose the closest to the internal configuration type of family available in an open source database. The variety of patent family types exists. Patstat contains two types of families – DOCDB and INPADOC families. In the

OECD Patent Statistics Manual, the authors define patent families as “the set of patents (or applications) filed in several countries which are related to each other by one or several common priority filings” (OECD, 2009).

Several criteria apply to distribute patent families into groups (Martinez, 2010):

Family type	Criteria	Definition	Example
Equivalents	Technological filter on the definition – members belong to precisely the same invention	applications are sharing precisely the same priority or combination of priorities (single invention, economic studies)	Espasnet; Harhoff equivalents
Extended families	Indirect priority linkage in addition to the direct	applications directly or indirectly linked through priorities (broadest links, legal and applicant strategies)	Algorithm INPADOC; OECD triadic families
Single priority families	Allow to belong to more than one patent family (non-mutually exclusive)	applications originating from a single priority, not mutually exclusive, one application can belong to more than one family – algorithm (filing flows, workload, forecasting)	Trilateral; WIPO families
DOCDB single families	The expert check of the family members	applications with the same “active” priorities, i.e., adding new technical content	EPO DOCDB families
Novelty-based families	The expert check of the family members	applications with technical content matching existing records, i.e., based on the novelty principle	DWPI families

Table 1 Patent Family Types

Different patent families are used for different purposes, which explains the existing variety. For instance, equivalents are commonly used for the analysis of the backward citation networks, differences in procedures, and legislations of patent documents protecting the same inventions in different jurisdictions.

Disruptions in patent families can result from aggressive patenting strategies, transcription errors, and variations in national patent issuing procedures or inconsistent treatment by databases (Simmons, 2009).

Technically, the DOCDB simple patent family consists of all publications that claim the same active priorities as the “exchange–document.” Priority claims that add new technical detail are "active" and included in the priority picture being the basis for a family. Priority claims that do not add further technical detail are "not active" and excluded from the priority picture. So that applications that claim the same "active" priorities have identical priority pictures and are considered to cover the same technical content and they treated as members of the same DOCDB simple patent family. Active priorities stand for "first filings" and filings that have properties comparable to those of "first filings." Continuations and divisionals would not be "active priorities," but members of the family of their parent application, as they do not add new technical detail concerning the parent.

It appeared that the closest patent family construction to the internal aggregation happens to be the DOCDB family type because it has a similar logic of assigning patents into families. The compositions of DOCDB and internally built families match in the majority of cases, which ensures that DOCDB is a reliable family type for the analysis. On the one hand, there is a problem with choosing this type. Recently abandoned and withdrawn patents after they published will appear in the Patstat and will not in the internal database. Consequentially, only family size as a parameter for the factor is affected (enlarged) because of the overdue update of the legal status of patent applications in the publicly available database. Thus, I expect that this minor divergence will not dramatically affect the valuation results. On the other hand, there are several clear benefits to choosing DOCDB. First, since the data for the valuation of the technical content of invention comes from the Patstat database, this type of family construction is available and compatible.

Secondly, Patstat provides users with citations aggregated to the DOCDB family level. It eliminates the problem of a double count of citations on a family level. In the case of divisional patents, forward and backward citations usually should be attributed only to a parent patent. In the DOCDB family, these patents (parental and divisional) form the same family. Thus, a distinct count of citations gives results that are more trustful. Originally, EPO experts to simplify and optimize the examination process constructed the DOCDB family type.

Thirdly, EPO examiners to exclude the possibility of having a "black sheep" manually check DOCDB families. Patent families can also have ''black sheep" as a family member. A "black sheep" is a patent that mistakenly belongs to the family due to missing or incorrect claims for priority, multiple priorities, ambiguous data formats, or typographical errors. Technically, the difference between the DOCDB family construction compares to INPADOC that are both available in the Patstat looks as presented in Figure 3.

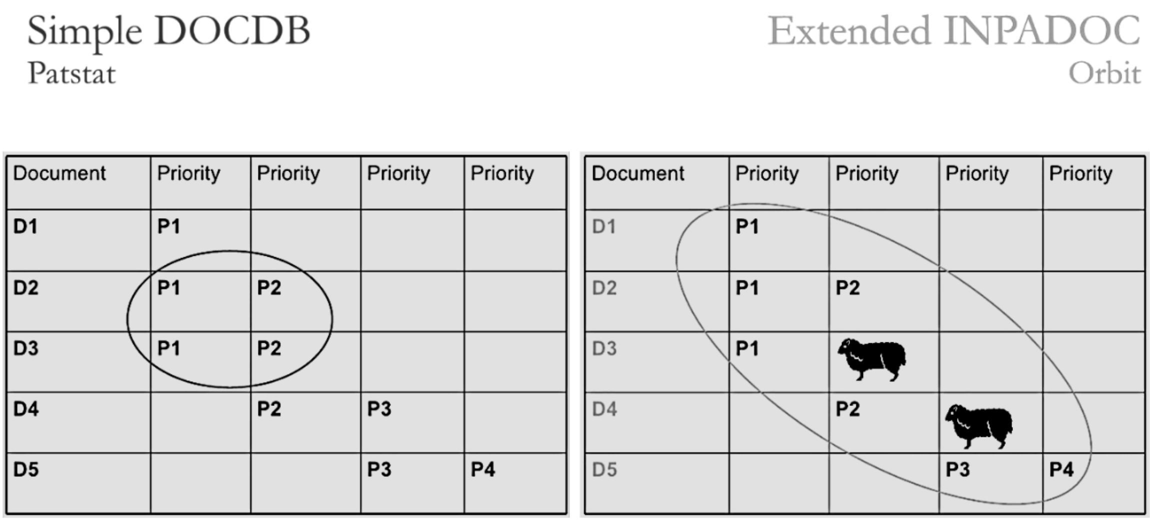

Figure 3 DOCDB vs INPADOC Family Structure

In the Patstat September 2008 (excluding families with one member only, i.e., singletons), the DOCDB family table reports 1'134'916 families, and the INPADOC family table includes 1'311'613 families. For the corporate data sample: I find 2'313 patents from overall 2'488 (93%), most of the patent records are missing due to their very recent filing date. As a result, there are 431 EP-granted patents identified, which form the basic sample for the analysis. To enable counting of factors, I match patents from the received list with the records in Patstat. To build the model, only patent applications published by EPO (European Patent Office) used in the analysis. Then corresponding to each EP-publication, a DOCDB patent family serves as a unit of valuation. If there are more than one EP-member in one DOCDB family, but in internal database these European patents belong to different families, these patent families share the average value in all measurements.

The working group specifies that *"…only EP filings should be considered for the factor modelling since there is a belief that EPO examination outcome is the most reliable data."* As the result, I focus on EP granted families, i.e. families with at least one EP-granted patent. For this family type, I calculate the "actual value" of such patents using factor model.

To better understand the decision-making process that the valuation model should address, I describe the patent-related responsibilities and functions in the company in details.

2.5. Patent Management – the corporate case study

Building a high performing team: "*Drive patent leadership and maintain full freedom to operate in all key categories*"

The Corporate Internal Guideline

As stated above, the participating company is a big European-based multinational company with a wide patent portfolio spread across a variety of businesses. Overall, there are more than 20'000 patent applications filed by the company, which results in around 3'000 DOCDB families.

The company allocates industries in which it operates in 15 business-clusters (BCs). From the patent management perspectives, at least one patent attorney is responsible for each business cluster and manages an associated patent portfolio.

The central patent department is responsible for patent portfolio management in the company. The department is a part of the Intellectual Asset Management (IAM) group, which, in turn, is a part of the R&D division. Such a close allocation of IP assets and related decision-making processes to the general R&D management finds to be crucial for a successful overall approach of IP issues (Pitkethly, 1997). Overall, three substructures represent the IAM group (Figure 4).

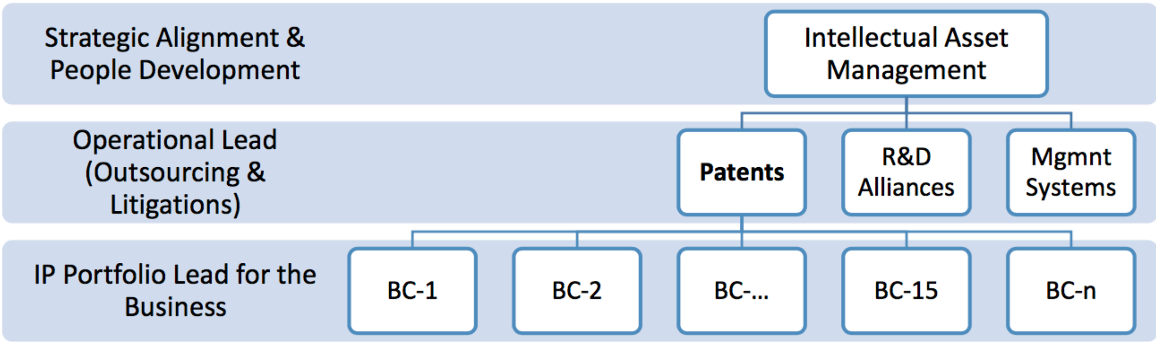

Figure 4 Corporate organigram

At some point, "knowledge management" (Nonaka, 1995) has become one of the primary activities for the company. At the same time, along with innovative development, the company needs to pay attention to many other businesses that determine its competitive dominance on the market. The orchestration of all kinds of assets should be the principal activity of the company and its top management.

In support of earlier statements, as highlighted by one of the senior managers:

"... Innovation and re-innovation are key elements of the compliance and sustainability principles of the company"

Furthermore, as stated by the top management:

"... Our company aims to extend the boundaries of its business beyond the core portfolio. Industry-leading research and development drives innovation and support the constant renovation of the portfolio. The company invests a tremendous effort to fully release its fast-growing ambitions in more focus market sectors. High-potential projects give these new businesses a strong innovation pipeline. To deliver on the promises made to consumers as well as to stakeholders, the company encourages innovations through active internal research and fruitful joint ventures with partners different in nature."

Thus, the management of intellectual assets that embodies innovations becomes a primary concern of the top-management. The patent department is responsible for the patent strategy development. Since patent attorneys are key decision makers in the process of strategy development and execution, I invited them to form the working group. As the outcome of these discussions along with statistical modelling, an algorithm for the patent valuation wad developed as described in the next section.

3. The Concept of the Patent Value

Since there is no automated or automatic approach to patent valuation; each case requires a specific investigation (Giuri, 2015), companies face difficulties defining the patent portfolio value, which creates major obstacles in defining strategies and managing assets.

Moreover, the concept of patent value often overlaps with the concept of patent quality (De Rassenfosse, 2018). In this paper I focus on patent valuation and define the value of a patent as a contributed inventive step to technological progress covered by a patent.

To build a patent value indicator I follow OECD methodology as a basis for the factor model developed. In the report authors propose to use 11 indicators collected from the literature addressing patent valuation and patent quality to build a patent quality index. The proposed measures are based on the information contained in the patent related documentation, such as claims, citations, etc. The unit of analysis in the report is a patent application that the authors suggest to aggregate later in portfolios either for companies or for countries. I build my indicators on the family level, meaning that I take an EP or US granted representative of a family, calculate all indicators on its individual levels and assign this value to a corresponding families. Then I aggregated families in a portfolio. Presumably, this allows me to exclude any double counting of patent applications in portfolio that could potentially belong to one family.

Almost all indicators are calculated on an individual level of an EP granted patent, like number of claims, grant lag, NPL citations, IPC scope. However, forward and backward citations as well as the number of oppositions are calculated on the DOCDB level. Patstat offers citations aggregated into DOCDB families. Oppositions can be filed against more than one patent family member, in this case I sum up all oppositions filed against a certain family.

Conclusively, each absolute value for a distinct patent application is normalized, i.e., divided by the average of the corresponding indicator of all patents belonging to the same year and technology cohort (IPC-4 level). If the normalized indicator is above one, it means that the company's patent performs "better" than the rest patents from the same year and the same technology class, and it performs "worse" than others do if it goes below one. Conceptually, in the situation, if it equals to one, it is a sign that only one company has filed a patent application in this year in this field, which is almost impossible considering the level of data aggregation (IPC4). Kuhn, Younge and Marco (2020) have shown that normalization is crucial, especially for the citation count since the nature of citations varies over time and depends on multiple factors.

4. The patent valuation model

An extensive literature exists in the patent research that suggests a mix of quantitative techniques with qualitative studies to cross-validate the findings. As the most profound way of obtaining qualitative estimates on the patent data are interviews and surveys of patent experts from multiple functional points of view: patent attorneys, examiners, inventors, etc. As stressed by Jaffe and De Rassenfosse (2019), the direct interaction with patent "data-producers" brings a lot of scientific advantage to the research outcome.

Harhoff with co-authors (1999) proposed to combine estimates of the value of patent rights from a survey of patent-holders with a set of indicator variables to model the value of patents. The results suggest that the number of references to the patent literature, as well as the citations a patent receives, is positively related to its value. The survey was directed at German patent-holders who were asked to assess the asset value of their patent rights in the research design authors used resulting scores from the study as a dependent variable in their analysis.

In this paper, I propose to turn it around and use the results obtained from the attorneys as an independent measure in the regression model. This approach allows us to associate which of the distinguished patent metrics derived from the Patstat can be related to the expert perception of the patent portfolio value. The patent attorneys' score stands for the rating of the perceived inventive value of patent family obtained from the survey of patent attorneys.

The results of the factor model are based on patent value components, such as:

- Backward citations
- Forward citations
- Claims
- Grant lag
- Patent IPC Scope
- Patent family size
- Citations to non-patent literature (NPL)
- Oppositions

Also, composite indicators are included in the set of estimating variables:

- Generality
- Originality
- Radicalness

A graphical representation of the modelling process:

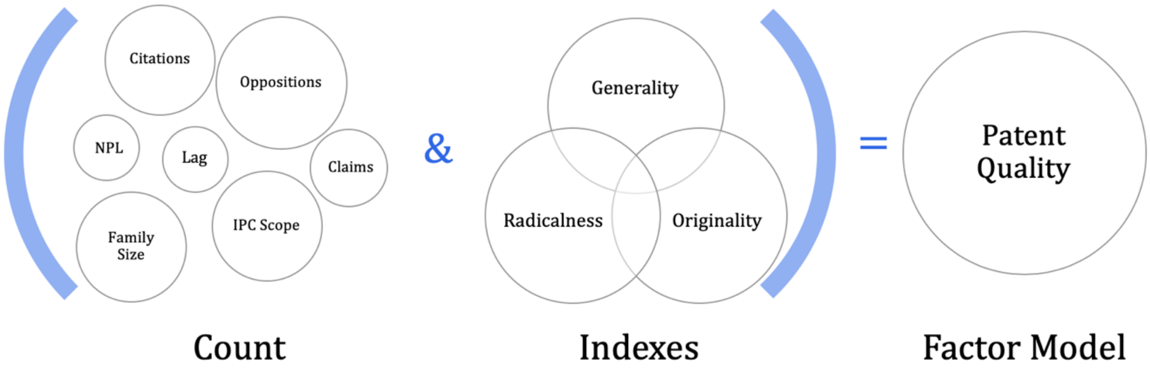

Figure 5 Factor Model Composition

4.1. Indicators and Definitions

1. *Patent IPC scope* is the number of distinct 4-digit subclasses of the IPC the invention is allocated to. This indicator used in previous research to measure the technological breadth of a patent application. The large number of IPC classes was shown to reflect the broad scope of inventions described in the patent. The scope of patents assumes to indicate the technological and economic value of the invention. As proved by Lerner (1994), the patent scope as a proxy for the breadth of patent protection significantly affects firm value. Moreover, he finds that broad protection is required for “non-unique” inventions, i.e., when there are many possible substitutes available on the market from the same technological cohort.

$$Scope_{pf} = n_p; n \in \{IPC_1^4; \dots; IPC_i^4; IPC_j^4; \dots IPC_n^4\} \& IPC_i^4 \neq IPC_j^4$$

Recent research has shown that in fact the number of IPC classes is a problematic measure of a patent scope (Kuhn, 2019). In this paper, I use the number of IPC classes to measure only how broad a patent is in terms of its technological variety but not the extent of the legal right to exclude afforded by a patent.

2. *Forward citations* count is the number of citations a given patent receives after its publication (including self-citations)[1]. According to Trajtenberg (1990), the forward citations count is a robust indicator of the value of patents. The author defines the value of innovations as social benefits that people, as consumers, enjoy in the form of additional surplus and the profit streaming that flows from innovations. However, Trajtenberg proved his idea based on the data for the US patents.

To generalize these findings across different patent offices, researchers (Harhoff D. S., 2003) found the same result for European systems with a primary focus on German patents. Since the corporate patent portfolio mainly locates in Europe and the US, the count of citations received from subsequent patents (in the project, patent families) is a reliable proxy of the value.

Other scholars (Moser, 2015) further investigate the relevance of citations to ensure the same pattern within different industries. The most important finding is that citations positively correlate with yields and other objective measures of the size of the inventive step. Authors support the assumption that citation count is an informative measure for the quality of patents. Additionally, findings are interpreted as suggesting that in rapidly growing industries (such as, e.g., biotechnology, information technology and business models in finance) early patents may receive a more significant number of citations – irrespective of the value of the innovation that they cover – because they establish patentable subject matter. In these industries, self-citations can be a useful predictor for follow-on (cumulative) invention. Therefore, the more citations the family receives, the more valuable it deemed to be for society and the company.

$$Fwd_{i,T} = \sum_{t=P_i}^{P_i+T} \sum_{j \in J(t)} C_{j,i}$$

[1] Also I tried to adjust the count for both Forward and Backward citations with respect to the Family Size. However, this resulted in a drop in the performance of the model.

In the formula, the components are defined as follows:

- Fwd is the total number of forward citations including self-citations received by i-patent family published in Pi-year;
- C is a dummy variable that equals to 1 if j-patent family cites i-patent family, and it gets 0 if it does not. (t) is the pool of all patent families published in year t.

3. *Backward Citations* count is the number of citations (references) made in a given patent (including self-citations). The count mirrors the degree of novelty of invention and intensity of the knowledge "takeover" from previously patented innovations. Despite this logic, Harhoff et al. (2003) argue that patent examiners, who add citations, may try to restrict a broad IPC scope of the invention by including more references to the patent application. Thus, a large number of backward citations may signal the innovation to be more incremental (Lanjouw J. O., 2001). At the same time, the more patent family cites other families, the more technically sophisticated it can be considered.

4. *Non-Patent Literature (NPL)* Citations count is the number of backward references by a given patent to publications in all non-patent scientific sources, such as academic journals, essays, conference presentations, books, public databases, etc. According to OECD, findings from these sources set boundaries of patents, claims for novelty, inventive activity, and industrial applicability. Conceptually, the propensity to cite NPL reflects the relatedness of scientific knowledge to the invention and delineates the affinity of claimed technology and scientific developments.

The previous literature indicates as well that NPL can be non-trivial. As firstly suggested by Narin, Hamilton, & Olivastro (1997) and further proved by Callaert, Van Looy, Verbeek, Debackere, & Thijs (2006) and Branstetter, Fisman, & Foley (2004) patents that contain non-patent references comprise complex and fundamental knowledge, since it is a clear sign of intensive technology-science liaison. To enrich the theory of citations as a proxy of value Von

Wartburg, Teichert, & Rost (2005) analysed complex citation networks of patents. Their findings reveal that complex and multi-level patent citations are common for inventions with a higher technological value-added. Thus, patent families with a rich, backward literature heritage should bear superior quality.

5. *Opposition count* is the number of oppositions received by a patent as a signal of a competitive hindrance to the opponent, i.e., a close competitor, for further technological development. A large number of oppositions is a clear sign of ongoing competition on the market for the technology, which is disclosed in the patent family. Opposition proceedings are notorious for the fact that they carry financial costs and are effort consuming since patent attorneys and engineers need to carefully work together through the case and prepare strong arguments to act successfully before the office. As an inference, it is clear that if a patent was opposed, it mirrors its crucial value as a preventing barrier for competitors to enter and openly market the technology. The study by Allison et al. (2003) found that litigated patents differed in statistically significant ways from issued patents by any measure and claimed them as if not the most valuable but precious in the portfolio. The results and interpretations of the study coincide with the results from the previous studies.

There are several offices offering to legally oppose a patent, including the European patent system. As an option, to partially equalize the quality assessment and prevent underestimation of patents other than EP (since oppositions find to be significant for the valuation), at least for the US patents data on re-examination requests may serve as an analogue. The comparative study on opposition and re-examination frequencies indicates that valuable patents are more likely to be challenged in both ways. However, the rate of opposition at the EPO is more than thirty times higher than the rate of re-examination at the USPTO (Graham, 2002). Nevertheless, according to the proposed methodology, families (not single patents) form a unit of analysis, thus if at least one patent receives oppositions, the total number of oppositions to this patent will be attributed to the whole family.

6. *Patent Family Size* is the distinct count of jurisdictions in which patent protection for the same invention is sought (Lanjouw J. O., 1998). Inventions protected by a large international family are of high value, given the many costs incurred in the international application process. Therefore, the more members the family has, the more valuable it is.
The initiative to use the patent protection breath originates from the research by Putnam (1996), where he found a positive correlation between the internationalization of the patent protection scope, i.e., the patent family size, and R&D expenditures. In its turn, the relevance of R&D expenditures to the firm market value has been proved in various research designs. Some of them addressed the interrelation of R&D Capex and stock-market returns (Chan, 1990); others looked at their overall importance for investors and stakeholders in terms of long-term benefits (Lev, 1996). Logically, if the R&D positively affects the firm market value and its connection to the patent quality as was stated previously, and the patent indicators, such as family size, has an impact on the quality, there should be a causal evidence that the patent family may have an indirect correlation to the company's value. As Lanjouw validates, the patent family measure serves as a significant indicator of the patent quality in terms of its technological advancement. The conclusion is that the large family covers a more scalable and relevant invention that is more capital intensive. It is, ergo, it brings more value to the company.

7. *Claims* count is the number of claims for a given patent, which codifies the inscription of the invention and constitute the scope of protection in case of obtaining a grant. Claims are the legal definition of the invention, or "building blocks" of the invention (Hall B. H., 2001). Depending on the patent office, the number of claims is limited. Extra-claims require additional payments.

According to the law, a European application, which contains more than fifteen claims at the time of filing the claims, incurs payment of a claims fee in respect of each claim over and above that number. Claims fee – for the 16th to the 50th claim 235 euro, claims fee – for the 51st and each subsequent claim 585 euro (EPO, 2016). However, even if there are financial incentives to reduce the number of claims, the total number of claims in the patent document provides more options to support the defence in case of infringement. The scope of the technical content determines the boundaries of the exclusive rights of a patent owner, given that only the technology or aspects covered in the claims can be legally protected and enforced. A large number of claims might also imply higher fees. Thus, it may reflect not only the technological breadth of a patent, but also its expected market value. Litigated patents have, on average more claims than "intact" patents (Allison, 2003). Even if there could be no direct causality, patents with more descriptive content are more expensive for the owner. It allows assuming, that the higher the number of claims, the higher the expected value of the patent.

8. *Grant Lag* is the number of days elapsing between the date of filing application and the date of obtaining a grant. The more controversial claims lead to slower grants, and well-documented applications are approved faster. In contrast to other indicators, the smaller the lag, the more innovative content of the patent application seems to be.

$$Grant_{Pi} = 1 - \Delta t / Max(\Delta t_i)$$

With the following definitions:

- Δt is the number of days from the priority filing date and the date of obtaining the grant;
- Δt_i is the maximum number of days that took for an applicant to get a grant on a patent from the same i-cohort (within the same IPC4 code and the same filing year).

Patent value is not just something that academics can identify after the fact but also something that patent owners themselves can predict in advance (Allison, 2003). For doing that, patents should be accounted only for their distinguished isolated metrics but also for their backward- and forward-looking contribution based on the value-added content.

4.2. Composite indicators

A simple count of the patent metrics is not enough to grasp the competitive advantage of the corporate portfolio even after the results were normalized relative to the average value performance of other patents. This comparison gives only a “static enclosed” value of a patent family because it reflects the family as it is. Some academics proposed more sophisticated measures, so-called “indexes,” to value patents according to their “dynamic, open” value by accounting for their technical contribution to the world of innovations. Some of them are discussed below and consequentially considered in the valuation model.

9. *Generality index* is a redefined version of the Hirschman-Herfindahl Index (HHI). In concordance with the proposed modification by OECD experts, the index relies on information concerning the number and distribution of forwarding citations and the technological classes (IPC) of the patents these citations come from (the patent “scope and scale”). The logic behind is that forward patent citations can be used to assess the range of later generations of inventions that have benefitted from a patent, using measuring the range of technology fields – and consequently industries – that cite the patent. In their pioneering research, Bresnahan & Trajtenberg (1995) proposed the methodology in the form of the algorithm to unfold what they called General Purpose Technology (GPT) clusters and capture the rate of technical advance in the cluster of associated application sectors. An application sector (AS) stands for an actual or probable field of implication (for example, a “computer” sector is AS of a “semiconductors” GPT).

For the valuation of the advancement of GPT itself instead of assessing AS the Generality measure has evolved. In further researches (Jaffe & Trajtenberg, 1996 and Hall, Jaffe, & Trajtenberg, 2001) have constructed and explored the validity of the generality measure. Unlike their approach, here the generality takes into account all IPC classes comprised in the citing patent and account for the number and scope of both 4-digit and n-digit IPC classes that are inside this referring patent. Here n-digit IPC class is the most granular level of the technological description. As specified in the OECD report:

- X is the focal patent family with Yi patent families citing family X, i.e. forward citations, $i \in [1, N]$;
- βij equals to:

$$\beta_{ij} = \frac{T_{ij}^{n}}{T_{i}^{n}}$$

- Tin is the total number of IPC n-digit classes in citing family yi;
- Tn is the total number of IPC n-digit classes in jth IPC4 digit class in citing family y;
- j = 1, is the cardinal of all IPC4-digit classes in citing family.

In this way, the Generality index is defined as:

$$Generality_{p} = 1 - \sum_{j=1}^{M_i} \left(\frac{1}{N} \sum_{i=1}^{N} \beta_{ij} \right)^2$$

Knowing βij, substitute it into equation and get the detailed equation as follows:

$$Generality_{f} = 1 - \sum_{j=1}^{M_i} \left(\frac{1}{N} \sum_{i=1}^{N} \frac{T_{ij}^{n}}{T_{i}^{n}} \right)^2$$

In the equation, a dominator equals to $T_i^n \times N$. Computationally, it appears in the form of a normalized value defined between 0 and 1. The indicator is high if a patent is cited by subsequent patents belonging to a wide range of fields – i.e., the considered invention has been relevant for several later inventions and not only in its technology class. Conversely, if most citations are concentrated in a few fields, the generality index is low, i.e., close to zero. Generality measures rely on forward citations; thus, as forward-looking, it may be biased since it suffers from natural time limitations.

10. *Originality* refers to the breadth of the technology fields on which a patent is built. It mirrors the idea of generality by gauging the technical "body" of cited patents; in other words, originality is based on IPC amplitude of backward citations. Trajtenberg et al. (1996) derive the indicator from the same paper. Their results suggest that if a patent cites previous patents that belong to a narrow set of technologies, the originality score will be close to 0. Whereas inventions with broader technological roots of the underlying research, which covers a wide range of diverse knowledge sources, should introduce more original results, should receive a score closer to 1.

$$Originality_f = 1 - \sum_{j}^{n_f} s_{fj}^2$$

11. *Radicalness* is a time-invariant count of the number of IPC technology classes in which the patents cited by the given patent are, but in which the patent itself is not classified. The more a patent cites previous patents in classes other than the ones it is in, the more the invention should be considered radical, as it builds upon paradigms that differ from the one to which it is applied.

$$Radicalness_f = \sum_{j}^{n_f} CT_j / n_p \ ; \ IPC_{fj} \neq IPC_f$$

5. Factor Model Analysis

5.1. Model settings

True patent value is unobservable and hard to get. In the literature, there have been attempts to get a proxy for the unobserved patent value using various patent characteristics. These value-proxies are typically constructed with factor models. For example, Lanjouw and Schankerman (2002) built a minimum-variance estimator using four different variables (he number of claims, forward citations to the patent, backward citations in the patent application, and family size). In this context, the patent quality indicates both the technological and economic value of innovations covered by the patent. The obtained measure represents a meaningful measure of corporate research productivity, and it finds to correlate with the social and private value of the patented inventions (Hall, 2005). The difference in average patent quality across firms is generally associated with the market evaluation of firms.

The idea behind the factor model is to recover the unobservable latent structure of multiple factors that drive the variation in my observed inputs. A patent quality is related to the underlying unobserved structure that is uncovered by the factor model.

In my factor analysis, I use 11 inputs: IPC cope, forward citations, backward citations, non-patent literature (NPL) citations, family size, number of claims, grant lag, number of oppositions, generality, originality and radicalness. Each input represents a count of metrics normalized by filing year and by IPC4 code. The normalization here stands for the statistical value adjustment by the standard deviation that is dividing of each components' simple count for the focal patent family's representative by the average performance of all patents in the same technological field in the same application year aggregated at the family level.

The formula is the following:

$$x_{norm} = \frac{x - \bar{x}}{\sigma}$$

Here, x_{norm} is a normalized value, x is an actual value of an observation, $\bar{x}$ is a mean of x and σ is a standard deviation.

First, I run the factor analysis on all inputs (see Appendix I,1). As the correlation matrix shows (see Appendix I,2) there are some significant correlations between the inputs, so there is evidence of an underlying structure the factor analysis would recover. The estimated formulas are 11 formulas that have the following representation:

$$x_{norm} = l_{i1}F_1 + l_{i2}F_2 + l_{i3}F_3 + e_i$$

$$i \in [1{,}11]$$

I build three factors. I choose three because if I run the factor analysis for further factors eigenvalues were too low.

To simplify the exposition of the factor structure I am using a promax rotation technique. Promax is an oblique rotation method, which means the underlying factors are not orthogonal. If I compare promax with alternative rotation techniques (like varimax), according to results from a comparative study (Finch, 2006) suggest that the two approaches are equally good at recovering the underlying factor structure, regardless of the correlations among the factors, though the promax is better able to identify the presence of a more simple structure.

Following the mixed-method approach, and as an external validation, I look at the correlation of the factor model results with the patent attorneys' scores obtained from the survey. The survey scores come from 27 internal patent attorneys distributed across more than 15 distinguished business clusters (the questionnaire is attached in Appendix II). I send a list of at least five directly used (product-associated) patent families to each patent attorney and ask to rate listed families. I correlate obtained scores with results from the factor model. The correlation is around 0.2, which is low but positive. The low correlation coefficient might be due to the social nature of survey results, it is hard to exclude biased judgments. For example, if a patent attorney considers an elder invention covered by a corresponding patent family as not technically excellent because s/he has already drafted a new generation of the invention.

The resulting correlation table is the following:

Correlation with the Patent Score	
0.215	**Factor 1**
-0.030	Factor 2
-0.042	Factor 3
0.057	IPC Scope
0.154	Forward Citations
0.129	Backward Citations
0.072	NPL citations
0.157	Family Size
-0.076	Claims
0.015	Grant Lag
0.017	Oppositions
0.081	Generality
-0.058	Originality
-0.025	Radicalness

Table 2 Correlation Matrix

To elaborate on this assumption, I perform the fixed effect model with a control effect of the age of the family. Presumably, older families are underestimated in the value due to a technological obsolesce of inventions, especially in businesses with shorter product life cycles. As studied by Haupt et al. (2007), data on patent applications can be used to study technological life cycles of inventions via the so-called patent activity index. Thus, the age parameter may affect a personal perception of inventive quality claimed in the patent. For instance, in case if a patent attorney knows that there was the next generation or substantial/incremental modification of the patent family listed in the survey, s/he can perceive that the invention/technology claimed in that patent family is not so advanced. However, at the time of drafting, this family may be a “nascent” discovery in the field. As anticipated, the attorney then will give a lower score to the family. To check this assumption, I control the filing year parameter of patent applications.

The results of three regressions are presented in Table 3. All results are entirely consistent with the row correlation matrix, where Factor 1 is the most correlated with the score. The first result shows the regression analysis on all three factors. When I test the assumption of age parameter in patent valuation by adding the filing year, I am having mixed results, suggesting that patent attorneys do not show evidence of treating the value of patents depending on their age. When I control for the business cluster fixed effect, my results for the factor remain unchanged.

	Patent score		
Const	0.000 (0.085)	22.983 (53.507)	-14.182 (47.055)
Factor 1 (Focal Patent Bibliometrics)	0.225** (0.091)	0.235** (0.095)	0.300*** (0.103)
Factor 2 (Technology Class Dispersion)	0.022 (0.089)	0.028 (0.090)	0.093 (0.090)
Factor 3 (Radicalness)	0.017 (0.090)	0.021 (0.091)	0.064 (0.080)
Filing Year		-.011 (0.027)	0.007 (0.023)
Business Cluster FE	No	No	Yes
R-squared Adj.	0.025	0.019	0.043
Observations	134	134	134

Table 3 Regressions of Patent Score on Factors

6. Conclusion and discussion

As expected, the results from the model aligned with a perception of patent attorneys regarding the value of patent families. As a limitation, the described methodology does not provide managers with a probable forward-looking value of a patent family.

Even though the factor model addresses the question of how the patent value can be obtained from the measures that, as confirmed by the previous research, are value-related indicators, it does not have a strong correlation with the experts' opinion on the patent value. Unexplained variation raises a question if the further research should look more into the validity of established patent value or patent quality measurements and how the relevance of such measures can be improved towards the experts' opinion on the value.

The model aims to serve managers as a tool for patent portfolio valuation. Relying on the observables, patent managers will develop tactics depending on a product segment. A thoughtful way of approaching business development is a crucial element to remain a leader on the market, maintain evolution and trust.

The results of this study provide decision-makers with valuable insight into the patent portfolio management. Concerning the portfolio diversification, the analysis was performed on the whole portfolio and each business cluster. The correlation between the concentration ration and the quality score changes depending on the level of data aggregation. Experts' opinion suggests splitting the portfolio into business-specific clusters. The resulting ranking of patent families for each cluster serves better the objectives of valuation. Likewise, executives can compare innovations across businesses, set priorities, and make wiser strategic decisions.
Certain pitfalls that should be considered while interpreting the results:

Young and local families are small in IPC scope. Consequentially, these families have a lower rank. It may lead to the underestimation of potential future value. However, the low value reflects actual ("tangible") achievements of such families. A forecasting model can be built to project the future value of young families based on current trends and tendencies.

Under the GP approach, all countries are equalized. For example, China has the same contribution as Mongolia, which may lead to incorrect score rankings. To deal with the issue, $p2$ is introduced as an alternative estimator, which considers disparities in population and purchasing power across countries. This methodology helps to provide the most expedient estimations. The best way to gauge financial coverage of patents is to prioritize countries and assign weights depending on their corresponding profitability.

Oppositions only for EP Any member of the public except for the proprietor himself can oppose a patent that is granted only by EPO. As an alternative, in the USPTO, the re-examination of a granted patent may be requested. As a European-based company, it usually has at least one EP representative in each family; the valuation occurs at the family level.

The DOCDB family type is not a perfect match to internal families' structure. The content of families is essential for patent qualification. The external/internal data congruence is less critical. A primary aim of the quality ranking is to look at the portfolio from the outside as an external viewer rather than an insider. It allows the company to understand what competitors may grasp from the internal databases in case they decide to analyse corporate patent strategies.

Missing data. To provide managers with a holistic view of the portfolio significance, all patent families should be included in the model. The analysis covers only a certain selection of patent families. For the same purpose, the internal data should be routinely cleaned, recovered, and updated by data managers to guarantee unbiased results with no black sheep, submarines, or lost record due to improper data tracking.

It is not a by-patent-contributed value but rather by-patent-protected value. The quality index mirrors the value of invention that is disclosed in a patent; financial value stands for the cash flow that comes from sales of the products, which use patented technologies. A patent here is just a mean to capture the intangible value of having a privilege to prevent competitors from entering/acting on the same market as well as enjoying a long-lasting (usually 20- years) period of promotion and brand building around these exclusivities.

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Appendix

Appendix I: Factor Analysis

1. Factor loadings from the principal factors method (without rotation)

Factor loadings (pattern matrix) and unique variances

Variable	Factor1	Factor2	Factor3	Uniqueness
norm_Scope	0.3527	0.3801		0.6442
norm_Fwd	0.8516			0.2647
norm_Bwd	0.6001			0.6211
norm_NPL				0.9312
norm_Size	0.7645			0.4098
norm_Claims	0.3907			0.8454
norm_Oppostn	0.7076			0.4926
Generality		0.4405		0.7378
Originality		0.6825		0.4813
Radicalness			0.5733	0.6236
Norm_lag_a~n				0.9327

2. Correlation matrix of inputs

	norm_~pe	norm_Fwd	norm_Bwd	norm_NPL	norm_~ze	norm_C~s	Norm_l~n	norm_O~n	Genera~y	Origin~y
norm_Scope	1.0000									
norm_Fwd	0.4128	1.0000								
norm_Bwd	0.3909	0.6809	1.0000							
norm_NPL	0.1444	0.1749	0.1046	1.0000						
norm_Size	0.2498	0.6048	0.5971	0.2156	1.0000					
norm_Claims	0.1043	0.3647	0.3557	0.3386	0.3628	1.0000				
Norm_lag_a~n	-0.1235	0.0614	0.0374	-0.0390	0.1168	0.0169	1.0000			
norm_Oppostn	0.3628	0.6964	0.5791	0.3538	0.7553	0.3877	0.0756	1.0000		
Generality	0.1943	0.0928	-0.1183	0.0403	-0.1300	-0.1095	-0.0747	0.0086	1.0000	
Originality	0.1841	-0.2464	-0.2026	0.0525	-0.2360	-0.2294	-0.1120	-0.1005	0.3570	1.0000
Radicalness	-0.4069	-0.1700	-0.0929	-0.0842	-0.0988	-0.0699	0.0876	-0.1459	0.0736	0.3938

	Radica~s
Radicalness	1.0000

3. Factor loadings and scoring coefficients from the factor model with promax rotation

```
Factor analysis/correlation                        Number of obs    =      393
    Method: principal factors                      Retained factors =        3
    Rotation: oblique promax (Kaiser off)          Number of params =       30
```

Factor	Variance	Proportion	Rotated factors are correlated
Factor1	2.58166	0.7046	
Factor2	0.90903	0.2481	
Factor3	0.56682	0.1547	

```
LR test: independent vs. saturated:  chi2(55) = 1080.03 Prob>chi2 = 0.0000
```

Rotated factor loadings (pattern matrix) and unique variances

Variable	Factor1	Factor2	Factor3	Uniqueness
norm_Scope	0.3743			0.6442
norm_Fwd	0.8597			0.2647
norm_Bwd	0.6027			0.6211
norm_NPL				0.9312
norm_Size	0.7469			0.4098
norm_Claims	0.3797			0.8454
norm_Oppostn	0.7114			0.4926
Generality		0.4375		0.7378
Originality		0.7326		0.4813
Radicalness			0.6215	0.6236
Norm_lag_a~n				0.9327

```
. predict f1 f2 f3
(regression scoring assumed)

Scoring coefficients (method = regression; based on promax(3) rotated factors)
```

Variable	Factor1	Factor2	Factor3
norm_Scope	0.08455	0.24857	-0.29525
norm_Fwd	0.42777	0.06981	-0.04189
norm_Bwd	0.14274	-0.08221	0.12131
norm_NPL	0.06682	0.02165	0.03741
norm_Size	0.24929	-0.13472	0.02852
norm_Claims	0.06452	-0.00519	-0.03426
norm_Oppostn	0.17655	0.02835	-0.04394
Generality	-0.02658	0.24242	-0.17892
Originality	-0.01088	0.48248	0.08526
Radicalness	-0.00646	0.03161	0.43008
Norm_lag_a~n	0.03083	-0.04991	0.10808

4. Regression on Factors

Regression on Factor 1

```
. reg PatentScore_n f1_n

      Source |       SS       df       MS              Number of obs =     134
-------------+------------------------------           F(  1,   132) =    6.41
       Model |    6.163486     1    6.163486           Prob > F      =  0.0125
    Residual |  126.836524   132  .960882759           R-squared     =  0.0463
-------------+------------------------------           Adj R-squared =  0.0391
       Total |   133.00001   133  1.00000008           Root MSE      =  .98025

------------------------------------------------------------------------------
PatentScor~n |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        f1_n |   .2152719   .0849981     2.53   0.012     .0471372    .3834066
       _cons |  -7.24e-08   .0846804    -0.00   1.000    -.1675062    .1675061
------------------------------------------------------------------------------
```

Regression on Factor 2

```
.  reg PatentScore_n f2_n

      Source |       SS       df       MS              Number of obs =     134
-------------+------------------------------           F(  1,   132) =    0.12
       Model |  .120626747     1  .120626747           Prob > F      =  0.7298
    Residual |  132.879383   132    1.006662           R-squared     =  0.0009
-------------+------------------------------           Adj R-squared = -0.0067
       Total |   133.00001   133  1.00000008           Root MSE      =  1.0033

------------------------------------------------------------------------------
PatentScor~n |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        f2_n |  -.0301159   .0869994    -0.35   0.730    -.2022092    .1419774
       _cons |  -7.38e-08   .0866741    -0.00   1.000      -.17145    .1714499
------------------------------------------------------------------------------
```

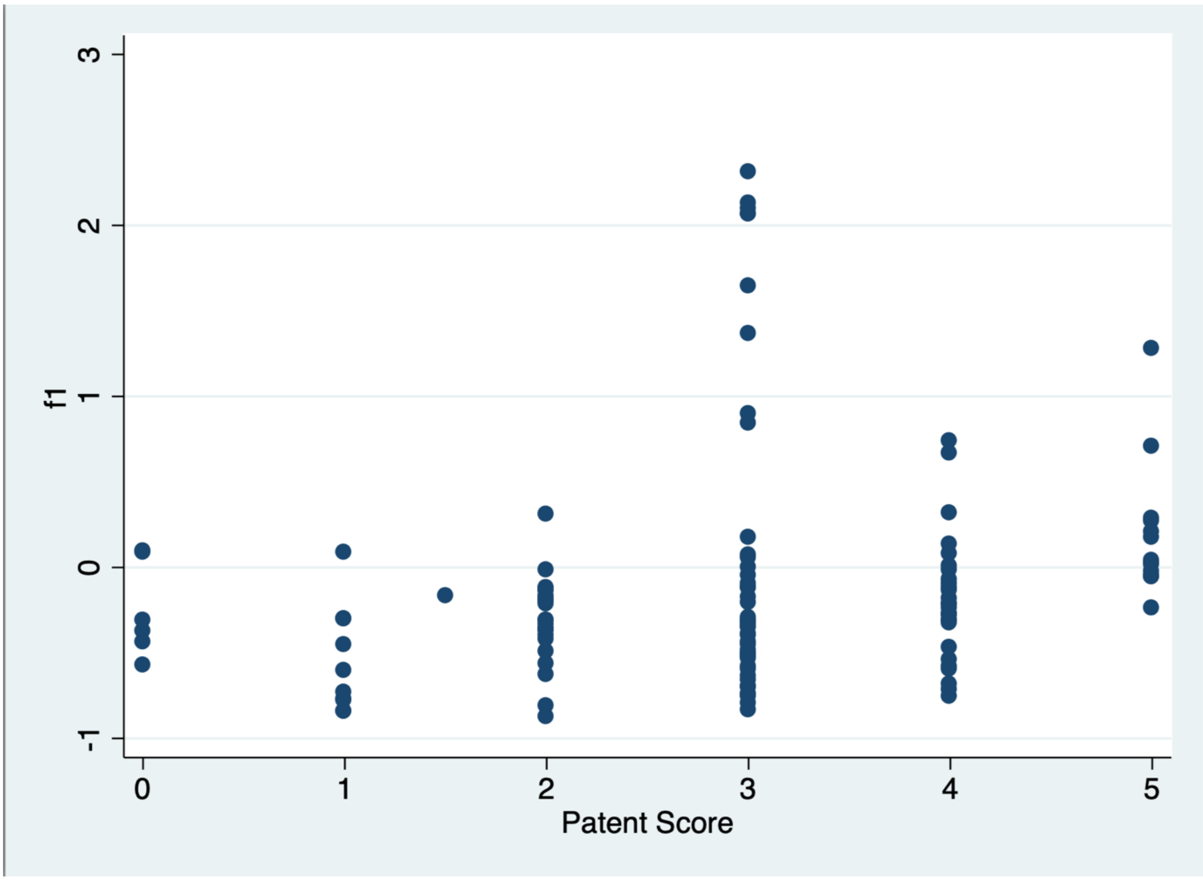
Regression on Factor 3

```
. reg PatentScore_n f3_n

      Source |       SS           df       MS      Number of obs   =       134
-------------+----------------------------------   F(1, 132)       =      0.24
       Model |  .238095088         1  .238095088   Prob > F        =    0.6274
    Residual |  132.761915       132  1.00577208   R-squared       =    0.0018
-------------+----------------------------------   Adj R-squared   =   -0.0058
       Total |   133.00001       133  1.00000008   Root MSE        =    1.0029

------------------------------------------------------------------------------
PatentScor~n |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        f3_n |  -.0423106   .0869609    -0.49   0.627    -.2143278    .1297066
       _cons |  -7.38e-08   .0866358    -0.00   1.000    -.1713742    .1713741
------------------------------------------------------------------------------
```

5. Scatter plot Patent score vs Factor 1



Appendix II: Survey

Dear XX,

As a part of the ongoing patent valuation project, I am inviting you to participate in a survey. The purpose of this survey is to validate the calculated Value Factor for the patent family by comparing the result with your expert opinion on its objective value. In the attached Excel spreadsheet, you will find a list of patent families from your portfolio. The list contains a maximum of six families per a patent attorney so that this exercise should not take much of your time.

Please evaluate each of families depending on your perception of its objective the technical value (assign a Score):

1 = Poor

2 = Fair

3 = Moderate

4 = Good

5 = Excellent

The more you consider the patent family as technically advanced, the higher the score you should assign to this family. The technical value in a given context could mean:

- The technical scope of the invention (broad or narrow)
- Degree of innovativeness (breakthrough or incremental invention)
- Relevance to the field (low or high, as indicated by the number of conflicts initiated by third parties)
- Consequent establishment of a new product category in state of the art

Please send back the spreadsheet with your scores via email by the end of this week. While assessing, please consider the inventive quality of the patent family at the time of filing. Judge impartially, regardless of any business perspective or your sympathy to the invention or inventor.

Patent valuation: toward a direct measurement

30 April 2020

Abstract

Corporate managers often have limited ability to quantify patent value and perform rigorous analyses of their patent portfolios due to their nature as intangible assets on corporate balance sheets. Measuring the full value of protection is a difficult task, as most associated data is highly confidential or not at all available and given the data it is challenging to identify causal links and relationships between the patent and the various measures of its intangible value. In this paper, we attempt to address both challenges. We collaborate with a large multinational company and analyze internal and highly confidential data on product sales, revenues, and other corporate performance measures by tracing each patent down to its product market. To establish causality, we design a randomized controlled trial together with the management of the company, in which some randomly chosen patents are dropped from the portfolio, while others are kept for the duration of the study. To our knowledge, this is the first study that conducts a randomized controlled trial to measure the real market effect of patent protection.

This is a co-authored Chapter:
Albina Khairullina (Ph.D. Candidate) –Initial planning, participant recruitment, research design, data collection, writing
Dr. Neil Thompson – Conceptualization, initial planning, participant recruitment, research design, power calculation, data analysis, results, writing
Professor Christopher L. Tucci – All around guidance, participant recruitment, research design, data access, writing

1. Introduction

Patent valuation has occupied the minds of researchers and practitioners for several decades. Being an important and intangible asset in corporate balance sheet, corporate managers often have a limited ability to quantify patent value and perform rigorous analyses of their patent portfolios (Matsuura, 2004). The value of each patent is hard to observe; however, holding a patent is costly and the cost is not negligible. For holding most patents in their portfolios, companies incur monthly and/or annual maintenance costs. When a company drops a patent, it saves on maintenance costs, and loses the intangible value of protection associated with the patent. The value of protection depends on the remaining life of the patent, the relative importance of the protected technology in production and competition with other companies, and the dynamics of the value of the protected technology over time during the life of the patent. Measuring the full value of protection is a difficult task, as most associated data is highly confidential or not at all available, and given the data, it is challenging to identify causal links and relationships between the patent and various measures of its intangible value. In this paper, we attempt to address both challenges.

To solve the data availability and corporate confidentiality issue, we collaborate with a large multinational company, use internal and highly confidential data on product sales, revenue and other corporate performance measures, and associate them with patents in the patent portfolio. To establish a causal relationship between patents and corporate performance data, we design a randomized controlled trial together with the management of the company. In that trial, some randomly chosen patents are dropped from the portfolio, while others are kept for the duration of the study. To our knowledge, this is the first study that conducts a randomized controlled trial to measure the real market effect of patent protection.

The literature on patent valuation has grown considerably over the last 50 years. Data on corporate patents is widely recognized as a proxy measurement for innovative performance, which is the main driver of growth (Kondratieff, 1979; Griliches, 1990; Grossman & Helpman, 1993; Jaffe & Trajtenberg, 2002) for companies (Patel & Pavitt, 1991; Hagedoorn & Schakenraad, 1994; Narin, Noma, & Perry, 1987) and even nations (Hall & Mairesse, 2006; Qian, 2007; Hasan & Tucci, 2010). Patent value has various interpretations in the literature depending on the level of analysis. Most papers on patent valuation focus on country-level, company-level, sector-level, etc. Citations counts is one proposed measure of patent importance (Hall, Jaffe, & Trajtenberg, 2000), (Sampat & Ziedonis, 2004). Patent production has been shown to have links with industry-level performance as well (Blundell, Griffith, & Van Reenen, 1999). On a larger scale, many papers attempt to understand the nature of associated technological spillovers (Jaffe, 1986), (Acs, Braunerhjelm, P., Audretsch, & Carlsson, 2009), (Harhoff, Henkel, & Von Hippel, 2003).

Event studies have often been proposed or used to estimate the value of individual patents and their protection. The value of patents can be estimated from reactions to renewal dates (Lanjouw, Pakes, & Putnam, 1998), (Cornelli, 1999) or licensing activities of patent holders (Teece, 1988), (Walsh, Arora, & Cohen, 2003), (Kamien, 1992). Patent assignment and licensing terms data can be used to estimate the monetary value of individual patents (Lemley & Myhrvold, 2007). These are examples of *indirect* measurements of patent value in the literature that rely on using a variety of different perspectives. We say that most of these valuation measures provide an indirect estimate of patent value because they are one step removed from the actual value itself.

In our study, we propose a randomized controlled trial carried out in concert with the management of the company. A carefully designed randomized controlled trial avoids bias in the selection of countries and patents and thus accounts for the behavioral heterogeneity in employees' behavior (Nagin, Rebitzer, Sanders, & L.J. Taylor, 2002). By definition, a randomized experiment is a valid approach to determine the causal effect between the treatment and the outcome that is commonly used in natural and social sciences (Sibbald & Roland, 1997) and has become more popular in managerial practice. The rise of field experiments and experimental evaluations within organizations has the potential to transform organizational decision-making by establishing true causal relationships. Indeed, the literature on randomized controlled trials is vast. In the finance literature, Lerner & Malmendier (2013) show how entrepreneurial peers influence classmates' decisions to be an entrepreneur. Randomized controlled trials are used in management Atkin et al. (2014), Blasco et al. (2016); marketing (Bertrand, Karlan, Mullainathan, Shafir, & Zinman, 2010), and labor economics (Bertrand, Duflo, & Mullainathan, 2004). Bloom et al. (2013) use a randomized controlled trial to find how different managerial practices affect corporate performance. In innovation, Bernstein et al. (2014) identifies strategies to attract early stage investors via a randomized controlled trial.

In the patent literature, authors employ mostly quasi-random experimental settings (e.g., (Farre-Mensa, 2017), (Galasso, 2015), (Sampat B. &., 2019)). Galasso and Schankerman (2015) conduct a quasi-random experiment in which patents are invalidated by court decisions in the US where judges are randomly assigned to cases. In such a situation, one implication is that patent invalidation facilitates cumulative innovation by increasing the number of citations to focal patents in complex technology domains. According to their results, only a patent owned by a large company enjoys an increase in citations after it enters the public domain. Farre-Mensa, Hegde and Ljundqvist (2017) study historical approval rates of patent applications with a quasi-random assignment of USPTO patent examiners. They find that first-time patent grants to startups facilitate capital access. Sampat and Williams (2019) study whether inventions with higher levels of scientific and commercial value are more likely to be patented. They use an example of human genes in which patented genes are more valuable prior to patent than non-patented genes. Kuhn and Thompson (2019) shows that quasi-random reductions in the scope of patents influences whether they become incorporated into standards. Moser (2012) constructs a dataset of innovations exhibited at world's fairs between 1851 and 1915 and documents that high-quality award-winning exhibits were more likely to be patented. Gambardella, Harhoff, and Verspagen (2008) study the hypothesis that people prefer to forego other productive pursuits in favor of creating non-rivalrous knowledge-related goods.

There are no studies of which we are aware that examine the direct effect of patents on corporate performance because of the confidentiality of corporate performance data and the lack of data on linkages between patents and products in the market. Companies never make information on sales, market share, or prices of their patented products public.

In this paper, we attempt to address these data and causality issues by examining product-market effects using a randomized control experimental design. The paper is organized as follows. Section 2 presents the theory of at-risk patents and our main hypothesis. Section 3 describes the setting in which the randomized controlled trial is based. Section 4 describes the methodology. Section 5 presents the results. Section 6 contains the conclusion.

2. Theory

The innovation management and economics of innovation literature describe the mechanisms of how patents create value via higher market share, product price, or both (Pakes, 1984), (Reitzig, 2009), (Sukhatme, 2014). When a company holds a broad patent portfolio, some of these patents are focal in terms of their contribution to the business (Hall R. , 1992). For example, some patents may cover a unique attribute of the invention that is accountable for most of the consumer or technological value (Kingston, 2001), (Galasso, 2015). Other patents are less important to the business as the product might be becoming obsolete and patent protection becoming less attractive. Patent attorneys can relatively easily identify the most and the least valuable patents. However, in between the two extremes lies the gray area of at-risk patents, those patents with ambiguous value to the business. These patents are where managerial decision making comes into play: on the margin.

Patent portfolios are maintained proactively so that most patents are relevant and useful for the business. It is expensive to hold all patents that have been filed in the past, so some of them are abandoned in favor of new ones coming in (Pitkethly, 1997). A decision on whether to abandon a patent or not follows several criteria: current and expected importance, patent coverage measures, the age, and competitive pressures.

An *at-risk* patent is a patent in use, protecting a technology embedded in a product on the market. However, the value of that patent is uncertain. It might be worth renewing or it might not. For example, patents could cover products at the end of their lifecycle, technologies on the edge of being replaced, or features that are only secondary to the functionality of the patent. The patent may describe a technical detail within a complex invention or one of many design attributes. Initially, companies tend to protect as many innovative aspects as possible and then reduce protection by dropping less relevant patents. The gray area of at-risk patents is the primary focus of our study. Among at-risk patents, a patent attorney uses judgement to decide on the ones to abandon and the ones to keep in place.

At-risk patents tend to be "troublemakers" for managers when it comes to portfolio pruning because it is uncertain if there is a value proposition behind them (Gans, 2008). In other words, examining the at-risk patent is actually more useful for practice since unimportant patents will not be pursued at all (not submitted) and obviously useful ones will be. So, the question facing managers is how far down the value curve one should be willing to pursue or continue patenting. Figure 1 describes the different patent types.

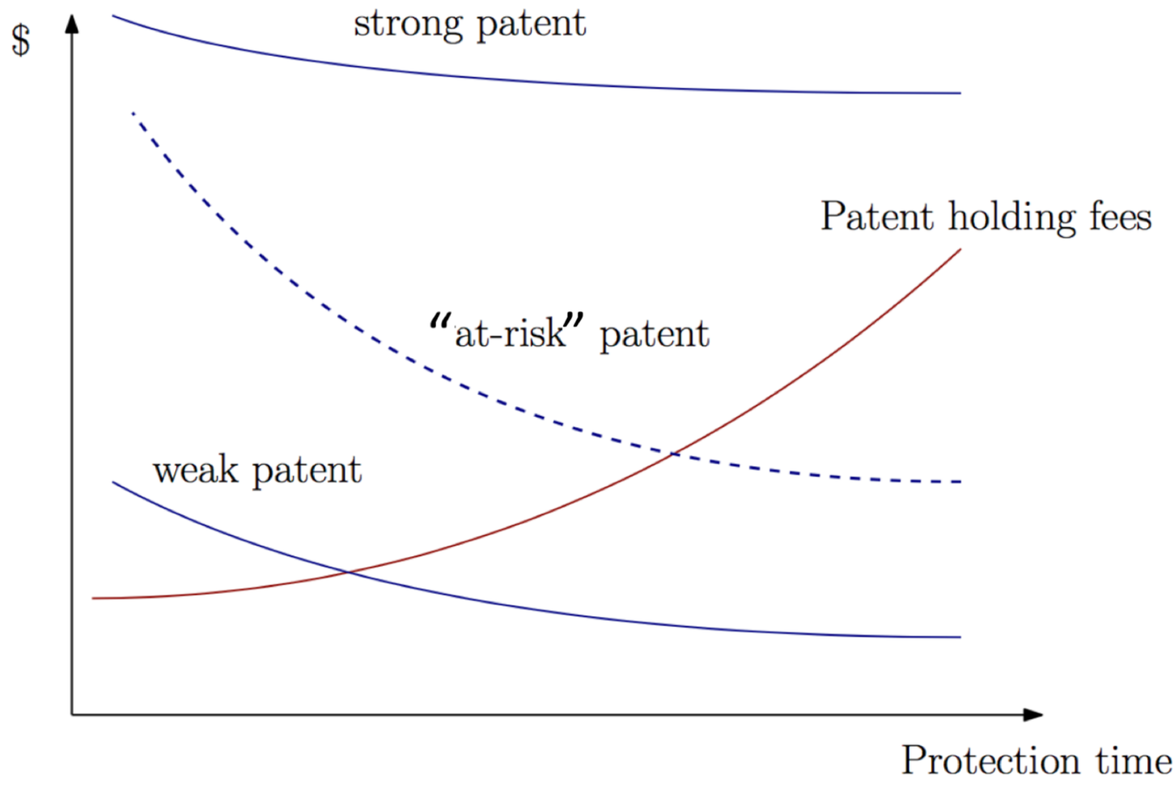


Figure 1 Patent fees over time

For the role of at-risk patents, we formulate the main hypothesis of our study.

- *H0:* Abandoning a patent has no effect on the market performance of related products (sales, price, units sold, or market share)

- *H1:* Abandoning a patent has a positive or negative effect on the market performance of related products (sales, price, units sold or market share)

Our hypotheses are driven by assumptions that lowering a patent protection should have an effect on price or units sold. The literature is ambiguous when it comes to the directionality of the impact patent abandonment has on corporate performance, but most scholars would predict that abandoning intellectual property protection would lead to lower performance overall, especially in market share and profitability, as it would encourage entry and price competition in the downstream market (Campbell, 1983), (Caves R. E., 1991), (Bloom N. &., 2002) (Pearce II, 2006), (Boldrin, 2008), (Song, 2016), much as patent expiration in drugs leads to generic competition almost immediately after expiration (Ching, 2010). A patent expiration in a pharmaceutical sector is an extreme example since on a drug market there is almost no competition until a patent on a certain drug expires. Actual competitive dynamics are difficult to predict because of competitive responses and consumers' behaviour.

However, economic theory would also lead one to conclude that lower prices may in fact lead to higher unit sales, even if overall market share drops (Klemperer, 1995). For example, in response to increased market competition and decrees in units sold, a focal company can raise prices to focus primarily on loyal customers.

That is why a certain subcommunity of innovation economists propose the radical idea of greatly reducing the scope of the patent system entirely, as it could be argued that consumers benefit from such reductions in intellectual property protection (Boldrin, 2002).

3. Setting

We collaborate with the management of the company to design a randomized controlled experiment and study the direct market response to patent abandonment. Patents are linked to products that are sold across many markets in many countries. Our study uses real performance measures traced back to exact patents in the portfolio.

In a natural experimental setting, we randomly assign whether we want to maintain patent protection or if we choose to abandon it in some countries versus others. The randomization avoids selection bias in countries and patents we assign to the treatment and control groups. We directly observe associated changes in corporate performance for products in the experiment, compare the differences among markets, check competitive positions in response to abandonment.

Patents may be held by a company either to protect products that are actually in the market (direct use) or not (indirect use). Indirect use would include, for example, patents on products that have yet to be put onto the market or those designed to be used as a bargaining chip in licensing or infringement negotiations (Hall & Ziedonis, 2001). Our analysis focuses on the roughly 20% of direct use patents (Table 1) and the subset of them that patent attorneys managing this portfolio think fall into the at-risk category.

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Direct use, %	24	11	19	19	15	27	28	22	12	25
Indirect use, %	76	89	81	81	85	83	72	78	88	75

Table 1 Use of Families

We have access to internal data describing real commercial outcomes of changes in patent portfolios. However, there is a selection into patenting—causality may not be established without the right experimental design. The two problems we attempt to solve in our study, as mentioned above, are (1) data limitations due to confidentiality, and (2) selection into patenting. The first problem we solve by collaborating with the company. The second problem we solve via a randomized controlled experiment design.

Data for our experiment comes from our commercial partner, who has this administrative data in its records. Depending on the geography that a particular patent applies to, the frequency and depth of the commercial outcomes vary.

Our analysis includes 26 patents, spanning 6 patent families, 13 countries and 17 product lines.

The sample size was determined based on patent availability; each quarter attorneys would review the patents due for renewal. Those that met our inclusion criteria we randomized in waves.

4. Methodology

1. Experimental Design

According to Chatterji et al. (2016), our research represents a strategy field experiment. A strategy field experiment measures a total effect of a strategic decision on performance indicators directly. In particular, our experiment seeks to answer the question of whether firms should do more or less patenting. By its nature, this is a decision on the margin. If the marginal patent is worth more than the cost of prosecuting and maintaining it, the firm should do more patenting. If not, they should do less.

The long lag for prosecuting patents and getting products on the market means that it would be infeasible to run an experiment randomizing whether patent protection is provided at all. This would also have the disadvantage that pre-treatment performance (e.g. product sales) would be unavailable – which would harm statistical power and the ability to have certain statistical controls. As such, our experiment randomizes patent protection at a later stage: at patent renewal. Some patents have their maintainance fees paid and are renewed, others are not paid and thus their protection lapses. This structure allows us to look at product performance in particular markets pre- and post-intervention.

As already mentioned, patents were included in the experiment on a rolling basis, as a result of quarterly reviews of patents needing maintenance fee payments. For inclusion in our experiment, patents needed to meet the following criteria:

1. **Active:** Protect a product currently on the market
2. **Comparable:** Patents from the same patent family are used in other counties; and
3. **Feasible:** Patent is considered "at-risk" by attorneys, meaning that it was neither so important that they would be unwilling to abandon it, nor so unimportant that they were unwilling to renew it.

Patents that met these criteria were randomized into treatment (abandon) and control (maintain) through complete randomization within blocks. Following Altman et al. (1999) and Chatterji et al. (2016), the block randomization ensures that the blocking parameters are balanced among experimental groups and provides a stronger methodological basis for the difference-in-means analysis we perform after.

Our experimental blocks were defined by the patent family and comparable country characteristics. So, for example, if the same patent had been filed in 4 countries (i.e. 4 members in the patent family), then it would form two blocks, each with a pair of patents, where the underlying invention is the same and the countries are as similar as possible in purchasing-power-parity GDP. Complete randomization thus means that one patent in each of these pairs would be assigned to treatment while the other is assigned to control, as shown in Figure 2.

Figure 2: Experimental design.

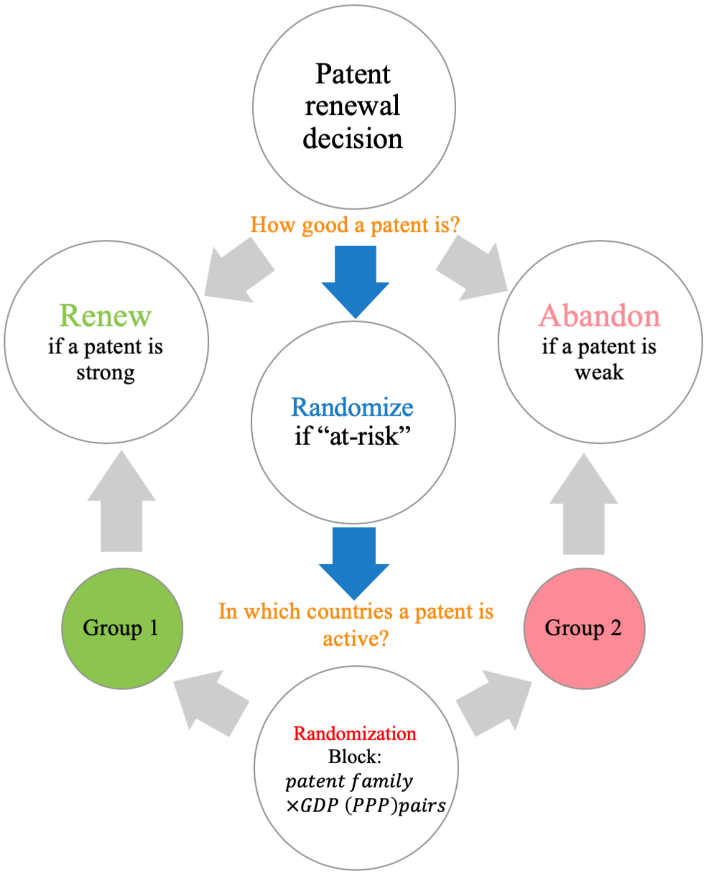


Figure 2 Patent randomization process

2. Implementation

Our experiment ran in mid-2017, with patents being abandoned or maintained based on our randomization. In total, our experiment includes 26 patents across six patent families. 13 countries and 17 product lines were part of the study. In each country, we examine the commercial outcomes of all products that the patent applies to. Thus, our variation is cross-country, within-patent, and our experiment impacts 84 products in various countries.

The actual intervention date varied slightly by patent within each wave of randomization, based on the actual renewal date for the patent in that country. But within each wave, the randomization happened in the same quarter (which is why attorneys had reviewed them in that cycle).

The patent families involved in randomization are families of different age and geographical breadth as shown in Table 2.

Family number	Age in years	Members	Importance to the business
1	10	30-40	high
2	15	70-80	high
3	14	20-30	high
4	11	20-30	high
5	11	30-40	high
6	11	40-50	very high

Table 2 Patent Families in RCT

As shown in Table 2, all families are highly important to the business, as classified in an internal database by patent attorneys at the moment of the first filing, and were filed in many countries. A patent family is considered important if it is believed to generate market value. After ten years, the business value of a patented feature may diminish, and thus patents that were originally high-value become “at-risk”.

For each product affected by the experiment, we attempted to gather data on the following market performance indicators (see Table 3).

Variable	Definition
Units	how many units of particular products are sold
Revenue	revenue from a product in that time period
Market share (revenue)	a fraction of the company’s revenues relative to competitors’ revenue
Market share (units)	a fraction of the company’s units relative to competitors’ units
Price	average retail price of units sold
Competitors’ Units	how many units sold by competing parties for the product related to the patent in question
Competitors’ Revenue	revenue from rival products in the market from competitors

Table 3 The measured variables

Based on the level of sales tracking done in each country and at corporate headquarters, we were able to gather some or all of this data at the monthly or yearly level and for either the local currency or in the consolidated currency of the company. Some external market data from GfK, a regional market data provider, were also included when available.

Based on data availability, the following number of observations are available for each of the following types of analysis:

Measure	Period	Unit	Products	Patents	Blocks
Price	Month	Euro	30	13	7
Price	Month	Local Currency	30	13	7
Price	Year	Euro	59	26	11
Price	Year	Local Currency	51	24	10
Units	Month	Count	40	17	9
Units	Year	Count	59	26	11
Revenue	Month	Euro	47	18	9
Revenue	Month	Local Currency	40	16	8
Revenue	Year	Euro	56	25	11
Revenue	Year	Local Currency	43	16	8
Market Share Revenue	Month	Percent	29	13	7
Market Share Units	Month	Percent	30	13	7
Market Share Revenue	Year	Percent	31	13	7
Market Share Units	Year	Percent	30	13	7
Competitor Units	Month	Count	10	10	7
Competitor Units	Year	Count	10	10	7

Table 4. Number of observations

3. Statistical Power

To understand the statistical power of our experiment, we used pre-treatment data (only) to estimate what size effects we could detect with confidence. Because of the complex aggregation needed (from product level to patent) and because of data availability issues (some periods are not reported) we did this using bootstrapping. In particular, we estimated post-treatment effects as $y_i + \tau$ where y_i is a bootstrapped estimate of the outcome of interest (e.g. monthly sales for product i) and τ is the (homogeneous) treatment effect. We tested for statistical power for treatment sizes from 0 to 2 standard deviations. For each treatment effect size, we perform 500 replications and calculate the fraction of replications showing a significant non-zero coefficient on the treatment variable. We use the 5% p-value threshold to define statistical significance.

Based on this analysis, we are able to reliably detect the following effect sizes with the corresponding statistical significance, per Table 5:

Variable	Period	Measure	Regression	Weights	80%	90%
Market share	month	revenue,%	treatment.only	equal.weights	0.4	0.4
Price	month	euro	treatment.only	revenue.weights	0.5	0.6
Revenue	month	euro	treatment.only	equal.weights	0.3	0.4
Units	month	units	strata	equal.weights	0.6	0.7

Table 5 Effect sizes (in standard deviations) detectable with statistical power of 80% and 90%

4. Estimation Strategy

Suppose m_i is the measurement of the corporate performance, I_i is the treatment dummy variable equal to one for the treated product-country pairs with patent abandonment, b_i is the stratified block fixed effect, c_i is the country fixed effect, and p_i is the product fixed effect. Suppose that we observe N^{POST} periods of after-treatment corporate performance indicators, for which the $POST_i$ dummy variable is equal to one. Then the difference-in-difference regression equation is:

$$m_i = \alpha + \textbf{optional FE} + \beta \cdot I_i + \gamma \cdot POST_i + \tau \cdot I_i \times POST_i + \varepsilon_i$$

The β coefficient measures the pre-treatment differences with the treatment group. The γ coefficient captures the possibility of the time trend in the data for corporate performance indicators. The τ coefficient measures the effect of the treatment in the after-treatment periods. To address missing data issues, we collapse the time series data for pre- and post-intervention outcomes into averages, i.e. m_{pre} and m_{post}.

For the set of optional fixed effects, we consider three possibilities:

1. None: this way we capture the treatment-only effect without controlling for differences among randomization blocks, countries, or products;

2. Fixed effect for blocks b_i only: this way we estimate the within-block effect of treatment;
3. Fixed effects for blocks b_i, countries c_i, and products p_i: this way we estimate the within-product effect with all else equal—the highest granularity and the lowest statistical power due to few degrees of freedom remaining.

5. Results

Preliminary results

Initial results suggest that products covered by patents that are abandoned as part of the experiment see at least a 0.5 standard deviation drop in price, as compared to controls. These effects are robust, persisting at the 0.1% to 5% significance levels irrespective of whether we add in additional controls or whether we weight products in various countries equally or on the basis of revenue.

6. Discussion

Our initial results provide preliminary *causal* evidence that abandoning patent protection for patents on the margin leads to those products being priced lower. Importantly, it is not important for this finding whether the company's product manager knows whether a patent has been abandoned for this effect to occur. It is sufficient that other characteristics of the market (e.g. competitor entry, competitor pricing, etc.) is affected and that this leads to a strategic pricing response.

7. Conclusion

The problem of finding a proper way to define the added value of a patent challenges both practitioners and researchers. It is important to understand and quantify how a patent contributes to the company's performance. The literature has identified various factors indicating the indirect value of patents—as measured by the number of citations a given patent generates, the number of claims in a patent document, predictions of stock performance, and the amount of venture capital received. In our study, we focus on a direct measurement of a patent value. We investigate the response in the common direct measures of corporate performance such as sales, prices, market shares of products protected. Various exogenous and endogenous factors contribute to the observed effect of changes in patents portfolios on corporate performance. In this study, we attempted to identify a causal relationship—that a market change occurs due to a patent abandonment holding everything else equal. Our analysis provides, to our knowledge, the first direct test of the market value of patents.

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Ideas-Driven Endogenous Growth and Standard-Essential Patents

Abstract

In this paper, we study the impact of standard-essential status for patents on production possibilities of the economy and long-term growth. As we show, the innovators' risk of losing the standard-setting game ex-ante attenuates the anticipation of a larger market share. Moreover, when the discovery rate of new technologies is smaller than the discounting rate of the monopoly profits, standards and standard-essential patents tend to be growth-reducing, despite a conjectured positive contribution of standards to the marginal productivity of human capital. Market failures associated with patent abuse have been treated historically by various measures ranging from compulsory licensing to imposing reasonable and non-discriminatory (FRAND) pricing on essential technologies. We show that mandated compulsory licensing has a negative impact on long-term growth, while a voluntary FRAND pricing together with faster rates of follow-up innovations may be growth-enhancing.

This is a co-authored Chapter:

Albina Khairullina (Ph.D. Candidate) — provided conceptualization, data collection, analysis and writing.

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Dr. Artem Neklyudov — provided analysis and writing.

Professor Christopher L. Tucci — provided conceptualization and all around guidance.

Introduction

In this paper, we study how standards-essential patents and their pricing mechanisms impact the long-term economic growth. Standards-essential patents (SEPs), where patent holders apply "essential" intellectual property (IP) to an emerging standard as explained in more detail below, is a phenomenon that has been taking on exponentially increasing importance over the last two decades (see Figure 1). This growth is likely related to the growing complexity of high-tech devices, hardware, and telecommunications products and services. They incorporate more and more technologies to make them work well, miniaturization of components in technological systems, as well as industry "deconstruction" where firms become less vertically integrated and produce fewer parts of a more modular system, relying on interfaces developed with partners. In this article, we analyze the economics of SEPs from a macroeconomic point of view, the incentives for participating in the production of technology with standards versus the final good production, under what circumstances standards enhance economic growth, and the consequences of the IP licensing terms for economic growth.

We model the endogenous technological change as in Romer [1990] and extend it to talk about standardization of technologies and standard-essential patents. We embed in a macro-model the interaction between two novel stock variables: patented ideas and standard-essential patents. We add a dynamic interaction between patented ideas and standard-essential patents and model how standard-essential patents emerge over time from patented ideas. The key to our dynamics is an observation that standardization of individual technologies occurs at some random points in time, i.e. that it is not exactly known which patents would become future standards. Yet, importantly, we show that in the long run both patents and standards grow at the same rate and so we can focus on balanced-growth equilibrium. As more and more patents become part of a standard and receive special treatment as standard-essential patents, they have the potential to become platforms for future innovation and create a possibility for accelerating economic growth.

In principle, we can plug in our dynamic model of the contribution of patented ideas and standard-essential patents to total factor productivity into a macro-model of any type. In our current working paper, we introduce standard-essential patents into the canonical endogenous growth model of Romer [1990]. Our research questions are how standardization of patents affects economic growth; whether standardization is growth-enhancing or not; and how regulation of pricing under standard-essential patents interferes with economic growth. Households choose between two sectors of the economy: the innovative sector and the final-good sector. Their endogenous choice drives the growth rate of the economy in the long run, and relative incentives depend on the productivity of standard-essential patents, the rate of standardization, the discount rate, applied to monopoly profits, among other parameters in the model.

Market failures associated with patent abuse have been treated historically by various measures ranging from compulsory licensing to imposing Fair, Reasonable and Non-Discriminatory (FRAND) pricing on essential technologies. As we show, the innovators' risk of losing the standard-setting game ex-ante attenuates the anticipation of a larger market share. Thus many of these measures, which reduce the monopoly rents for patent owners, may have a negative impact on long-term growth. However, this finding assumes no change in the rates of further and follow-up innovation after the standard is set. In an extension of our model, in which every standard brings a number of additional patents as a follow-up innovation, the long-term growth increases with standardization.

There has been a growing research interest in the process of standardization and standard-essential patents. Lerner and Tirole [2015] develop a seminal theoretical framework to study the optimal standard composition and incentives of end-users to implement a standard technology with competitive price commitments. In particular, they show how standards are often are inefficiently small (under-inclusive) and how the SSOs create competition among owners of technology and lower licensing fees. In our paper we take the composition of a standard as given and focus on the long-term growth dynamics. In this sense, we complement the analysis in Lerner and Tirole [2015] with a macro-view on standards and the regulation of licensing fees. Kung and Schmid [2015] study the asset-pricing consequences of innovation and patenting in a general equilibrium macroeconomic setting. We complement their analysis by bringing standardization process of patents into the relatively standard macro environment and focusing on long-term growth rather than short-term business cycle. Our model of innovation is different from Gârleanu and Panageas [2017], who use labor instead of human capital as the main factor to pin down the growth rate of the economy. Standards will not play much role in a setting like Gârleanu and Panageas [2017] because the trade-off for suppliers of labor does not fully take into account the present value of monopoly profits coming from patents, like in Romer [1990] setting.

Standardization and SEPs received a relatively broader coverage in the empirical studies. In Blind and Thumm [2004] authors model the probability of a patent holder joining the standardization processes. They demonstrate that companies with higher patenting intensities are less likely to join standardization race. The intuition behind these results is that a company with a high patenting intensity possesses a strong technological advantage that yields market success without the support of formal standardization. Blind and Thumm [2004] discuss incentives and deterrents of firms to join standardization process. On the one hand, the decision to apply for a standard might be driven by the economies of scales (diffusion of well-protected know-how) and positive network externalities. On the other hand, companies may be reluctant to spread their technologies as they seek a dominant position in the market and exclude others from having access to their unique technologies. The results suggest that the positive economic effects of standards will not be fully exploited because big technological companies are still reluctant to participate in standardization.

In a comprehensive report, OECD [2013] describes SSOs, how they work to develop new knowledge, and how standards can contribute to innovation. According to OECD, SSOs have to strike a delicate balance between what we are calling the IP holders or the "supply-side" of technology and the "demand side" of potential adopters. FRAND terms are seen as a potential solution to hold-up problems, although the authors acknowledge the lack of commitment once IP holders pledge to adhere to FRAND terms and the problems this can cause. Hold-up is only one problem associated with "thicketed" technology spaces such as technology standards, and the other is "royalty stacking." Both of these may lead to costs that greatly outweigh the benefit from adopting or commercializing the standard OECD [2013].

Bekkers and Updegrove [2012] provide an extensive treatment of the interrelations between IP and standards and the challenges of IP rights in standards. The authors describe the workings of several well-known SSOs and the difficulties of combining different IP claims in a standard. They stay at the level of "IP" because patents may be only one form of IP critical to conform to a standard without infringing on it. The definition of what "essential" means varies widely from SSO to SSO, with large variation in practices across many areas. Relevant practices are whether to include copyrights and other non-patent IP, whether the "essentiality" includes commercial or purely technical, whether the timing of essentiality is defined, whether pending applications are included, whether expired or invalid patents are included, and several more.

The paper is organized as follows. Section 1 describes the mechanics of technological standardization and demonstrates exponential growth of the stock of SEPs. Section 2 develops the theoretical model of endogenous balanced growth with patents and standards. Section 3 discusses policy implications, reasonable pricing, and the regulation of mark-ups in the context of our theoretical model. Section 4 concludes.

1 Standard-Essential Patents

A standard is a description of an interface (e.g., a plug and socket for electricity or audio component connection), a technical specification (e.g., wifi connectivity), a "dominant design" in a marketplace (e.g., DVD format, or historically, internal combustion engine automobile), or a way of doing things (e.g., driving on the right side of the road). These are not mutually exclusive, and there can be different ways of developing and commercializing them. In this article, we will focus primarily on the first three, with an emphasis on the established norms in a technical system.

How do standards come into force? Standards are normally classified as de facto and de jure. De facto standards are usually developed and commercialized by private parties, for example, firms, either in a private consortium or even individually, introduced into the market and then accepted by the market. The firm may or may not coordinate the development of the standard with other parties, what is important is that the de facto standard is a standard in use and its claim to legitimacy is that the market finds it useful. A de jure standard, on the other hand, is something that is intentionally negotiated by a third party, which is often called a "standards-setting organization" (SSO) or a "standards committee." Examples of SSOs include the IEEE (Institute of Electrical and Electronics Engineers), ISO (International Organization for Standardization), or ITU (International Telecommunications Union). These bodies coordinate the development of standards by managing the various parties to determine the functionality of the standard, the technical specifications, and the interfaces needed to comply with and use the standard.

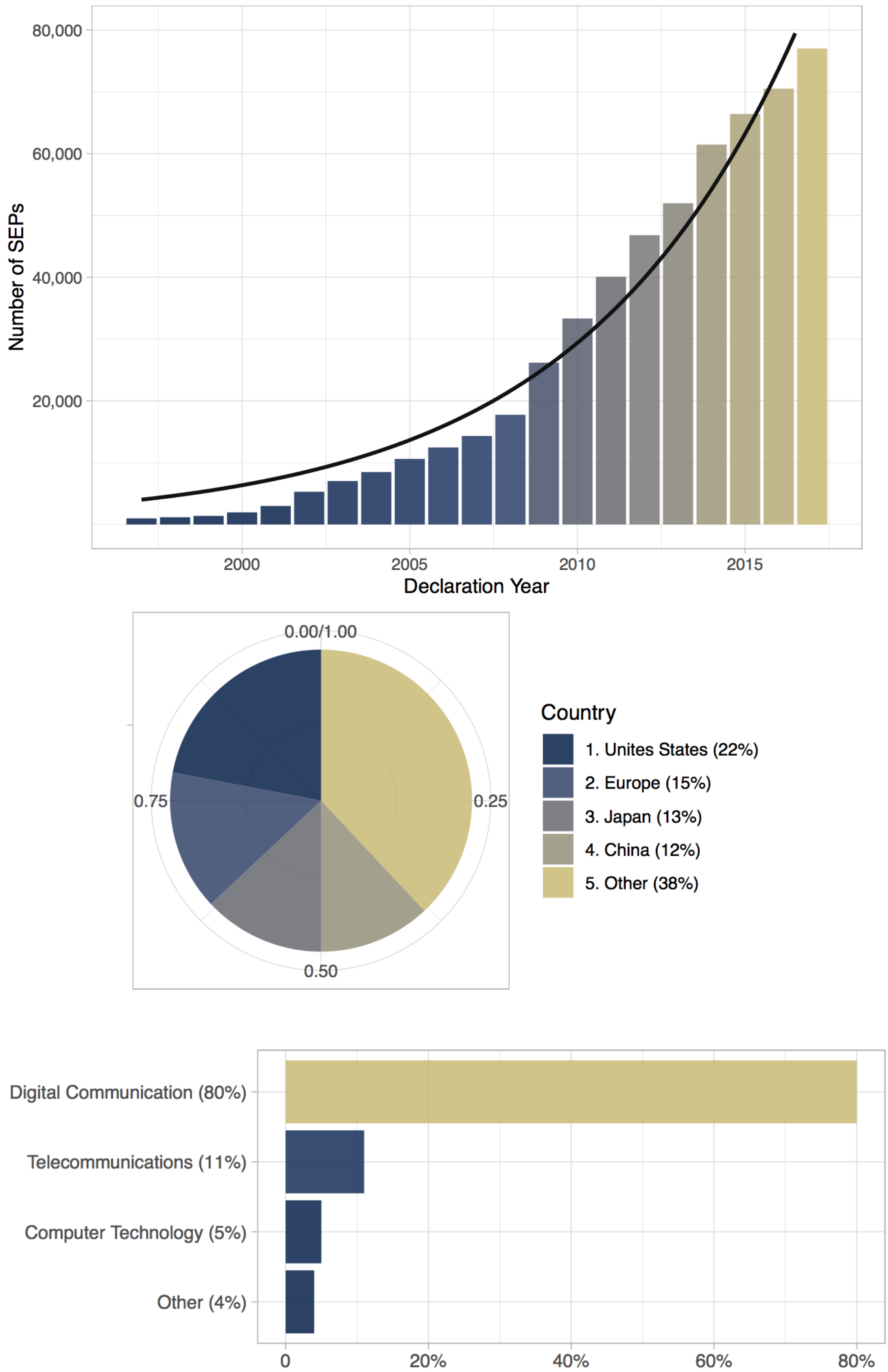
One apparent complication of the standard-setting process described above is that with increasing complexity, there are more parties involved in setting the standards, and these parties may or may not bring IP that is owned by them and that will be crucial for complying with the standard. If a third party would like to adopt the standard, the third party would have to negotiate a license agreement with every IP holder involved in the standard; otherwise, the third party would be an infringement of some IP in the standard. In some cases, there are dozens or even hundreds of IP owners staking some claim to the IP of the standard and this negotiation process would become lengthy and expensive. Furthermore, it is not clear that an IP holder would even grant a license at any price, or threaten to withhold a license. Therefore, in such a situation, potential adopters would be highly unlikely to adopt the standard and thus in the extreme case none of the IP holders would receive royalties for their technologies.

Such examples of patent abuse have a long history since the 18th century and one of the oldest governmental response has been compulsory licensing. Under compulsory licensing scheme the government or the regulatory body grants a license the the IP user at some reasonable price often predetermined in a court ruling. The IP holder loses full protection of the IP and the associated monopoly mark-up. These measures have been profound in the context of public healthcare systems to ensure continuous availability of essential drugs (Son [2019]). Compulsory licensing is an extreme example of "fair and reasonable" pricing, which entails very little negotiation with the IP holder once implemented.

The policy of treating standard-essential patents (also called "essential patents") was developed in recent years to deal with the standard-specific situation of patent abuse. SEPs are patents that are required for a third party to comply with a given standard (Tucci [2013]). The IP holders promise to charge "fair and reasonable" license fees, and to do so in a "non-discriminatory" way; in other words, to not deny anyone who wants a license to have one. Such pricing is called "FRAND" terms for Fair, Reasonable, And Non-Discriminatory. The argument goes that an IP holder trades off FRAND terms in exchange for a higher likelihood of adoption of the standard since if no-one adheres to FRAND, the standard ends up in a prisoners-dilemma-type problem and no-one profits from the adoption of the standard as described above. In practice, the details of FRAND terms are not negotiated in advance and are only solved by negotiation and litigation. There has been attempts to make the price setting mechanism for SEPs more efficient, for example see Lemley and Shapiro [2013].

Our data on standard-essential patents (SEPs) covers 80,935 patents with application years spanning 1995 to 2017 provided by the IP-lytics. Out of all patents published Figure 1 shows the distribution of patents applied for in different years. As seen in that figure, SEPs represent a phenomenon of growing importance for the economy. 22% of patents were published by the US patent office, 15% of patents were published by the European patent office, these are the two biggest patent offices in our data. All the SEPs in our data belong to electrical engineering sector and cover a variety of industry fields. Digital communication, telecommunication, and computer technology are the three most populated industry fields in our data.

Figure 1: Stock of SEPs by declaration year, country, and patent type



Legend: The first panel of the figure shows the total number of declared standard-essential patents grouped by the declaration year. Black line shows the exponential fit of the data. The pie chart shows the ratio of standard-essential patents granted by patent offices of different countries. The last panel of the figure shows the percentage of different industry types among the SEPs.

2 The Model

In this section, we describe our theoretical framework to study the effect of standardization on innovation and economic growth. We describe agents who produce innovation—innovators, the process of technological change and formalize the notion of technological standardization. Standardization of a technology results in a substantial increase in the economy-wide demand for that technology. For example, when JPEG became a standard image format, most producers of photo cameras moved to JPEG and abandoned alternative formats of image encoding. Our idea, in brief, is that technologies become standard-essential over time at some rate and standardization of one technology crowds-out demand for a set of rival technologies. Innovators are running a risk of their patents becoming irrelevant for the production process if a competing technology is standardized.

2.1 Innovators and technological change

We model the endogenous technological change as in Romer [1990] and extend it to include standardization of technologies and standard-essential patents. In our model, the economy is populated by a fixed number of agents $H = 1$, which represents the stock of human capital. A subset of agents H_A decide to be innovators and the remaining $1 - H_A$ agents contribute their human capital to final good production. Economic growth is endogenously driven by decisions of agents to become innovators—as more agents choose to be among H_A in equilibrium, economy grows at a higher rate.

As in Romer [1990], there is a separation between the "rival component of knowledge", H, and the "nonrival, technological component", A, both of which are "excludable" factors of production. We model A as discoverable patentable technologies. Time runs continuously and at every point in time $t \geq 0$ a patentable technology arrives to an innovator as a random event with a Poisson rate $\kappa \cdot A_t$. The growth rate of the stock of discovered patented technologies A_t is:

$$\frac{dA_t}{A_t} = \kappa \cdot H_A \cdot dt \tag{1}$$

According to the equation (1), the discovery of technologies exhibits increasing returns to scale driving the growth of the economy.

In addition, we assume that at some point in time an individual patented technology may be included in a standard. We denote industry standards by $A_{sep,t}$ and, as we discuss later, each standard includes $N > 1$ individual patented technologies in it. We denote the technologies that have not been included in a standard by $B_t < A_t$. The accounting identity for all technologies is:

$$A_t = N \cdot A_{sep,t} + B_t \tag{2}$$

The stock of discovered technologies A_t enhances the production of the final good Y_t, which is consumed by households. To focus our analysis of economic growth on the role of human capital H_A and productive technologies A_t we use a parsimonious production function of the final good Y[1]:

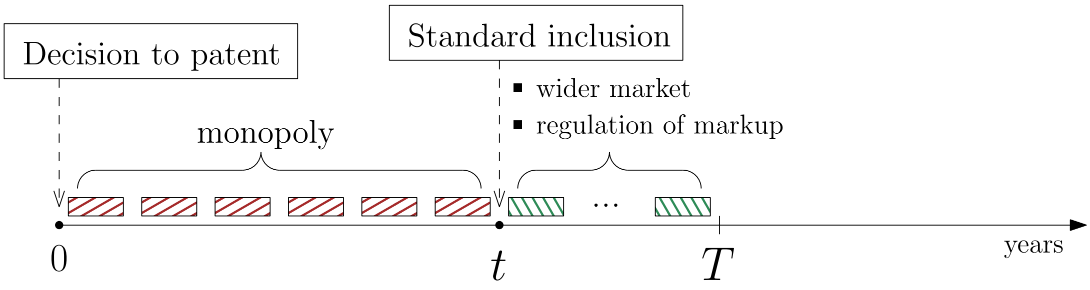
$$Y_t = (1 - H_A)^{\alpha} \left(\int_{i \in B_t} x_{i,t}^{1-\alpha} \, di + (1 + \epsilon_{sep}) \cdot \int_{j \in N \cdot A_{sep,t}} x_{j,t}^{1-\alpha} \, dj \right) \tag{3}$$

Each individual technology in B_t is used to produce an intermediate good x_i, which enters the production function as an input and has diminishing returns to it. Each industry standard in $A_{sep,t}$ is used to produce N intermediate goods x_j, which all enter the production function as inputs with diminishing returns. Further, we assume standardization itself has some additional effect on the total factor productivity, so we put an extra $(1 + \epsilon_{sep})$ term for all the inputs which are produced under standards. The marginal productivity of standardized technology is:

$$\frac{\partial Y}{\partial x_{j \in N \cdot A_{sep,t}}} = (1 + \epsilon_{sep}) \frac{\partial Y}{\partial x_{i \in B_t}}$$

[1] As in Romer [1990] the results on the endogenous growth are not affected by changes in labor supply. Governed by this insight we implicitly assume a perfectly inelastic labor supply $L = 1$ and focus our analysis on the effect of human capital allocation on long-term growth.

Figure 2: The lifetime of a patent in the model



When standardization has a positive effect on the total factor productivity, $\epsilon_{sep} > 0$, the marginal product of standardized technology is higher. Alternatively, standardization may have no effect or a negative effect on the total factor productivity, $\epsilon_{sep} \leq 0$. We discuss the role of these alternative assumptions in detail in our analysis.

2.2 Patents

A successfully granted patent gives the innovator a monopoly right in production of an intermediate good, which is valuable in the final good production process. The patent expires after $T = +\infty$ years, which is a normalization—a finite patent life would not affect our qualitative results.

Each patent i has value P_B and it allows to produce an input x_i. In the future life of a patent two events may happen: A new relevant standard may encapsulate a patent, or a new standard may make it obsolete. Before either of these events the inventor enjoys a monopoly right to produce x_i. The inverse demand for x_i from the final good production sector has a constant price-elasticity:

$$p(x_i) = \chi \cdot x_i^{-\alpha} \quad (4)$$

$$\text{where:} \quad \chi = (1-\alpha)(1-H_A)^{\alpha}$$

The unit cost of production of input x_i is the cost of capital $r(t)$ times the amount of capital needed η. The optimal monopolistic price $p^M(t)$ and the monopolistic output of the input $\overline{x}_i$ every period is:

$$p^M(t) = \frac{r(t)\cdot\eta}{(1-\alpha)} \tag{5}$$
$$\overline{x}_i = (1-H_A)\cdot\left(\frac{r(t)\cdot\eta}{(1-\alpha)^2}\right)^{-\frac{1}{\alpha}}$$

The monopoly profit per unit of time is:

$$\pi^M(t) = \alpha\cdot(1-\alpha)(1-H_A)\left(\frac{(1-\alpha)^2}{r(t)\cdot\eta}\right)^{\frac{1}{\alpha}-1} \tag{6}$$

This expression is the monopoly profit of a patent that has been successfully granted, and has not been included in any standard. Moreover, no existing standard replaced the productive role of this patent. In this case the value of patent i is:

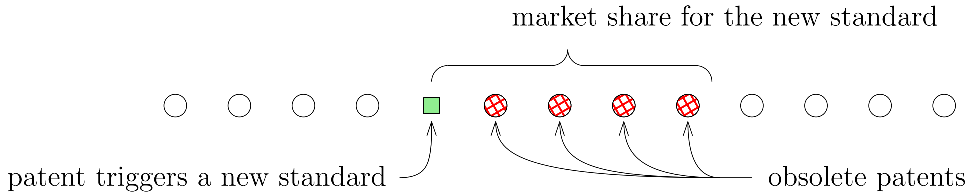
$$P_B = \pi^M(t)/r(t) \tag{7}$$

What happens with standardization we describe in the next subsection.

2.3 Standards

At an exogenous rate γ_{sep} an individual patent wins a standardization race with the standard-setting organization. In our model, γ_{sep} is the i.i.d. Poisson intensity of this event happening to an individual patent. Once it becomes a standard, it consumes the market share of $N-1$ other technologies. We refer to N as the scope of a standard in the economy: One standardized technology substitutes $N-1$ individual rival technologies, which become obsolete when a standard is approved by the standard-setting organization. For example, in case of JPEG the scope N would equal one plus the number of alternative image encoding technologies that lose their market share in favor of JPEG when it becomes an industry standard.

Figure 3: Standardization of patents



The event with rate γ_{jpeg} has occurred to the patent marked by a green box. The scope of a new standard is $N = 5$, so the winning patent eats the market share of the $N - 1 = 4$ other patents that used to protect a sufficiently similar technology.

The growth in the stock of standard technologies $A_{sep,t}$ over time is:

$$\frac{dA_{sep,t}}{dt} = \gamma_{sep} \cdot B_t \tag{8}$$

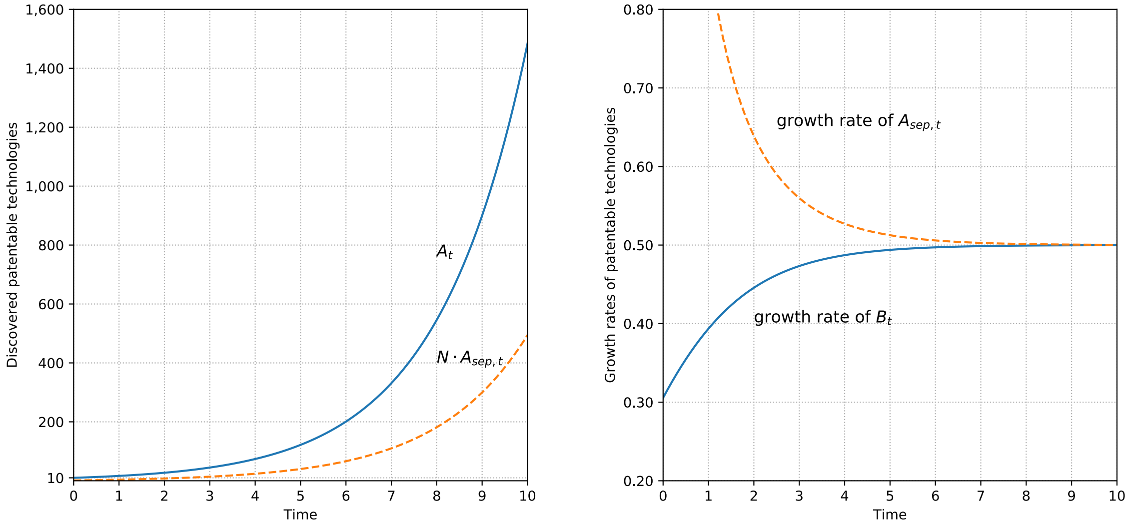
This results in the dynamics for individual patents not included in a standard:

$$\frac{dB_t}{dt} = \kappa \cdot A_t \cdot H_A - N \cdot \gamma_{sep} \cdot B_t \tag{9}$$

When there are no standards and $A_{sep,t} = 0$ we have $A_t = B_t$ and the growth in newly-set standards is $\dot{A}_{sep,t}/A_{sep,t} = \gamma_{sep}$. As standards cover all discovered technologies so that $A_{sep,t} = A_t/N$ we have no individual patents remaining $B_t = 0$ and the growth in standards stops $\dot{A}_{sep,t}/A_{sep,t} = 0$. In the balanced growth equilibrium there could be a steady-state situation when the growth in standards is equal to the growth in patents and is equal to the overall growth of technological discovery $\kappa \cdot H_A$. Note that H_A is endogenous.

Now we explore how standardization affects the value of a patent P_B. Suppose the standardization event occurs and the owner of the patent enjoys the extended market share $N > 1$ and the contribution of standardization to productivity $(1 + \epsilon_{sep})$. The

Figure 4: Growth in standards: Example



Dashed line shows standard-essential patents $N \cdot A_{sep,t}$, solid line shows the stock of discovered technologies A_t. In the beginning there are $A_0 = 10$ technologies and $B_0 = 9$ individual patents. The rate of standardization $\gamma_{sep} = 0.05$, the scope of standards is $N = 5$ and the parameters of technological growth are $\kappa = 0.5$ and $H_A = 1$. The figures show how the growth rates in technologies, standards and individual patents all converge to $\kappa \cdot H_A = 0.5$.

per-unit demand for the resulting input x_j is:

$$p(x_j) = \overline{\chi} \cdot x_j^{-\alpha} \tag{10}$$

$$\text{where:} \qquad \overline{\chi} = (1 + \epsilon_{sep})(1 - \alpha)(1 - H_A)^{\alpha}$$

The unit cost of production of input x_j is the cost of capital $r(t)$ times the amount of capital needed η. The optimal monopolistic price is still the same because we assume there is no change in the demand elasticity, however the monopolistic output of the input $\overline{x}_j$ per unit of time changes to:

$$\overline{x}_j = \overline{x}_i \cdot (1 + \epsilon_{sep})^{\frac{1}{\alpha}}$$

The monopoly profit per unit of time becomes:

$$\pi_{sep}^{M}(t) = N \cdot (1+\epsilon_{sep})^{\frac{1}{\alpha}} \pi^{M}(t) \tag{11}$$

Let the inter-temporal cost of capital be $r(t)$. The HJB equation for the value of an individual patent P_B before standardization implies:

$$(r(t) + N \cdot \gamma_{sep}) \cdot P_B = \pi^{M}(t) + \underbrace{\gamma_{sep}\left(\frac{N \cdot \pi_{sep}^{M}(t)}{r(t)}\right)}_{\text{set as a new standard}} + \underbrace{(N-1)\,\gamma_{sep} \cdot 0}_{\text{eaten by a new standard}}$$

$$P_B = \frac{\pi^{M}(t)}{r(t)} \cdot \left(\rho(t) + (1-\rho(t))\,(1+\epsilon_{sep})^{\frac{1}{\alpha}}\right) \tag{12}$$

$$\text{where: } \rho(t) = \frac{r(t)}{r(t) + N \cdot \gamma_{sep}}$$

There are several economic insights that come out of the last equation. When $\epsilon_{sep} = 0$, i.e., there is no contribution of standardization to productivity due to standardization, the monopolist gets the same expected profits as if there is no standardization in equation (7). However, when $\epsilon_{sep} = 0$ there is a redistribution of market shares in the production of different intermediate goods. Each monopolist ex ante faces $\gamma_{sep}/(N-1)\,\gamma_{sep}$ odds of winning the N times larger market and the residual odds of losing business. In expectation, this market share effect does not affect incentives. Only when $\epsilon_{sep} \neq 0$ standardization may change the incentives that drive technological innovation.

2.4 Balanced growth equilibrium

We are primarily interested in the balanced growth equilibrium of the model, in which the economy grows at a constant rate. According to the equation (3), the growth rate is determined by: 1) the productivity of human capital in the innovative sector relative to the final good production sector, and 2) the dynamics of standardization of patents and the contribution of standardization to productivity ϵ_{sep}.

From our previous discussion recall the dynamics of standard-essential patents and all other patents over time:

$$\frac{dA_{sep,t}}{dt} = \gamma_{sep} \cdot B_t \quad \text{and} \quad \frac{dB_t}{dt} = \kappa \cdot A_t \cdot H_A - N \cdot \gamma_{sep} \cdot B_t \tag{13}$$

Substitute for the stock of discovered technologies the total sum of patents and established standards by using the accounting identity in the equation (2). The system of equations below capture the time-dynamics of the stock of patents and the stock of standards:

$$\begin{aligned} \frac{dB_t}{dt} &= (\kappa \cdot H_A - N \cdot \gamma_{sep}) \cdot B_t + \kappa \cdot H_A \cdot N \cdot A_{sep,t} \\ \frac{dA_{sep,t}}{dt} &= \gamma_{sep} \cdot B_t \end{aligned}$$

Lemma 1. *There exists a balanced-growth equilibrium in which the long-term growth rate of the stock of patents B_t and the growth rate of the stock of standards $A_{sep,t}$ converge to the growth rate of discovered technologies A_t irrespective of the initial values.*

Proof. The outline of the formal proof follows. The system of the two ODEs that describe the time-dynamics of patents and standards has a closed-form solution. The solution for both standards and patents has the common form $C_1 \cdot \exp^{\lambda_1 \cdot t} + C_2 \cdot \exp^{\lambda_2 \cdot t}$; C_1 and C_2 are constants that differ for patents and standards and depend on the initial values of patents and standards; λ_1 and λ_2 are the two eigenvalues of the matrix of coefficients A of the system of equations describing the dynamics of patents and standards:

$$A = \begin{pmatrix} \kappa \cdot H_A - N \cdot \gamma_{sep} & \kappa \cdot H_A \cdot N \\ \gamma_{sep} & 0 \end{pmatrix}$$

The eigenvalues of the matrix A are the roots of the equation:

$$(\kappa \cdot H_A - N \cdot \gamma_{sep} - \lambda)(-\lambda) - \gamma_{sep} \cdot \kappa \cdot H_A \cdot N = 0 \tag{14}$$

The equation (14) has two roots, one strictly negative and one strictly positive. This can be seen by plugging in $\lambda = 0$ in the left-hand side of the equation, which is a U-shaped parabola with a strictly negative intercept at $\lambda = 0$. In the long-term as $t \to +\infty$ all terms with a negative eigenvalue disappear from the solution form $C_1 \cdot \exp^{\lambda_1 \cdot t} + C_2 \cdot \exp^{\lambda_2 \cdot t}$ for both standards and patents. This leads to the ratios of standards and patents being asymptotically-constant, and thus the growth rates being identical in the long-term limit. □

When B_t grows at the same rate as A_t in a conjectured balanced growth equilibrium, the standard-essential patents $A_{sep,t}$ grow at that same rate as well. Thus the ratios B_t/A_t and $A_{sep,t}/A_t$ are constant in the balanced growth equilibrium. We solve for these ratios using the dynamics above:

$$\begin{aligned} B_t &= \zeta_B \cdot A_t \\ A_{sep,t} &= \frac{1}{N}(1-\zeta_B) \cdot A_t \\ &\text{where: } \zeta_B = \frac{\kappa \cdot H_A}{\kappa \cdot H_A + N \cdot \gamma_{sep}} \end{aligned} \tag{15}$$

Proposition 1. *The endogenous growth rate g is the solution to the equation:*

$$\begin{aligned} \left(1 - \frac{g}{\kappa}\right) \cdot \frac{\rho + (1-\rho)(1+\epsilon_{sep})^{\frac{1}{\alpha}}}{\zeta_B + (1-\zeta_B)(1+\epsilon_{sep})^{\frac{1}{\alpha}}} &= \frac{r}{\kappa} \cdot \frac{1}{(1-\alpha)} \\ \textit{where: } \rho = \frac{r}{r + N \cdot \gamma_{sep}} \end{aligned} \tag{16}$$

Proof. Using (15), rewrite the final good production function in (3) as:

$$Y_t = (1-H_A)^{\alpha} A_t \left(\zeta_B + (1-\zeta_B)(1+\epsilon_{sep})^{\frac{1}{\alpha}}\right) \cdot \overline{x}_i^{1-\alpha}$$

In this formula everything is constant except the stock of discovered technologies A_t, which grows at an endogenous rate g. Thus the total output Y_t grows at g as well. Both patents and standard-essential patents grow at the same rate $\dot{B}_t/B_t = \dot{A}_{sep,t}/A_{sep,t}$ as the stock of discovered technologies $\kappa \cdot H_A$.

In equilibrium, the marginal product of human capital employed in the final good production sector is equal to the marginal product of human capital in the innovative patent-production sector. The equilibrium condition for the human capital allocation is:

$$\alpha\left(1-H_A\right)^{\alpha-1}\left(\zeta_B+\left(1-\zeta_B\right)\left(1+\epsilon_{sep}\right)^{\frac{1}{\alpha}}\right)\cdot\overline{x}_i^{1-\alpha} = P_B\cdot\kappa \tag{17}$$

Note that to calculate the marginal product of human capital in the innovative patent-production sector we take the growth of newly discovered patents $\kappa \cdot A_t \cdot H_A$ rather than the growth of the patents without standards $\kappa \cdot B_t \cdot H_A$. The latter includes the effect of existing patents being eaten by newly set standards, while to measure productivity of human capital we count only newly discovered patents. Simplifying we get the endogenous growth rate g as the solution to the equation in the proposition. □

The last term in the equation in Proposition 1 captures the effect of standards and standard-essential patents on the endogenous growth rate g. Denote this term as:

$$G_{sep} = \frac{\rho+(1-\rho)\left(1+\epsilon_{sep}\right)^{\frac{1}{\alpha}}}{\zeta_B+\left(1-\zeta_B\right)\left(1+\epsilon_{sep}\right)^{\frac{1}{\alpha}}} \tag{18}$$

$$\text{where:} \quad \rho = \frac{r}{r+N\cdot\gamma_{sep}}, \qquad \zeta_B = \frac{g}{g+N\cdot\gamma_{sep}}$$

Equation (18) demonstrates that when $\epsilon_{sep}=0$ there is no effect of standards on economic growth and $G_{sep}=1$. When standards only reallocate market share among technologies, relative incentives of agents to engage in technology production are unchanged.

Either of the two conditions are required for standards to be growth-enhancing $G_{sep} > 1$:

1. Standards have a productivity-enhancing effect so that $\epsilon_{sep} > 0$ and the growth rate of the economy is higher than the cost of capital so that $g > r$.

2. Standards reduce marginal productivity of patents so that $\epsilon_{sep} < 0$ and the growth rate of the economy is lower than the cost of capital so that $g < r$.

Consider the first condition above. When growth rate of the economy g is relatively high, there are relatively more patents which are less productive than standards among the discovered technologies. This reduces incentives for the human capital to choose final good production sector, raises H_A in equilibrium, and increases the endogenous growth rate of the economy g. Alternatively, consider the second condition above. A relatively low growth rate g combined with the productivity-reducing effect of standards $\epsilon_{sep} < 0$ implies relatively fewer patents which are more productive than standards. This, as well, reduces incentives for the human capital to choose final good production sector.

As Romer [1990] for simplification we could use Ramsey consumers with CRRA utility function, risk aversion σ and inter-temporal discounting β. Then the interest rate on capital in the balanced growth equilibrium is $r = \sigma \cdot g + \beta$. When risk-aversion of consumers is sufficiently high, the risk-free rate is above the balanced growth rate g: $r > g$. When taken together with an assumption of a positive contribution of standardization to productivity $\epsilon_{sep} > 0$ our model predicts a surprising negative impact of standardization on long-term economic growth.

2.5 Extension with standards and M new patents

Recall that according to our original assumption, once a patent becomes a standard, the standardized technology substitutes for $N - 1$ individual rival technologies. However, a successful standardization of one technology may give birth to additional patentable ideas. To capture this technological spillover, we assume that with every new standard there are $M > 0$ new patents appearing and extending the stock of technologies in the economy. There are two changes to the equilibrium introduced by this extension: 1) the balanced growth will be affected by the additional dynamics of new patents, and 2) the patent value P_B will take into account the additional value created if we assume the new M patents belong to the owner of the standard.

Firstly, the new dynamics describing the balanced growth equilibrium are:

$$\frac{dA_{sep,t}}{dt} = \gamma_{sep} \cdot B_t \quad \text{and} \quad \frac{dB_t}{dt} = \kappa \cdot A_t \cdot H_A - (N - M) \cdot \gamma_{sep} \cdot B_t$$

Solving for the steady-state growth rates of patents and standards, we get:

$$\begin{aligned} B_t &= \zeta_B^M \cdot A_t \\ A_{sep,t} &= \frac{1}{N}\left(1 - \zeta_B^M\right) \cdot A_t \\ &\text{where: } \zeta_B^M > \frac{\kappa \cdot H_A}{\kappa \cdot H_A + N \cdot \gamma_{sep}}, \ \frac{d\zeta_B^M}{dM} > 0 \end{aligned}$$

The new patent value P_B is the same as before if the new patents do not belong to the owner of the standard. The modified equilibrium condition for the human capital allocation is:

$$\alpha \left(1 - H_A\right)^{\alpha - 1} \left(\zeta_B^M + \left(1 - \zeta_B^M\right)\left(1 + \epsilon_{sep}\right)^{\frac{1}{\alpha}}\right) \cdot \overline{x}_i^{1-\alpha} = P_B \cdot \kappa \tag{19}$$

Alternatively, if we assume the new M patents belong to the same person who owns the standard, the modified patent value P_B^M is:

$$\begin{aligned} P_B^M &= \delta_M \cdot P_B \\ &\text{where: } \delta_M = \frac{r(t) + N \cdot \gamma_{sep}}{r(t) + (N - M) \cdot \gamma_{sep}} \end{aligned}$$

To avoid bubbles in the patent valuation, we need to make an additional assumption that $M \leq N$. The modified equilibrium condition for the human capital allocation is:

$$\alpha \left(1 - H_A\right)^{\alpha - 1} \left(\zeta_B^M + \left(1 - \zeta_B^M\right)\left(1 + \epsilon_{sep}\right)^{\frac{1}{\alpha}}\right) \cdot \overline{x}_i^{1-\alpha} = \delta_M \cdot P_B \cdot \kappa \tag{20}$$

Since $\frac{d\zeta_B^M}{dM} > 0$ we know that the fraction of patents in the population will be higher, the higher is M. This would have a dampening effect on the incentive to produce final good if standards are productivity-enhancing $\epsilon_{sep} > 0$, and vice versa. In addition, if we assume the new M patents belong to the owner of the standard, the incentive to join the innovative sector strengthen. We conclude that for this when standards are productivity-enhancing $\epsilon_{sep} > 0$, the positive $M > 0$ increases the likelihood of the growth-enhancing outcome in equilibrium even when $r > g$.

3 Policy implications

3.1 Mandated compulsory licensing

Standard-essential patent, just like any patent, protects the monopolistic revenue π^M_{sep}, or at least some fraction of it, of the patent holder. The supra-competitive revenue remunerates the ex-ante efforts of generating innovation and obtaining the patent. In some fields, e.g., public provision of healthcare, the monopoly rents of patent holders may lead to an under-provision of an important service, and a market failure which justifies a governmental measure. One of the oldest policy have been compulsory licensing, in which the patent holder is obliged by the government to release the intellectual property to the end-users at some mandated price. More recently, under the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) governments can authorize various forms of compulsory licensing for its own purposes (Son [2019]).

Compulsory licenses on standard-essential patents are mandated, with fixed renumeration for patent holders, and recover some fraction $\delta < 1$ of the monopolistic revenue π^M_{sep}. In the context of our model, such regulation reduces the monopoly profit of the owner of the standardized technology so that equation (11) changes to:

$$\pi^M_{sep}(t) = \delta \cdot N \cdot (1 + \epsilon_{sep})^{\frac{1}{\alpha}} \pi^M(t) \tag{21}$$

In the extreme case of compulsory licensing for free, δ can be the probability of a favorable court ruling resulting in a significant loss of the monopoly power protection. The equilibrium effect of standards on the endogenous growth in equation (18) changes to:

$$G_{CL} = \frac{\rho + \delta \cdot (1-\rho) \cdot (1+\epsilon_{sep})^{\frac{1}{\alpha}}}{\zeta_B + (1-\zeta_B) \cdot (1+\epsilon_{sep})^{\frac{1}{\alpha}}} < G_{sep} \tag{22}$$

where: $\rho = \frac{r}{r + N \cdot \gamma_{sep}}$

$\zeta_B = \frac{g}{g + N \cdot \gamma_{sep}}$

When $\delta < 1$ our model predicts a reduction in the equilibrium long-term growth g according to the equation (17). When there is a positive contribution of standardization to productivity $\epsilon_{sep} > 0$ and $r > g$ we have:

$$G_{CL} < G_{sep} < 1$$

In case there is a negative contribution of standardization to productivity $\epsilon_{sep} < 0$ and $r > g$ there are two benchmark regions for the value of δ which are relevant for the prediction about the equilibrium long-term growth g:

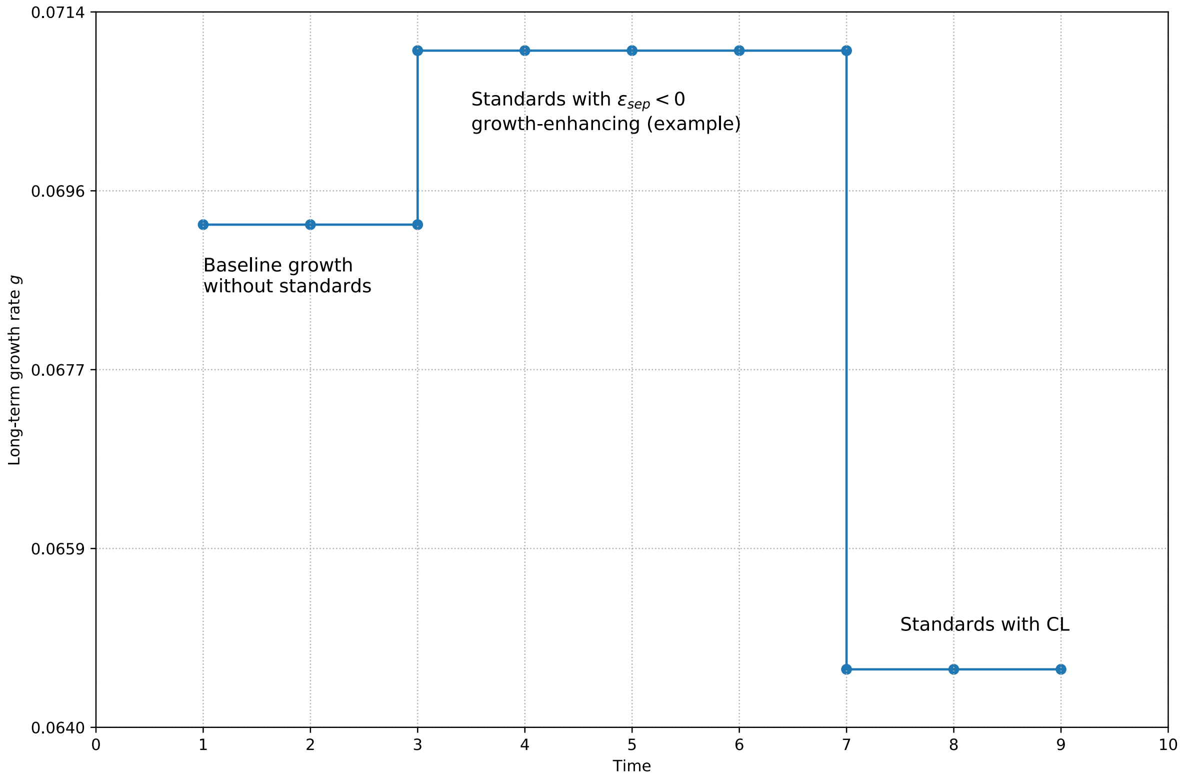
1. When $\delta > \overline{\delta} > (1 + \epsilon_{sep})^{-\frac{1}{\alpha}}$ standards are still growth-enhancing, however the increase in growth due to introduction of standards is lower than when there is no regulation of mark-ups $\delta = 1$. The cutoff $\overline{\delta}$ is determined as the solution to the following equation:

$$\zeta_B + (1 - \zeta_B) \cdot (1 + \epsilon_{sep})^{\frac{1}{\alpha}} = \rho + \overline{\delta} \cdot (1 - \rho) \cdot (1 + \epsilon_{sep})^{\frac{1}{\alpha}} \tag{23}$$

2. When $\delta \leq (1 + \epsilon_{sep})^{-\frac{1}{\alpha}}$ our model implies $\pi^M_{sep}(t) \leq N \cdot \pi^M(t)$ and standards reduce economic growth. Compulsory licensing cancels the effect of standards on the human capital incentives. In this setting standards have a negative contribution to productivity but the lower monopoly profits dominate and so incentives to innovate are lowered relative to incentive to produce final goods. The effect of standard-essential patents on the endogenous growth is $G_{CL} < 1$, which makes final good production more promising than innovation production for investment of human capital.

We conclude that compulsory licensing in our framework is growth-reducing. Compulsory licensing does offer a solution to the market failure, but at the cost of lower collaborative efforts today.

Figure 5: Growth with standards and compulsory licensing



The figure shows growth rates in the balanced growth equilibrium with a negative contribution of standardization to productivity $\epsilon_{sep} < 0$ and $r > g$. First three points on the graph correspond to growth rate in an equilibrium with no standards. Next five points correspond to growth rate in an equilibrium with standards and no regulation of mark-ups. The last three points correspond to growth rate in an equilibrium with standards and with price regulation in which $\delta = (1 + \epsilon_{sep})^{-\frac{1}{\alpha}} < 1$. Compulsory licensing reduces the endogenous growth rate of the economy.

3.2 SEPs with voluntary FRAND

The baseline model predicts a drop in long-term growth following an introduction of mark-ups regulation, e.g., in the form compulsory licensing. An alternative pricing mechanism for essential patents is FRAND. Unlike compulsory licensing, FRAND is voluntary and could be renegotiated periodically. In this section we argue that FRAND can be growth-enhancing if standards with reasonable pricing give rise to M new patents, as in the section 2.5.

Unlike compulsory licensing, which is a "stick-measure" and has been documented to be often limited and sporadic (Son [2019]), the "carrot-measure" of FRAND pricing seem to be more promising in speeding up further development of the IP due to simplifying the "basics" of standard usage as an interface for everybody to use. Our model suggests it is important to complement mark-up regulation with promoting further innovation when addressing patent abuse.

Next, we discuss the patent pricing implications and how welfare can change in response to alternative pricing mechanism used to determine FRAND royalties. According to our model patent value, which takes into account the expected standardization in the future, is the key determinant of human capital incentives in equilibrium, as in the equation (17). Thus the actual pricing mechanisms behind FRAND have direct impact on the endogenous growth rate of the economy. There are several alternative pricing mechanisms, which differ in the timing of royalties negotiations and the set of participants in these negotiations. Those happening before the actual composition of the standard is set are called "ex ante" mechanisms, and are advocated in the analysis by Lerner and Tirole [2015] (as structured price commitments). Those happening after are called "ex post" and are much more common in practice, but supposedly less efficient due to potential hold up situations. In terms of the negotiations themselves, "ex ante" mechanisms may involve many potential patent holders and may be set up as an auction (Swanson and Baumol [2005]). The winning bidders in the auction will participate in the newly-formed standard. Farrell and Simcoe [2012] argue in favor of the collective negotiation of royalty rates which solves many practical difficulties arising from bilateral negotiation, including the hold up situations. Alternatively, in a bottom up approach, each patent holder will negotiate patent-specific royalties individually and independent of other patent holders with relevant patents (e.g. Contreras [2017]). The bottom up approach would be less preferable as it excludes direct participation of many other stakeholders and feedback effects among participating patents from the royalty negotiation process.

In the context of our model, a pricing mechanism which favors the patent owner and provides more bargaining power would imply a higher net present value of all future royalties collected P_B, however, it may make the standard composition sub-optimal and reduce the associated productive efficiency ϵ_{sep}. There is a trade-off between the better efficiency of the standard and the human capital incentives that affect long-term growth. Ideally, the pricing mechanism should strike well on both dimensions.

Illiquidity of patents and difficulty to resell ideas on a secondary market is another factor that hurts human capital incentives and lowers the right-hand side of the equation (17). Standard-essential patents may be made more liquid via the right market regulation and this effect will have an impact on the patent values through the discounting of the future expected rents. Thus we advocate for the stricter standard rules and making patents' secondary markets more liquid.

Moreover, there may be market-based enhancement of FRAND pricing, e.g., FRAND strips. FRAND strips could be designed as financial instruments to be offered by registered financial intermediaries. Each strip would trade license-related cash flows of individual patents in the standardized pool of IP. Importantly, trading FRAND strips would not result in surrendering of IP rights. FRAND strips may improve patent valuation via better market-based estimates of the expected profits π_{sep}^{M}, and enhance professional practices in portfolio patent management.

4 Conclusion

In this paper, we explore the role of standard-essential patents and technological standardization in the endogenous long-term economic growth setup. We show that the zero-sum redistribution of market share which occurs when the winning technological standard overtakes competing innovations is not enough by itself to raise incentives to innovate on an aggregate level. The innovators' risk of losing the standard-setting game ex-ante attenuates the anticipation of a larger market share. Secondly, since the discovery of new technologies is typically slower than the discounting rate for the monopoly profits in equilibrium, standards with a positive contribution to productivity tend to be growth-reducing. The monopoly profits are discounted at a greater rate than the marginal productivity of the final good sector, and so relatively more benefits from standardization accrue to the less innovative sector of the economy, which on aggregate reduces marginal incentives to innovate. Then we show how positive spillovers of standards on innovation via the additional patents per standard may result in an additional endogenous economic growth despite the aforementioned discounting effect.

In our model mandated compulsory licensing of essential technologies has a negative impact on long-term growth. Compulsory licensing does offer a solution to the market failure, but at the cost of lower collaborative efforts today. Unlike compulsory licensing, which is a "stick-measure", the "carrot-measure" of FRAND pricing seem to be more promising in speeding up further development of the IP due to simplifying the "basics" of standard usage as an interface for everybody to use. Our model suggests it is important to complement mark-up regulation with promoting further innovation when addressing patent abuse.

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Conclusion and discussion

In this chapter, I go through each of my essays and discuss different methods and angles from which we can address the patent valuation question from micro and macro perspectives — all three papers bridge theory of patent valuation with the real-world data and assumptions. I will also discuss the possibilities of research areas, which can further address the question of what the reliable measures for the patent-related contribution are; if and how patents create value for companies and economies.

Factor Model of Patent Valuation

As expected, the results from the model aligned with a perception of patent attorneys regarding the value of patent families. As a limitation, the described methodology does not provide managers with a probable forward-looking value of a patent family.

The results of this study provide decision-makers with valuable insight into the patent portfolio management. Concerning the portfolio diversification, the analysis was performed on the whole portfolio and each business cluster. Experts' opinion suggests splitting the portfolio into business-specific clusters. The resulting ranking of patent families for each cluster serves better the objectives of valuation. Likewise, executives can compare innovations across businesses, set priorities, and make wiser strategic decisions.

Even though the factor model addresses the question of how the patent value can be obtained from the measures that, as confirmed by the previous research, are value-related indicators, it does not have a strong correlation with the experts' opinion on the patent value. Unexplained variation raises a question if the further research should look more into the validity of established patent value or patent quality measurements and how the relevance of such measures can be improved towards the experts' opinion on the value.

Patent valuation: toward a direct measurement

The problem of finding a proper way to define the added value of a patent challenges both practitioners and researchers. It is important to understand and quantify how a patent contributes to the company's performance. The literature has identified various factors indicating the indirect value of patents—as measured by the number of citations a given patent generates, the number of claims in a patent document, predictions of stock performance, and the amount of venture capital received. In our study, we focus on a direct measurement of a patent value. We investigate the response in the common direct measures of corporate performance such as sales, prices, market shares of products protected. Various exogenous and endogenous factors contribute to the observed effect of changes in patents portfolios on corporate performance. In this study, we attempted to identify a causal relationship—that a market change occurs due to a patent abandonment holding everything else equal.

Ideas-Driven Endogenous Growth and Standard-Essential Patents

In this paper, we explore general equilibrium conditions for standards to affect the endogenous long-term economic growth. We show that the zero-sum redistribution of market share is not enough to reshape incentives to innovate on an aggregate level. As we show, the innovators' risk of losing the standard-setting game ex-ante attenuates the anticipation of a larger market share. Secondly, since the discovery of new technologies is typically slower than the discounting rate for the monopoly profits in equilibrium, standards with a positive contribution to productivity tend to be growth-reducing. Then we show how positive spillovers of standards on innovation via the new technologies are discovered may dampen incentives to engage into final good production relative to the innovative sec24 tor, which enhances endogenous economic growth. However, the FRAND regulation of mark-ups has an unambiguous negative effect on growth and long-term growth-destroying consequences.

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Honours and Awards

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Conferences and Presentations

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- 2017 Eighth Erasmus Liquidity Conference, Rotterdam, Netherlands. Topics of interest: text-based analysis of patents
- 2017 Society for Financial Studies Cavalcade North America, Nashville, USA. Topics of interest: financial value of patents, collateral value of patents
- 2016 EPO Patent Information Conference, Madrid, Spain
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