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Conference Paper

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31st European Conference of the International Telecommunications Society (ITS): "Reining in Digital Platforms? Challenging monopolies, promoting competition and developing regulatory regimes", Gothenburg, Sweden, 20th - 21st June 2022

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Gamarra, Yanis; Friedl, Gunther (2022) : Firms' Involvement in Standardization and Average Total Costs per Patent Family, 31st European Conference of the International Telecommunications Society (ITS): "Reining in Digital Platforms? Challenging monopolies, promoting competition and developing regulatory regimes", Gothenburg, Sweden, 20th - 21st June 2022, International Telecommunications Society (ITS), Calgary

This Version is available at:

<https://hdl.handle.net/10419/265630>

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Firms' Involvement in Standardization and Average Total Costs per Patent Family ^{*}

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Abstract

Technology standards such as the Wi-Fi or 5G mobile communication standard rely on standard-essential patents (SEPs). Increasing licensing revenues and several disputes between owners and users of SEPs raise the question about the patenting behavior of firms developing standardized technologies. A better understanding of this patenting behavior can help to improve the standard-setting process and standard adoption. We propose the average total costs per patent family as an economic assessment criterion and an indicator of patenting behavior for technology standards. Using this criterion, we examine how increasing SEP family portfolios and their ownership concentration are associated with firms' patenting behavior. We find that increasing ownership concentration of SEP families is negatively associated with firms' average total costs per patent family, suggesting that decreasing competition around SEP families might decrease firms' investments per patent family. We conclude that policy makers and standard-setting organizations (SSOs) should discourage blanket declarations since increasing SEP transparency could improve comparability across standard-setting processes and reduce uncertainties in subsequent standard adoption for SEP holders and implementers. SSOs should further closely monitor how increasing (decreasing) ownership concentration of SEPs affects their standard-setting processes.

Keywords: Average total costs, standardization, standard-essential patents, patenting, R&D

JEL Classification: L15, L96, O32, O34

*The authors thank colleagues at Technical University of Munich for their constructive feedback on this work.

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1. Introduction

Technology standards have, among others, the purpose of achieving compatibility and interoperability and are essential whenever international trade is promoted (see, e.g., [Baron and Spulber, 2018](#); [Swann, 2010](#)). While de facto standards can emerge through market processes, formal standards are established by government bodies or standard-setting organizations (SSOs) (see, e.g., [Belleflamme, 2002](#); [Chiesa et al., 2002](#); [Greenstein and David, 1990](#)). Consequently, standardization processes can provide significant degrees of market power to those companies whose patented technologies are included in the standard, especially if the technologies are standard-essential (see, e.g., [Spulber, 2019](#); [Lerner and Tirole, 2015](#); [Spulber, 2013](#); [Layne-Farrar, 2011](#)). Formal standards in the telecommunications industry, such as Wi-Fi, 4G, and 5G, rely on thousands of standard-essential patents (SEPs) owned by a large number of SEP holders (see, e.g., [Pohlmann et al., 2020](#); [Baron and Pohlmann, 2018](#); [Galetovic et al., 2018](#)). Complications can arise especially for implementers, as any standard implementation without a license agreement with the SEP holders will, by definition, infringe these SEPs (see, e.g., [Baron and Pohlmann, 2018](#); [Kang and Bekkers, 2015](#)).

Numerous concerns about firms' patenting and licensing behavior have been linked to standardization: One concern is that numerous patent holders and SEPs might result in so-called "patent thickets", situations in which patents are highly fragmented ([Shapiro, 2000](#)). Another concern addresses the risk that "stacking" numerous licenses could lead to excessively high cumulative royalties (see, e.g., [Lerner and Tirole, 2015](#); [Lemley and Shapiro, 2007](#)). A third concern is patent "hold-up", where SEP holders use their market power and opportunistically increase SEP royalties to standard implementers ([Farrell et al., 2007](#)). Nevertheless, there is no empirical evidence supporting patent hold-up or excessively high cumulative royalties (see, e.g., [Galetovic et al., 2018](#); [Sidak, 2016](#); [Galetovic et al., 2015](#); [Mallinson, 2015](#); [Layne-Farrar, 2014](#)). Last but not least, previous literature addresses the opposing concern of patent "hold-out", where patent implementers deliberately ignore patent demands and delay licensing negotiations despite legitimate claims (see, e.g., [Heiden and Petit, 2018](#); [Epstein and Noroozi, 2017](#); [Chien, 2014](#)).

In order to ensure that implementers are protected while SEP owners receive a fair reward for their research and development (R&D) investments, many SSOs, such as the European Telecommunications Standards Institute (ETSI), introduced licensing terms where patent owners participating in standardization commit themselves to license their SEPs on fair, reasonable and non-discriminatory (FRAND) terms ([ETSI, 2021](#); [Ménière, 2015](#); [Sidak, 2013](#)). However, numerous patent disputes have revealed vast discrepancies regarding views on the interpretation of FRAND commitments. The patent disputes occur not only among standard implementers but have also given rise to so-called patent assertion entities (PAEs), companies that are not active at the downstream production level but use patents to maximize their licensing revenues ([Lim, 2014](#)). At the same time, the number of declared SEPs has more than

tripled and the number of companies declaring SEPs has more than doubled since 2010 across industries such as telecommunications (Pohlmann, 2021). With increasing Internet of Things (IoT) applications in many industry verticals, it is reasonable to assume that firms' patenting and licensing behavior will also adjust (Henkel, 2021; Nikolic and Galli, 2021a). This study proposes a new perspective on firms' patenting behavior in standardization to further improve the standardization process and adoption.

Previous studies analyzing firms' patenting behavior in standardization have mainly looked at patent numbers as they play an important role in identifying technology leadership, such as in 5G (see, e.g., Parcu et al., 2021; Luby et al., 2020; Pohlmann et al., 2020). Bekkers and West (2009b) compare the GSM (2G) and UMTS (3G) patenting. They show strong increases in SEPs and SEP holders and find an increasing ownership concentration of SEPs. Kang and Bekkers (2015) look at the development of 3G and 4G. They find that firms file patents with low technical contributions shortly before standardization meetings and then have their employees incorporate the patents into the standard to strategically increase the company's SEP portfolio. Layne-Farrar (2011) analyzes patent citations of ETSI-declared patents in UMTS standardization and finds that patenting may be a combination of predominantly incremental innovation and fewer strategically filed patents. However, these studies rely primarily on the number of patents or patent citations as analysis variables. They do not aim to consider the economic value of patents. This study proposes the average total costs per patent family as an economic assessment criterion and an indicator of firms' patenting behavior. Using this criterion, we examine how firms' involvement in standardization at ETSI, measured through the ownership of declared SEP families and its concentration, is associated with firms' patenting behavior.

Against this background, the study has two main contributions: First, it contributes to the literature on patent valuation methods by applying a FRAND-conform, cost-based valuation approach to a long time series and emphasizing its ease of application. We calculate the yearly average total costs per patent family from 1996 to 2017 using a methodology suggested by Friedl and Ann (2018), where R&D expenditures are allocated to patent family portfolios to estimate how much a patent family costs on average. In cases where an entire portfolio valuation is needed, the cost-based approach of Friedl and Ann (2018) can be beneficial, as it relies on the idea that, at least in the telecommunications industry, patent holders usually hold broad patent portfolios, are regularly audited and provide reliable information on their R&D expenditures. These figures also consider overhead costs and allow a reasonable first estimate of the yearly average total costs per patent, even for large data sets. We define a patent family according to the DOCDB family definition of the European Patent Office (EPO), i.e., a collection of related patent applications that cover the same technical content (European Patent Office, 2017; Martínez, 2011). Second, the study examines how firms' involvement in standardization is related to firms' yearly average total costs per patent family. We measure firms' involvement in standardization through their SEP family declarations and the concentration of SEP family ownership at ETSI. The study then derives implications for firms'

patenting behavior. The study uses SEP data from the Searle Center Database ([Baron and Pohlmann, 2018](#)). It further focuses on publicly listed companies that participate in standard-setting at ETSI and hold more than 14,500 patent families (equivalent to more than 66,000 patents) over the entire observation period.

We find a negative association between increasing SEP family ownership concentration and firms' yearly average total costs per patent family. Furthermore, we find that increasing SEP family portfolios are positively associated with firms' yearly average total costs per patent family. However, the magnitude of the corresponding coefficients does not outweigh that of ownership concentration in any of our models. The analyses take into account that there might be time lags between R&D expenditures and patent applications, such that the cost allocations consider time lags between zero and five years (see, e.g., [Danguy et al., 2009](#); [de Rassenfosse and Guellec, 2009](#); [Hall et al., 1986](#)). Overall, the results remain consistent when applying costs with different time lags and accounting for econometric challenges of the data set, confirming the relationship between SEP family ownership, its concentration and yearly average total costs per patent family. We conclude that both measures for firms' involvement in standardization, SEP family ownership and its concentration, should be considered when examining their impact on firms' average total costs per patent family. We argue that policy makers and SSOs should discourage blanket declarations since increasing SEP transparency could improve comparability across standard-setting processes and reduce uncertainties in subsequent standard adoption for SEP holders and implementers. SSOs should further closely monitor how increasing (decreasing) ownership concentration of SEPs affects their standard-setting processes.

The paper is organized as follows: Section 2 reviews the relevant literature on standard-setting, standard-essential patents and FRAND-conform licensing. It further derives the research gap. Section 3 describes the data and methodology used in the paper. Section 4 shows the empirical results and robustness checks. Section 5 discusses the main findings and section 6 provides some concluding remarks.

2. Literature review

This section reviews the underlying literature of the study. First, it introduces relevant standard-setting literature and presents central studies on SEPs. It then discusses patent valuation methods from the FRAND literature and derives the research gap.

2.1. Standard-setting and SEPs

In recent years, the development of the 5G standard has led to a growing body of literature covering different perspectives of the 5G technology. [Oughton et al. \(2021\)](#) contrast the two leading next-generation wireless broadband technologies, 5G and Wi-Fi 6. [Cave \(2018\)](#) points out that 5G has the potential to enable significant change and digital transformation in our society and across a wide range of industry verticals. [Oughton and Frias \(2018\)](#) discuss the roll-out of 5G in Britain, identifying cost characteristics

for seven different geotypes and calculating the roll-out costs for different demand scenarios. More research mainly looks at patent data and sheds detailed light on technology leadership in 5G (see, e.g., [Parcu et al., 2022](#); [Massaro and Kim, 2021](#); [Parcu et al., 2021](#); [Pohlmann et al., 2020](#); [Lemstra, 2018](#)). [Buggenhagen and Blind \(2022\)](#) consider additional metrics and show that companies offering FRAND licensing terms for SEPs optimize their 5G technology development contributions using publications, patenting and standard contributions. [Mendonça et al. \(2022\)](#) provide a systematic overview of 5G-related research until 2020, consisting of more than 10,000 scientific and technical publications. [Nikolic and Galli \(2021b\)](#) stress that patent thickets, as well as infringement jungles, could threaten the deployment of 5G and emphasize the necessity for policies. However, according to [Bauer and Bohlin \(2021\)](#), policy makers should align regulations with the respective value chains and consider direct, indirect and systemic impacts on participants of 5G standardization. [Rossi \(2021\)](#) emphasizes the importance of technology openness and new non-discrimination policies to facilitate innovators' introduction of new services.

It becomes evident that technology standards are an essential economic driver. They facilitate the exchange between industry participants and play a central role in promoting international trade ([Baron and Spulber, 2018](#)). Technology standards further aim to reduce diversity, achieving higher product quality, compatibility and interoperability. These purposes, in turn, affect several economic variables such as economies of scale, network effects and transaction costs ([Swann, 2010](#)). The underlying standard-setting activities from which technology standards emerge are considered part of the competitive product development process. The reason is that a technology included in a standard can lead to critical competitive advantages for the technology owner, especially if many products will subsequently adopt the standard ([Weiss and Sirbu, 1990](#)). In the first step of the product development process, the company must initially decide how much it will invest in R&D ([Harhoff, 1997](#)). The next decision concerns the innovation protection mechanism that the firm wants to apply to the new technology. Typically, patent protection is only sought for a portion of all patentable innovations, as there are also other ways to protect innovations, such as through secrecy, lead time advantages, complementary sales and services, or complementary manufacturing facilities ([Danguy et al., 2009](#); [Cohen et al., 2000](#)). If the firm wants to submit the innovation to a standard, patents are a commonly used option, especially in telecommunications. Patents guarantee the exclusive use of an invention for a certain period if the invention is new, involves an inventive step and is industrially applicable ([European Patent Office, 2020](#)). Nevertheless, besides filing patents to protect their inventions from imitation, previous studies have shown that firms have several other motives to file patents ([Blind et al., 2009](#); [Cohen et al., 2000](#)). [Blind et al. \(2006\)](#) use a factor analysis and find in their sample of German firms that firms have the following additional patenting motives: First, firms might want to block competitors defensively and offensively. While defensive blocking ensures a company's technological freedom of action vis-à-vis its competition, offensive blocking shall prevent competitors from making technological improvements. Second, firms can

use patents to improve their technological image and the company’s value (reputation motive). Third, firms can use patents to improve their bargaining position, e.g., in licensing negotiations (exchange motive). Fourth, firms can use patents as internal performance indicators and thereby motivate their employees (incentive motive). After deciding to use patents, the firm must decide how many patents it wants to propose to a standard (Blind, 2002). Previous literature shows that not all industries are affected equally by standard-setting activities. For instance, the results of Blind (2002) suggest that patent-intensive sectors standardize more than R&D-intensive industries with a lower corresponding patent output. The literature further shows that firms profit from the diffusion of standards, such as through an increasing user acceptance (Brynjolfsson and Kemerer, 1996), through positive effects on technologies or products (Weitzel et al., 2006) and economic growth (Blind and Thumm, 2004). However, standard-setting activities also come hand in hand with high financial costs that firms should consider (Chiao et al., 2007).

Standard-setting classifies into two categories: *de facto* standardization and formal standardization. On the one hand, *de facto* standards emerge through market-regulated processes and imply a critical mass applying a technology. While intellectual property rights (IPR) can protect *de facto* standards, this must not necessarily be the case (Belleflamme, 2002; Chiesa et al., 2002; Greenstein and David, 1990).¹ Blind and Thumm (2004) describe *de facto* standards as an extension of IPR like patents and copyrights which have established themselves successfully on the market. On the other hand, *formal* standards are either mandated by government bodies or result from formal, transparent procedures within other voluntary SSOs (Belleflamme, 2002; Greenstein and David, 1990).² As stated by Chiesa et al. (2002), SSOs can also function as a bridge between *de facto* and *de jure* standards by turning former *de facto* standards into *de jure* standards.³ Most standards developed by SSOs are described as open standards and considered to be a public good (Blind and Thumm, 2004; Baron and Spulber, 2018). In addition, SSOs have strict policies in place to ensure that their standards are accessible to a wide range of interested users. For instance, participating patent owners have to commit themselves to license terms that are FRAND in many cases. Apart from this, SSOs require their members to disclose if patented technologies included in a standard are standard-essential (Sidak, 2013; Spulber, 2013). Any standard implementation without a license agreement with SEP holders will infringe upon such SEPs (see, e.g., Baron and Pohlmann, 2018; Kang and Bekkers, 2015).

Patents involved in formal standard-setting procedures provide their owners with a temporary monopoly position concerning the protected knowledge (Blind and Thumm, 2004). Particularly in the

¹Examples of *de facto* standards include the video cassette recorder (VCR), the compact disk (CD-ROM), the IBM or Microsoft standards, the QWERTY keyboard layout standard and other audio and video equipment (Hunt et al., 2007; Blind and Thumm, 2004; Greenstein and David, 1990).

²Examples include the standards for information communications technologies (ICT) by ETSI or standards for wireless local area networks called "W-LAN" or "Wi-Fi" by the Institute of Electrical and Electronic Engineers (IEEE) (see, e.g., Lim, 2014; Sidak, 2013).

³For instance, Adobe’s Portable Document Format (PDF), previously a *de facto* standard, became a *de jure* standard through the ISO 19005-1: 2005 in 2005 (ISO, 2005).

case of SEPs, there exists a frequent concern that firms may deliberately abuse their market power, for example, by charging inflated licenses (see, e.g., [Pohlmann et al., 2016](#); [Sidak, 2013](#); [Berger et al., 2012](#); [Layne-Farrar, 2011](#)).⁴ Findings from previous literature support the view that SEPs can be a valuable asset for firms. An initial perspective was provided early on by [Bekkers et al. \(2002\)](#), whose analyses of the GSM standard show that the number of SEPs is a crucial factor in strengthening a firm's position within a network. [Rysman and Simcoe \(2008\)](#) find that patents declared essential to a standard receive double citations compared to patents that are not standard-essential. They conclude that SSOs significantly contribute to the patent's future value. [Bekkers and West \(2009b\)](#) examine UMTS standardization and note that a critical form of strategic patenting is when firms anticipate the development of a standard to then create patents that fit that standard. Their analyses of patent filing and timing show that Nokia and Ericsson played a central role in UMTS standards development. They also show that both firms might have used their knowledge of standards development to expand their essential patent portfolios in a targeted way. [Layne-Farrar \(2011\)](#) uses forward citations to measure the value of patents declared as essential to the UMTS standard. The findings indicate that most UMTS-essential patents (between 70% and 80%) are value-adding and that patenting after the first release of a standard is not necessarily strategic, but the truth probably lies more between both extremes. The empirical findings of [Berger et al. \(2012\)](#) indicate that firms active in standard-setting activities are strategically shaping their filing behavior of potential SEPs. For instance, the time until the firms finalize their decision on the application is significantly longer for essential patents. They argue that firms might do so to have greater certainty about the outcome of the standardization process and align their SEPs to the developing standard. [Kang and Bekkers \(2015\)](#) study the relationship between SEP inventorship and standardization meetings. They find additional evidence of strategic patenting. They observe that companies file low-value patents shortly before standardization meetings and then have their employees incorporate them into the standard to strategically increase the company's SEP portfolio. [Hussinger and Schwiebacher \(2015\)](#) indicate that firms' technology contributions to a standard positively correlate with firms' market valuation. [Pohlmann et al. \(2016\)](#) extend the literature by finding an inverted U-shaped relationship between SEPs and firms' return on assets (ROA). Their results suggest that filing standard-essential patents increases firms' ROA only up to a certain point. They conclude that firms should be aware that there might be an optimal level of owning SEPs.

⁴One of the first examples of strategic patenting within SSOs to gain market power and then charge excessive licenses is that of the US company Rambus. Rambus was a member of the Joint Electron Devices Engineering Council (JEDEC) in the 1990s and participated in the standard-setting for memory standards. Rambus had filed patent applications that it did not disclose during the standardization process. In 1996, Rambus left JEDEC because they disagreed with the FRAND licensing terms. Rambus subsequently adjusted its patent applications, turning them standard-essential as soon as the standard was established. Rambus consequently gained critical market power and sued numerous chip manufacturers to demand excessive royalties (see, e.g., [Bekkers and West, 2009a](#); [Lerner et al., 2007](#); [Tansey et al., 2005](#); [Patterson, 2003](#); [Lemley, 2002](#)). In 2006, the Federal Trade Commission (FTC) ruled that Rambus exploited its participation in JEDEC standardization through fraudulent conduct. The FTC went on to set maximum allowable royalty rates for Rambus ([Federal Trade Commission, 2007a,b](#)).

2.2. FRAND-conform patent valuation approaches

A significant concern in economics is the ex-post market power of standard-essential patent holders. As the FRAND requirements by SSOs are vague in many cases, various approaches have emerged to derive FRAND royalties for SEPs:

A relatively simple approach – the *Proportional Contribution* method – suggests calculating royalties as the product of (1) the price of the final product, (2) the marginal value added from the patent to the standard and (3) the marginal value added from the standard to the product. A drawback of this approach can arise if the product contains too many standards and patents, turning it impossible to separate each marginal contribution from others (Sidak, 2013). Sidak (2013) states that the *Top-Down* approach derives royalties by multiplying the profits of the smallest salable unit incorporating the patented technology with the marginal value added to the standard by the observed patent. Again, the patent’s marginal value added to the standard may not be observable. Further, the smallest salable unit may not reflect the entire value of the standard. Alternative top-down approaches first calculate the total license fees for all relevant SEPs to measure the extent of their contributions. In a second step, the aggregate royalty is apportioned to individual SEPs or SEP portfolios, for instance, by using numeric proportionality criteria (SEPs Expert Group, 2021; Japan Patent Office, 2018). The *Ex Ante* approach suggests evaluating patents just before the standard incorporates them. At this point, the patented technologies are still competing with other potentially integrable technologies. The licensing terms offered in this situation can more likely reflect the patent’s fair value (Baumol, William and Swanson, Daniel, 2005). Its disadvantage is that it can hardly be applied to already existing standards since it is very challenging to retrospectively define the value of SEPs at the time just before the standard was set (see, e.g., Friedl and Ann, 2018; Lerner and Tirole, 2015).

When switching from output-oriented to input-oriented approaches, the focus is on costs to derive appropriate royalties. The *Bottom-Up* approach first determines the costs that would have been necessary to implement a reasonable alternative to the infringing patent. Then, the costs have to be divided by the number of infringing units to specify a maximum royalty per product (Sidak, 2013). One alternative to the cost-based Bottom-Up approach could be to use comparable licenses of patents from the same or third party patent holders or even from pools (Japan Patent Office, 2018). In contrast to these Bottom-Up approaches, Friedl and Ann (2018) propose a novel method. From their perspective, the integration into a standard should ensure the patent holder that the patent’s underlying R&D costs are covered and that holders achieve an appropriate return on investment (Friedl and Ann, 2018; Murphy et al., 2012). A significant advantage of this approach is that the calculated royalties are consistent with the FRAND approach, as there is no discriminatory royalty differentiation. Such discrimination is often criticized among SEP implementers since, in practice, SEP holders usually charge different fees depending on the value chain level.

Although only a fraction of bilateral negotiations results in litigation, these are the most visible cases that have resulted in many licensing methods and can assist SSOs in clarifying their FRAND policies (Lim, 2014). When applying patent valuation approaches in litigation, only a few patents are usually valued because the data basis for the valuation of an entire portfolio is not sufficient. Furthermore, in many cases, the valuation process would be either too time-consuming or is not desired in the context of litigation. However, in cases where an entire portfolio valuation is needed, the cost-based approach of Friedl and Ann (2018) can be beneficial, as it relies on the idea that, at least in the telecommunications industry, patent holders usually hold broad patent portfolios, are regularly audited and provide reliable information on their R&D expenditures. These figures also consider overhead costs and allow a reasonable first estimate of the yearly average total costs per patent, even for large data sets. Once the yearly average total costs per patent and standard are available, costs per license and standard in a given year can be easily determined by allocating the costs of a patent to the number of devices using that patent (Friedl and Ann, 2018). Thus, their approach enables a much simpler valuation of an entire patent portfolio and simplifies initial estimates. However, in current literature, their cost-based approach has not yet been applied to a wide range of data to support its use and confirm its strengths.

2.3. Research gap

The two previous sections have indicated two aspects, namely: First, to our knowledge, no previous literature has applied a FRAND-conform patent valuation approach to a long time series emphasizing its ease of application. Second, most of the previous literature on standardization analyzes firms' patenting behavior by looking at the increase in patent numbers or citations (see, e.g., Kang and Bekkers, 2015; Layne-Farrar, 2011; Bekkers and West, 2009b; Rysman and Simcoe, 2008; Bekkers et al., 2002). This paper aims to provide an economic assessment criterion at the patent family level and establish a link to firms' involvement in standardization. In order to do so, we apply a FRAND-conform, cost-based valuation approach suggested by Friedl and Ann (2018) and calculate the yearly average total costs per patent family from 1996 to 2017. We analyze how frequently applied measures for firms' involvement in standardization, namely, ownership and concentration of declared SEP families, are associated with the average total costs per patent family. We use a linear regression model to investigate the associations. The following sections will first present the final sample composition, introduce the model and show descriptive statistics. Subsequently, we apply the econometric model to the final sample.

3. Methodology

The final sample consists of 16 firms covering a total of 307 firm-years from 1996 to 2017 in the non-lagged total cost scenario. The entities hold over 14,500 patent families in total, corresponding to more than 66,000 patents over the entire observation period. The following sections explain the construction of the

data set and the cleaning of the sample. They further describe the central independent and dependent variables, introduce the econometric model and show the summary statistics.

3.1. Calculating yearly average total costs per patent family

To ensure that enough financial data is available to calculate the yearly average total costs per patent family, we only consider publicly listed companies part of the STOXX Global 1800 Index between 1996 and 2017. Since we use the STOXX Global 1800 Index, the sample is biased towards large firms. All financial firm-level data is from Thomson Reuters Datastream’s commercial database (now Refinitiv).

The cost-based approach suggests calculating yearly average total costs per patent family relying on the cumulative R&D expenditures of the past 20 years (Friedl and Ann, 2018). Consequently, if one wants to derive the patent costs in 1996, one needs the R&D expenditures from 1977 to 1996 for all selected companies in 1996. Accordingly, the R&D expenditures from 1978 to 1997 are necessary for all selected companies’ patent family cost calculations in 1997. Using this approach, we calculate the yearly changing cumulative R&D expenditures from 1996 until 2017 using the preceding 20 years of each company. We calculate the cumulative R&D expenditures using inflation-adjusted R&D expenditures from a given year to the benchmark year, 2017, for all companies in the sample. Occasionally missing data is interpolated.

In a second step, we estimate the yearly changing size of the patent family portfolios per company, sourcing the necessary data from the ‘EPO Worldwide Patent Statistical Database’ (PATSTAT). We define a patent family according to the DOCDB family definition of the EPO, i.e., a collection of related patent applications that cover the same technical content (Martínez, 2011). Similar to Pohlmann et al. (2016), we identify the companies’ patent family portfolios using keyword searches in the PATSTAT database. We assume that a patent family is held in the company’s portfolio for the full theoretical term of 20 years from its granting time. Similar to the previous examples for the calculations of the cumulative R&D expenditures, patent families granted in 1977 would remain in a company’s portfolio until 1996. On this basis, we calculate the dynamically changing patent family portfolios for the period 1996 to 2017. We drop all portfolios containing less than 100 patent families. This specific sample cleaning aspect is necessary due to the cost-based approach theory. According to this theory, a clear relationship between patented technologies and their corresponding R&D expenditures is only establishable over larger numbers of patents (and related families) (Friedl and Ann, 2018).

We then merge both previously described data sets by firm-identifier and year to one data set. We calculate the yearly average total costs per patent family with the resulting data.

The approach of Friedl and Ann (2018) is as follows: While there are industries that make greater use of patents, other industries rely less heavily on patents. Consequently, the first step is to determine the share of the cumulative, inflation-adjusted R&D expenditures that we can allocate to the patent family portfolios. As mentioned previously, patent protection is only sought for a share of all patentable innovations. We refer to the findings of Arundel and Kabla (1998) and multiply the cumulative, inflation-

adjusted R&D expenditures with the overall innovation propensity for communication equipment of 36.5%. We divide the result by the number of patent families held by the company in the respective observation year, which leads to the average R&D expenditures per patent family. Next, we add external expenses associated with the patent application, prosecution, validation and maintenance over the entire patent family lifetime. According to [van Pottelsberghe de la Potterie and Mejer \(2010\)](#), we assume those costs to be on average USD 21,120. We divide the resulting sum by the effective lifetime of a patent family. The effective lifetime of a patent family is the total lifetime of 20 years minus the average duration of the examination process (i.e., the time until the decision if a patent family is granted or not). [Van Zeebroeck \(2007\)](#) uses a data set including all patent applications filed to EPO between 1980 and 2000 and concludes that the time to decision is on average 4.41 years. As the data set covers a similar period, we assume this average value to be appropriate here. After calculating the yearly costs per patent family, the cost-based approach suggests estimating a reasonable return. We estimate the return by multiplying the average capital employed with the weighted average cost of capital (WACC). [Friedl and Ann \(2018\)](#) argue that companies may only invest in R&D aimed at obtaining patentable inventions if they can expect future returns to be at least as high as their alternative investment options. Therefore, the average capital employed is estimated as follows: The capital employed (average R&D expenditures per patent family) is fully bound until the granting decision. Afterward, it continuously decreases to zero so that we have to recognize, on average, half of the capital employed for the effective patent family lifetime. We then multiply the resulting average capital employed per patent family with the WACC to obtain a reasonable return. Following [Damodaran \(2022\)](#), we refer to the WACC of the telecommunications equipment industry and apply the WACC of 5.82% to all companies in the sample. Finally, we take the sum of the reasonable return per patent family and the previously calculated yearly costs per patent family to obtain the yearly average total costs per patent family.

As current literature commonly suggests, there may be a time lag between initial R&D expenditures and patent applications (see, e.g., [Hall et al., 1986](#); [Danguy et al., 2009](#); [de Rassenfosse and Guellec, 2009](#)). That is why we repeat the calculations considering a varying time lag between one and five years when allocating the cumulative R&D expenditures to the current patent family portfolios.⁵ Overall, the yearly average total costs per patent family are the result of a time-lagged allocation of cumulative R&D expenditures that varies between zero and five years.

3.2. SEP data

We restrict the analyses to companies active in standard-setting procedures at ETSI ([Besen, 1990](#)) between 1996 and 2017. We do this for several reasons: First, ETSI has been central in developing mobile

⁵According to [de Rassenfosse and Guellec \(2009\)](#), the mean time lag between R&D expenditures and patent applications is ten months but may reach up to five years.

telecommunication standards.⁶ Second, previous literature focusing on the patenting behavior of firms active in standardization also mainly looked at ETSI and therefore concentrated on telecommunication standards (Berger et al., 2012; Layne-Farrar, 2011; Bekkers and West, 2009b, 2006; Bekkers et al., 2002; Besen, 1990). Third, ETSI is not only one of the largest SSOs worldwide. Its members also perform reasonably well when providing detailed information on SEP family declarations instead of delivering only blanket declarations. Layne-Farrar (2011) states that blanket declarations are of no value when performing empirical analyses so that ETSI data provides a reasonable basis for studies on patenting behavior.⁷ Finally, most SEP declarations from the publicly available database of Baron and Pohlmann (2018) are declarations at ETSI, making the data availability best for this SSO. We then use the data to build the two main explanatory variables: Similar to Baron et al. (2016), *SEP family ownership* indicates the yearly cumulative number of SEP family declarations by company. We then use this variable to compute an annually varying standardized Herfindahl-Hirschman Index (HHI) of SEP family ownership (values can lie between 0 and 1). The HHI measures *the concentration of SEP family ownership* for all companies under consideration. While an increasing HHI indicates increasing concentration (decreasing fragmentation), a decreasing HHI indicates decreasing concentration (increasing fragmentation). Before calculating the standardized HHI, we exclude companies with ownership of fewer or equal 50 SEP families resulting in a total of 16 entities holding over 14,500 patent families equivalent to over 66,000 patents over the entire observation period.⁸

3.3. Control variables

We consider the following control variables in the empirical analyses. First, we include the annual number of patent family applications. Second, we consider the yearly changing number of forward citations to a company’s patent portfolio and the average family size of the respective portfolio. Third, we add the firm’s yearly varying number of employees to control for firm size effects.

3.4. Model specifications & summary statistics

This section discusses the construction of the regression models and the variables used therein. Table 1 provides summary statistics for these variables. The Appendix A3 reports additional sample statistics, such as how the sample variables correlate with each other. It further contains figures illustrating the development of SEP family ownership concentration (see figure 4) and SEP family ownership (see figure 5

⁶ETSI significantly contributed to developing the GSM and UMTS standardization (Baron and Pohlmann, 2018; Bekkers and West, 2009b). ETSI is therefore of high relevance for all research that analyzes patenting behavior related to telecommunications.

⁷Unlike the disclosure of specific patents or patent claims, blanket declarations are general statements by a company that it owns one or more SEPs for a particular standard or standards project (see, e.g., Baron and Spulber, 2018)

⁸The Searle Center Database dataset includes 2015 as the latest available year for SEP family declarations. We first exclude the following companies as they cumulatively declared fewer than 50 SEP families to ETSI until 2015, with the number of cumulative SEP family declarations in parentheses: Microsoft (47), General Dynamics (38), Infineon Technologies (29), Deutsche Telekom (21), Renesas Electronics (18), Fujitsu (15), Broadcom (6), Lockheed Martin (5), HP (3), Cisco Systems (2), Daimler (1), Emerson Electric (1), STMicroelectronics (1), Thales (1), Vodafone (1). For the remaining companies, we interpolate the SEP family declarations for 2016 and 2017. The final sample composition includes the following companies: Apple, Ericsson, Intel, Kyocera, Mitsubishi Elec., Motorola, NEC, Nokia, Panasonic, Philips, Qualcomm, Sharp, Siemens, Sony, Texas Inst., Toshiba.

to figure 7).⁹ The graphs indicate increasing ownership of declared SEP families and increasing ownership fragmentation in our final sample.

In the econometric model, we regress firms' yearly average total costs per patent family on the time-variant HHI of SEP family ownership, including the cumulative number of SEP family declarations and other innovation- and financial-related control variables. To adjust for skewness, we log-transform the variables where necessary. The resulting log-log model is as follows:

$$\begin{aligned} \log YATCPF_{it} = & \beta_0 + \beta_1 \log HHI_SEP_t + \beta_2 \log SEP_{it} + \beta_3 \log PFA_{it} + \beta_4 \log CIT_{it} + \\ & + \beta_5 \log FAM_{it} + \beta_6 \log Size_{it} + FE_i + \zeta_{it} \end{aligned} \quad (1)$$

with $i = 1, \dots, n$ and $t = 1, \dots, T$ where $YATCPF_{it}$ denotes the yearly average total costs per patent family and HHI_SEP_t is the concentration of SEP family ownership in year t . SEP_{it} is the cumulative number of SEP family declarations of unit i in period t . PFA_{it} describes the patent family applications. CIT_{it} and FAM_{it} are the number of total forward citations to a company's patent portfolio and the average family size of the respective patent portfolio of unit i in period t . $Size_{it}$ approximates firm size using the number of employees in the main model. In further robustness checks, we will also use total assets as an alternative for firm size. Due to the results of the Hausman (Hausman, 1978) and the Breusch-Pagan Lagrange multiplier tests (Breusch and Pagan, 1980), we also include firm fixed effects in the regression models. ζ_{it} stands for idiosyncratic errors.

First, all models are estimated using Ordinary Least Squares (OLS) estimators with "usual" (homoskedastic) standard errors. According to Wooldridge (2010), usual standard errors are appropriate if the number of cross-sectional units is smaller than the number of periods. Nevertheless, in the later robustness analyses, we will also address some econometric challenges that arise from the data set and then conduct corrective examinations.

⁹We classify the firms into thirds when ranking their cumulative SEP family ownership over the entire observation period. Firms plotted in the top third have the highest cumulative SEP family ownership. Firms in the bottom third have the lowest cumulative SEP family ownership.

Table 1: Descriptive statistics of the sample variables.

	Count	Mean	Std. Dev.	Min	p25	p50	p75	Max
Dependent variables:								
YATCPF - 0-Year Lag	307	79,777.10	56,442.44	8,385.84	36,215.41	65,542.47	105,960.84	251,293.41
YATCPF - 1-Year Lag	291	75,739.10	53,971.54	8,119.21	35,081.73	56,470.74	100,087.16	264,480.69
YATCPF - 2-Year Lag	275	72,217.69	52,221.72	7,987.77	34,098.70	49,686.67	95,102.21	276,207.00
YATCPF - 3-Year Lag	259	69,109.09	50,975.89	7,971.78	32,580.99	46,027.18	91,758.30	286,886.81
YATCPF - 4-Year Lag	243	66,326.66	50,031.30	7,884.40	31,784.96	44,184.28	90,672.91	295,639.09
YATCPF - 5-Year Lag	227	63,818.42	49,239.24	7,783.59	30,633.96	42,249.89	87,612.32	301,067.84
Independent & control variables:								
HHI of SEP Family Ownership	307	0.14	0.06	0.05	0.10	0.13	0.15	0.31
SEP Family Ownership	307	348.42	570.57	0.00	10.00	98.00	392.00	2,901.00
Patent Family Applications	307	4,688.07	4,236.74	91.00	1,414.00	3,450.00	6,725.00	21,918.00
Avg. # FW-Citations (in thousands)	307	398.00	190.91	18.56	279.45	384.52	493.73	863.61
Avg. Family Size	307	4.01	2.44	1.20	2.44	3.12	4.43	14.12
Number of Employees (in thousands)	307	125.41	104.65	6.50	51.58	103.29	161.00	484.00
Total Assets (in billions)	307	57.34	49.56	6.32	26.62	42.61	68.78	375.32

Notes: This table shows descriptive statistics of all variables that are in the multivariate regressions *before* undergoing a log-transformation. As we consider a time lag of up to five years when calculating the yearly average total costs per patent family (YATCPF), this table reports several variations of the dependent variable. All financial variables are in 2017 USD.

Figures 1 to 3 illustrate the yearly average total costs per patent family calculated using the two-year time-lagged cumulative R&D expenditures.¹⁰ As the scales indicate, yearly average total costs per patent family range from roughly USD 10,000 to over USD 250,000 in 2017. While costs remain pretty constant in the bottom third, firms in the middle and upper third are subject to more variation. Apple, for instance, significantly decreased its yearly average total costs per patent family, which might indicate a noticeable change in its patenting behavior. At the same time, Philips, Nokia and Motorola record the most substantial increases in their yearly average total costs per patent family across all firms. Further regression analyses show that most firms significantly increased their yearly average total costs per patent family during the observation period.¹¹ The upcoming regression analyses shall take a deeper look into the association between SEP family ownership, its concentration and the yearly average total costs per patent family.

¹⁰We classify the firms into thirds when ranking their cumulative yearly average total costs per patent family over the entire observation period. Firms plotted in the top third have the highest cumulative costs per patent family. Firms in the bottom third have the lowest cumulative costs per patent family.

¹¹We ran regressions of the log-transformed yearly average total costs per patent family on the year and received a positive and highly significant slope for 11 out of 16 companies. The slopes of Siemens and Toshiba were positive but non-significant. Apple, Kyocera and Mitsubishi Electric had highly significant negative slopes. Running these regressions without log-transforming the patent family costs confirms the results. Repeating these regressions with patent family costs having time lags of more than two years results in a right shift of the slopes. For instance, regressing the log-transformed patent family costs with a time lag of five years leads to 14 positive slopes, of which 13 are highly significant.

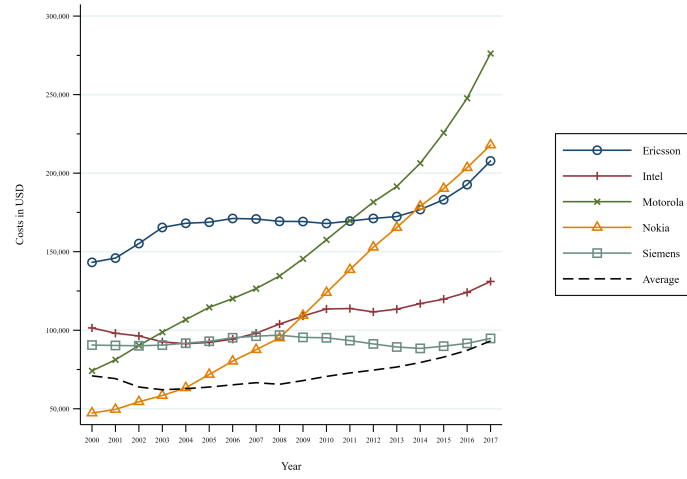


Figure 1: Yearly average total costs per patent family (2-year lagged, top third).

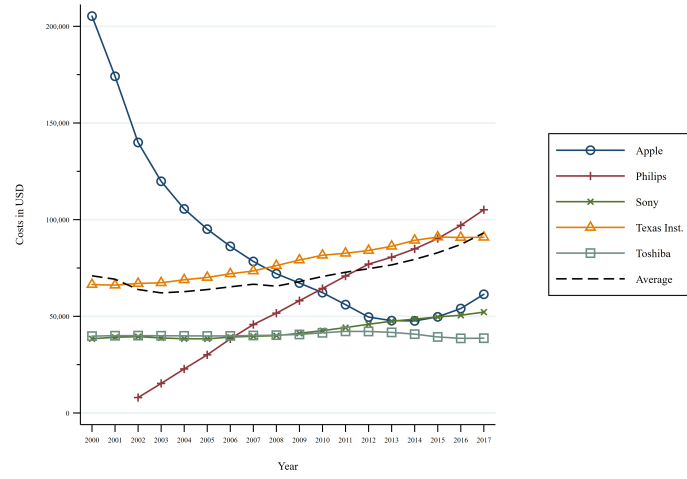


Figure 2: Yearly average total costs per patent family (2-year lagged, middle third).

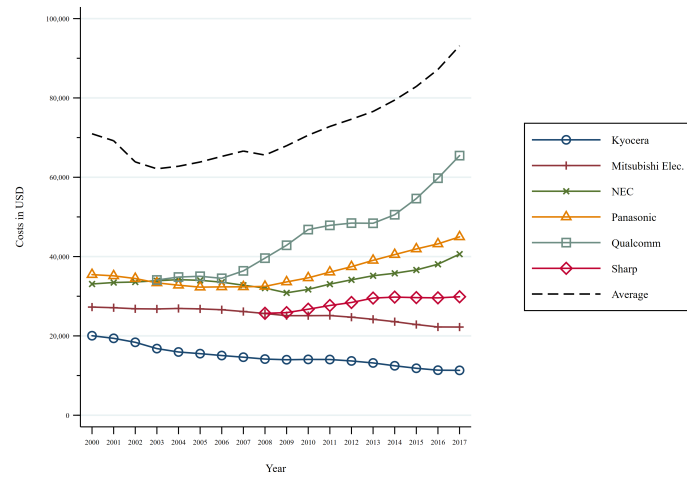


Figure 3: Yearly average total costs per patent family (2-year lagged, bottom third).

4. Results

This section presents the empirical results of the econometric analyses. It further presents additional econometric checks to verify whether the results remain robust when accounting for the econometric challenges of the data set.

4.1. Main results

Table 2: Results of the multi-factor regression models using the number of employees as a firm size measure.

	(1) (No Lag)	(2) (1-Y. Lag)	(3) (2-Y. Lag)	(4) (3-Y. Lag)	(5) (4-Y. Lag)	(6) (5-Y. Lag)
HHI of SEP Family Ownership	-0.047 (0.069)	-0.090 (0.072)	-0.143* (0.078)	-0.180** (0.077)	-0.166** (0.074)	-0.168** (0.072)
SEP Family Ownership	0.019 (0.024)	0.031 (0.024)	0.043* (0.024)	0.060** (0.024)	0.093*** (0.024)	0.113*** (0.024)
Patent Family Applications	-0.167*** (0.034)	-0.193*** (0.034)	-0.210*** (0.034)	-0.225*** (0.034)	-0.247*** (0.033)	-0.257*** (0.032)
Avg. # FW-Citations	0.201** (0.100)	0.218** (0.105)	0.215** (0.109)	0.231** (0.113)	0.197* (0.114)	0.111 (0.114)
Avg. Family Size	-0.922*** (0.212)	-1.223*** (0.215)	-1.546*** (0.221)	-1.859*** (0.234)	-2.170*** (0.249)	-2.315*** (0.266)
Number of Employees	-0.265*** (0.062)	-0.287*** (0.064)	-0.293*** (0.067)	-0.305*** (0.070)	-0.290*** (0.070)	-0.244*** (0.070)
Constant	13.480*** (0.546)	13.877*** (0.570)	14.243*** (0.592)	14.508*** (0.593)	15.016*** (0.582)	15.398*** (0.575)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
F-Value	20.816	28.445	35.304	41.160	48.454	52.490
R ²	0.357	0.441	0.506	0.555	0.606	0.636
Observations	247	238	229	220	211	202

Notes: This table presents the main regression results using a log-log scale multi-factor model (see also equation 1). The models use the *number of employees* as a firm size measure. Standard errors are in parentheses. Significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The results of the central econometric estimations are stated in table 2. As introduced earlier, we take into account time lags of up to five years when determining the dependent variable, as R&D expenditures usually do not immediately have an impact on the current patent family portfolio (Danguy et al., 2009). We use the number of employees in the models presented here to estimate firm size adequately. The upcoming robustness analyses will further consider total assets as an alternative firm size indicator.

All results of models 1 through 6 in table 2 indicate a negative relationship between the HHI of SEP family ownership and the yearly average total costs per patent family. The effect is significantly different from zero, at least at the 10% level for all models with a time lag of minimum two years. Looking at the columns where the HHI coefficient is significantly different from zero, we see the following: The HHI coefficient varies between a value of -0.180 (3-year lagged, see column 4) and -0.143 (2-year lagged, see column 3). Hence, in the 2-year (3-year) lagged model, a doubling of the HHI would be associated with a 14.3% (18.0%) decrease in total costs per patent family. Therefore, the results indicate that an increasing ownership concentration is associated with decreasing yearly average total costs per

patent family. Conversely, decreasing concentration (increasing fragmentation) of SEP family ownership is related to increasing yearly average total costs per patent family.

The variable on SEP family ownership further captures some effect on the yearly average total costs per patent family. The variable's coefficient on SEP family ownership is significantly different from zero, at least at the 10% level for all models with a time lag of minimum two years. We see the following for the coefficients significantly different from zero: The coefficient increases constantly and varies between a value of 0.043 (2-year lagged, see column 3) and 0.113 (5-year lagged, see column 6). Hence, in the 2-year (5-year) lagged model, a doubling of the SEP family portfolio would be associated with a 4.3% (11.3%) increase in total costs per patent family. The results indicate that increasing SEP family ownership is associated with increasing yearly average total costs per patent family. Nevertheless, the magnitude of the corresponding coefficients does not outweigh that of ownership concentration in any of our models.

The annual number of patent family applications consistently negatively affects the total costs per patent family across all time lags, always statistically significant at the 1% level. We explain this effect by the high pairwise correlation between the granted patent family portfolio size and the number of annually filed patent family applications: It results in a value of 0.74, which is statistically significant at the 1% level. Since the same amount of cumulative R&D expenditures will be distributed over a more substantial number of patent families with an increasing portfolio size, we can expect a decrease in total costs per patent family. The number of forward citations is often used to measure patent value. The results confirm that more forward citations to a company's patent portfolio can be associated with larger average total costs per patent family, statistically significant in all models up to a time lag of four years. Further, the average family size variable consistently negatively affects the total costs per patent family, always statistically significant at the 1% level. Similarly, a larger firm size measured by the number of employees sales has a significantly negative effect on the total costs per patent family, also always statistically significant at the 1% level.

In summary, the multivariate results add to the previous literature and show that an increasing concentration of SEP family ownership is associated with decreasing average total costs per patent family. The results further support that increasing SEP family portfolios are positively associated with firms' yearly average total costs per patent family. However, the magnitude of the corresponding coefficients does not outweigh that of ownership concentration in any of our models.

4.2. Robustness checks

Table 3: Results of the multi-factor regression models using the number of employees as a firm size measure and with robust standard errors.

	(1) (No Lag)	(2) (1-Y. Lag)	(3) (2-Y. Lag)	(4) (3-Y. Lag)	(5) (4-Y. Lag)	(6) (5-Y. Lag)
HHI of SEP Family Ownership	-0.047 (0.086)	-0.090 (0.081)	-0.143* (0.076)	-0.180** (0.071)	-0.166*** (0.059)	-0.168*** (0.058)
SEP Family Ownership	0.019 (0.021)	0.031 (0.019)	0.043** (0.019)	0.060*** (0.018)	0.093*** (0.015)	0.113*** (0.017)
Patent Family Applications	-0.167*** (0.035)	-0.193*** (0.032)	-0.210*** (0.032)	-0.225*** (0.033)	-0.247*** (0.037)	-0.257*** (0.043)
Avg. # FW-Citations	0.201* (0.111)	0.218** (0.103)	0.215** (0.101)	0.231** (0.102)	0.197** (0.088)	0.111 (0.086)
Avg. Family Size	-0.922*** (0.233)	-1.223*** (0.217)	-1.546*** (0.200)	-1.859*** (0.194)	-2.170*** (0.180)	-2.315*** (0.200)
Number of Employees	-0.265*** (0.078)	-0.287*** (0.064)	-0.293*** (0.060)	-0.305*** (0.063)	-0.290*** (0.063)	-0.244*** (0.066)
Constant	14.292*** (0.696)	14.793*** (0.647)	15.239*** (0.607)	15.600*** (0.519)	16.183*** (0.421)	16.592*** (0.441)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
F-Value	457.428	416.439	398.319	401.859	443.735	455.333
R ²	0.903	0.908	0.913	0.919	0.927	0.932
Observations	247	238	229	220	211	202

Notes: This table presents the main regression results using a log-log scale multi-factor model (see also equation 1). The models use the *number of employees* as a firm size measure. Robust standard errors are in parentheses. Significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

First, we repeat the regressions keeping normal standard errors but applying total assets as a firm size indicator. As shown in table B1, the results remain mostly robust. With total assets as a firm size indicators, the HHI coefficient is significantly different from zero at the 10% level with a time lag of minimum three years (see column (3) in table B1). Moreover, the variable on SEP family ownership remains statistically significant at least at the 10% level with a time lag of minimum two years.

However, the applied data set has several econometric issues that may bias the presented results. While the Wooldridge (2010) test suggests a serial correlation, the Modified Wald statistic indicates significant heteroskedasticity and the Pesaran (2004) test further reveals cross-sectional dependence for almost all model specifications. We repeat the analyses using robust standard errors since they are considered an appropriate correction method. Clustered standard errors would also be acceptable, but using them would not allow a meaningful interpretation since the sample size is too small (Wooldridge, 2010). We perform all robustness checks for all time lags and firm size measures (the number of employees and total assets).

Using robust standard errors and the number of employees as a firm size measure, the results around the HHI coefficient remain broadly similar even under this more stringent econometric assumption. The HHI coefficient remains statistically significant, at least at the 10% level in all models with a time lag of minimum two years. The variable on SEP family ownership is also statistically significant, at least at the 5% level in all models with a time lag of minimum two years (see table 3). The situation is similar

when using total assets as a firm size indicator. The HHI coefficient remains statistically significant for a time lag of minimum three years, however, now with a higher significance at the 5% level. The variable on SEP family ownership turns statistically significant at least at the 10% level in all models with a time lag of minimum one year (see table B2).

Overall, the robustness analyses come to comparable results and confirm the findings. Regarding the standard-setting processes at ETSI, increasing SEP family ownership concentration is associated with decreasing yearly average total costs per patent family, suggesting that decreasing competition might decrease firms' investments per patent family. Further, the results indicate that increasing SEP family ownership is associated with increasing yearly average total costs per patent family. Nevertheless, the magnitude of the corresponding coefficients does not outweigh that of ownership concentration in any of our models. We summarize that both measures of firms' involvement in standardization, SEP family ownership and its concentration, should be considered when examining firms' patenting behavior using average total costs per patent family.

5. Discussion

This section reflects on the study's findings in the context of past literature and addresses potential implications. It further discusses the study's limitations and presents an outlook.

Several disputes between owners and users of SEP (see, e.g., [Lim, 2014](#)) and strongly rising numbers of declared SEPs and SEP families ([Pohlmann, 2021](#)) have raised concerns regarding the patenting behavior of firms developing standardized technologies. Previous literature analyzing firms' patenting behavior in standardization has mainly looked at the sheer increase in patent numbers or analyzed patent citations (see, e.g., [Kang and Bekkers, 2015](#); [Berger et al., 2012](#); [Layne-Farrar, 2011](#); [Bekkers and West, 2009b](#); [Rysman and Simcoe, 2008](#); [Bekkers et al., 2002](#)). To the best of our knowledge, they do not aim to consider the economic value of patents. This study proposes the average total costs per patent family as an economic assessment criterion and an indicator of firms' patenting behavior. Using this criterion, we examine how firms' involvement in standardization at ETSI, measured through the ownership of declared SEP families and its concentration, is associated with firms' patenting behavior.

This study has two main contributions: First, it contributes to the literature on patent valuation methods by applying a FRAND-conform valuation approach to a long time series. For this purpose, we estimate the yearly average total costs per patent family from 1996 to 2017. The valuation approach relies on the cost-based methodology suggested by [Friedl and Ann \(2018\)](#), where R&D expenditures are allocated to patent family portfolios to estimate how much a patent family costs on average. The approach relies on the idea that, at least in the telecommunications industry, patent holders usually hold broad patent portfolios, are regularly audited and provide reliable information on their R&D expenditures. These figures also consider overhead costs and allow a reasonable first estimate of the yearly average

total costs per patent, even for large data sets. Second, the study examines how firms' involvement in standardization at ETSI is related to firms' yearly average total costs per patent family. Therefore, the study uses SEP data from the Searle Center Database ([Baron and Pohlmann, 2018](#)).

We initially observe increasing ownership of SEP families declared at ETSI and increasing fragmentation (decreasing concentration). The results support the perception that there is an increasing need and broad implementation of standards. As a result, technologies become more complex and the number of companies participating in standardization as well as SEP declarations increase (see, e.g., [Pohlmann, 2021](#)). We would expect that as firms declare more SEP families and ownership becomes more fragmented, companies increase their R&D expenditures per patent family to keep up with the increasing competition for innovation. Another reason could be that fragmented SEP family ownership increases transaction costs in standardization, eventually manifesting in increasing firms' average total costs per patent family. Indeed, our results show increasing average total costs per patent family for most of the firms in our observation period.

The first main result of this study shows a negative relationship between SEP family ownership concentration and average total costs per patent family, suggesting that decreasing competition might decrease firms' investments per patent family. If companies reduce their investments per patent family as competition decreases, this could, on the one hand, indicate increased patenting efficiency. On the other, lower investments per patent family could harm standardization if innovative strength declines. The results complement those of [Bekkers and West \(2009b\)](#), who show an increasing concentration of SEP ownership and attribute this to increasingly strategic patenting by a few firms. The analyses consider that there may be time lags between initial R&D expenditures and patent applications. They hence include time lags between zero and five years in the cost calculations (see, e.g., [Danguy et al., 2009](#); [de Rassenfosse and Guellec, 2009](#); [Hall et al., 1986](#)). Overall, the results remain consistent when time lags increase, confirming the relationship between SEP family ownership concentration and yearly average total costs per patent family.

The second main result of this study shows a positive relationship between SEP family portfolios and average total costs per patent family. In fact, SEPs are often considered more valuable than non-SEPs (see, e.g., [Rysman and Simcoe, 2008](#)). Assuming that more valuable patents come hand in hand with higher investment costs, the results would justify such a relationship. Besides, it seems reasonable that companies have little incentive to invest little, especially when it comes to SEPs. Having higher R&D expenditures, firms can always justify higher licensing requirements afterward. Nevertheless, the magnitude of the corresponding coefficients does not outweigh that of ownership concentration in any of our models. Altogether, both measures of firms' involvement in standardization, SEP family ownership and its concentration, should be considered when deriving conclusions about firms' patenting behavior using average total costs per patent family.

Several implications arise from these findings: First, with telecommunications standards applied in a growing number of industries and IoT applications on the rise, it is reasonable to assume that firms' patenting and licensing behavior will also adjust ([Henkel, 2021](#); [Nikolic and Galli, 2021a](#)). Therefore, it is not clear whether most SSOs' requirements that their members declare their essential patents and license them in a FRAND-compliant manner ([Baron and Spulber, 2018](#)) will be sufficient in the future. Indeed, many SSOs continue to allow so-called blanket declarations. Such blanket declarations may help to identify the relevant SEP holders. Still, they do not allow determining the actual size of the portfolios, leaving the standardization process, the subsequent commercialization and the licensing process opaque in many ways. Discouraging blanket declarations would allow more detailed future research on essential patents and increase transparency throughout standardization. Second, and as an alternative to discouraging blanket statements, SSOs could introduce more IPR search requirements in their policies or set policies with similar effects. Previous literature has noted that most SSOs have historically refrained from requiring their members to conduct IPR searches ([Bekkers and Updegrove, 2013](#); [Farrell et al., 2007](#); [Lemley, 2002](#)). Indeed, such searches can be time-consuming and costly, especially if they are not conducted by the patent owner but by outsiders such as the SSO. At the same time, patent owners are likely to have decisive advantages over outsiders in evaluating their patent portfolios as it is much easier for them to gain access to all the necessary patent information ([Farrell et al., 2007](#); [Lemley, 2002](#)). Therefore, it would be reasonable to hold patent owners more accountable. [Lemley \(2002\)](#) also points to the rules of a specific SSO, the Open Group, which do not require an active IPR search. Instead, patent owners must agree not to litigate standard users for patents not disclosed during standardization, which has a similar effect to the requirements for an IPR search. Increased SEP transparency could lead to far-reaching benefits for licensing negotiations, the involved parties and industries. Even though the initial efforts by SEP holders might increase, they could profit from licensing negotiations being concluded in a more cost- and time-efficient manner, leading to quicker licensing revenues. On the other hand, standard users could benefit from decreasing costs associated with identifying relevant SEPs and their owners. Consequently, predictability in the product development process would increase, ultimately leading to falling customer prices. Even SSOs could benefit from increased transparency due to more disclosure policies, as this would mean that differences between them diminish and comparability between sectors and standards increases ([SEPs Expert Group, 2021](#)). Third, suppose SEP family ownership and its concentration are well observable, as in the case of ETSI. In this case, SSOs could benefit from the results of this study and should consider potential implications for standard-setting resulting from increasing (decreasing) ownership concentration of SEP families. Increasing (decreasing) concentration of SEP families could be seen as a proxy for lower (higher) competition in standardization. One possible implication of increasing concentration could be that the standardization process is easier and faster due to the smaller number of participants (see, e.g., [Blind, 2002](#)), which could lower members' transaction

costs and ultimately decrease total costs per patent family. Yet, lower investments per patent family could harm standardization if innovative strength declines. If fragmentation increases (concentration decreases), we would expect that transaction costs in standardization increase, resulting in longer standardization processes and ultimately increasing total costs per patent family. SSOs should closely monitor how increasing (decreasing) ownership concentration of SEPs affects their standard-setting processes.

However, when deriving concrete policy solutions relying on the results, multiple factors need to be considered. First, all companies in the sample are listed on the stock exchange and are part of the STOXX Global Index 1800, which contains the largest 1800 listed companies from a wide range of industries. Consequently, it biases the results towards large firms. Second, this study uses a monetary valuation approach to examine firms' patenting behavior. Although this is a novelty compared to the existing literature, the method might suffer from the aspect that a correlation between R&D expenditures and patents does not always exist. For instance, previous literature shows that such a relationship may depend on the type of industry. Yet, the communications industry tends to be one of the industries with a relatively high level of patenting propensity (see, e.g., [Danguy et al., 2009](#); [Cohen et al., 2000](#); [Arundel and Kabla, 1998](#)). [Friedl and Ann \(2018\)](#) suggest that the cost-based approach could benefit the telecommunications industry, where companies hold large patent portfolios, invest a lot in R&D and where market competition is high. Third, the reported estimates of SEP family ownership and its concentration are limited exclusively to firms declaring essential patents at ETSI as the data availability is best for this SSO. Therefore, the study cannot rule out that the results would have differed if we had considered more SSOs with differing properties. Previous research shows that the effects of SEPs might vary depending on the type of SSO where their owners declare them ([Pohlmann et al., 2016](#)). Therefore, it is conceivable that companies will strategically choose which kind of SSO they want to contribute their patents to and adjust their investments per patent family, depending on the regulations that prevail there. In addition, the study does not distinguish between possible quality differences in patents. The average total costs per patent family are always calculated for the entire portfolio making no distinction between R&D expenditures for SEPs and non-SEPs. Consequently, the study cannot rule out that companies invest more in the development of SEPs and incur higher costs for SEPs than non-SEPs. Past literature suggests that patents increase in value when included in standards ([Rysman and Simcoe, 2008](#)). Nevertheless, it can be questioned whether companies already distinguish between potential future SEPs and non-SEPs at the time of the R&D investment or whether the value differences only arise upon standard inclusion. Finally, the results describing the relationship between SEP family ownership, its concentration and total costs per patent family are not necessarily causal. Instead, the study proposes an indication of potential causality that future research should investigate.

Due to the stated design limitations, further research is necessary to confirm and extend these findings. Future studies could include companies that are not publicly traded but have taken a crucial

role in standard-setting procedures and hold large SEP portfolios. Doing so might require more detailed research to estimate the yearly average total costs per patent family through R&D expenditures, as those R&D expenditures might be less easily accessible. Second, future studies could also look at how costs per patent family vary by sector or standard. This could include looking at the 3rd Generation Partnership Project (3GPP) procedures and developments to generalize the results further. Another research focus could be to analyze how policy changes within an SSO affect firms' patenting behavior when evaluated using total costs per patent family.

6. Conclusion

With the increasing adoption of standards in many industry verticals, there is a growing necessity for a comprehensive understanding of firms' patenting behavior as they engage in standardization. Despite the growing literature on standardization, little research has considered the economic value of patents to evaluate firms' patenting behavior.

To our knowledge, this is the first attempt to investigate the average total costs per patent family as an economic assessment criterion and an indicator of firms' patenting behavior for technology standards. The two central findings of this study are that total costs per patent family decrease with increasing ownership concentration of SEP families. Second, we find that total costs per patent family increase with increasing SEP family portfolio sizes. However, the magnitude of the corresponding coefficients does not outweigh that of ownership concentration in any of our models. Our cost allocations consider time lags between zero and five years, as there might be time lags between R&D expenditures and patent applications shaping firms' patent portfolios. Our results remain consistent when applying costs with different time lags and accounting for econometric challenges of the data set, confirming the relationship between SEP family ownership, its concentration and yearly average total costs per patent family. We conclude that both measures for firms' involvement in standardization, SEP family ownership and its concentration, should be considered when examining firms' patenting behavior using average total costs per patent family.

The study contributes to the literature on patent valuation by applying a FRAND-conform, cost-based valuation approach to a long time series from 1996 to 2017 and emphasizing its ease of application. It further contributes to the growing body of empirical evidence on standardization. Using data on SEPs, we observe declared SEP families at ETSI and establish a link between our economic assessment criterion and frequently applied measures for firms' involvement in standardization. We show those cost assessments can be a valid tool to improve our understanding of firms' patenting behavior in standardization. The economic implications of our results should be further explored in other sectors, SSOs and standards to highlight potential distinctions.

Finally, while further research is needed to deepen our findings, our results support ongoing policy

discussions on regulatory measures in the standardization process. Policy makers and SSOs should discourage blanket declarations since increasing SEP transparency could improve comparability across standard-setting processes and reduce uncertainties in subsequent standard adoption for SEP holders and implementers. SSOs should further closely monitor how increasing (decreasing) ownership concentration of SEPs affects their standard-setting processes.

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Appendix A

Table A1: Pairwise correlation matrix of sample variables.

	1	2	3	4	5	6	7	8	9	10	11	12
1 YATCPF - 0-Year Lag	1.00											
2 YATCPF - 1-Year Lag	1.00	1.00										
3 YATCPF - 2-Year Lag	0.98	1.00	1.00									
4 YATCPF - 3-Year Lag	0.97	0.99	1.00	1.00								
5 YATCPF - 4-Year Lag	0.95	0.97	0.99	1.00	1.00							
6 YATCPF - 5-Year Lag	0.92	0.95	0.97	0.99	1.00	1.00						
7 HHI of SEP Family Ownership	-0.01	-0.06	-0.13	-0.17	-0.19	-0.21	1.00					
8 SEP Family Ownership	0.40	0.42	0.42	0.41	0.40	0.37	-0.36	1.00				
9 Patent Family Applications	-0.50	-0.49	-0.48	-0.47	-0.46	-0.45	0.20	-0.29	1.00			
10 Avg. # FW-Citations	-0.24	-0.23	-0.22	-0.21	-0.21	-0.21	-0.18	-0.05	0.55	1.00		
11 Avg. Family Size	0.37	0.35	0.33	0.32	0.30	0.28	-0.07	0.57	-0.37	-0.21	1.00	
12 Number of Employees	-0.19	-0.17	-0.15	-0.13	-0.12	-0.10	0.05	-0.21	0.60	0.55	-0.24	1.00
13 Total Assets	-0.09	-0.10	-0.10	-0.11	-0.11	-0.12	-0.08	-0.13	0.33	0.54	-0.09	0.54

Notes: This table presents the pairwise correlation matrix of all sample variables *before* undergoing a log-transformation and in accordance with the descriptive statistics in table 1.

Table A2: Descriptive statistics of the log-transformed sample variables.

	Count	Mean	Std. Dev.	Min	p25	p50	p75	Max
Dependent variables:								
log YATCPF - 0-Year Lag	307	11.04	0.73	9.03	10.50	11.09	11.57	12.43
log YATCPF - 1-Year Lag	291	10.99	0.72	9.00	10.47	10.94	11.51	12.49
log YATCPF - 2-Year Lag	275	10.94	0.72	8.99	10.44	10.81	11.46	12.53
log YATCPF - 3-Year Lag	259	10.89	0.72	8.98	10.39	10.74	11.43	12.57
log YATCPF - 4-Year Lag	243	10.85	0.73	8.97	10.37	10.70	11.42	12.60
log YATCPF - 5-Year Lag	227	10.80	0.73	8.96	10.33	10.65	11.38	12.62
Independent & control variables:								
log HHI of SEP Family Ownership	307	-2.03	0.40	-2.90	-2.28	-2.02	-1.92	-1.16
log SEP Family Ownership	247	5.00	1.79	0.00	4.22	5.25	6.21	7.97
log Patent Family Applications	307	8.03	0.99	4.51	7.25	8.15	8.81	10.00
log Avg. # FW-Citations (in thousands)	307	5.82	0.67	2.92	5.63	5.95	6.20	6.76
log Avg. Family Size	307	1.24	0.52	0.19	0.89	1.14	1.49	2.65
log Number of Employees (in thousands)	307	4.47	0.93	1.87	3.94	4.64	5.08	6.18
log Total Assets (in billions)	307	3.76	0.77	1.84	3.28	3.75	4.23	5.93

Notes: This table shows descriptive statistics of all variables that are in the multivariate regressions *after* undergoing a log-transformation. As we consider a time lag of up to five years when calculating the yearly average total costs per patent family (YATCPF), this table reports several variations of the dependent variable. All financial variables are in 2017 USD.

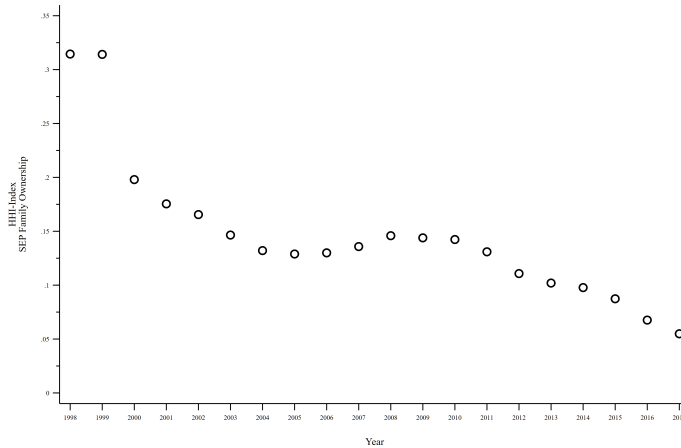


Figure 4: Yearly derived HHI describing the ownership concentration of SEP family ownership.

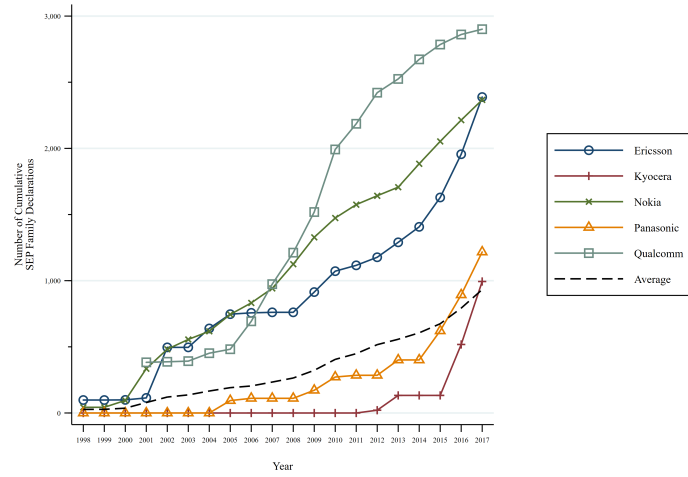


Figure 5: Yearly cumulative number of SEP family declarations by company (top third).

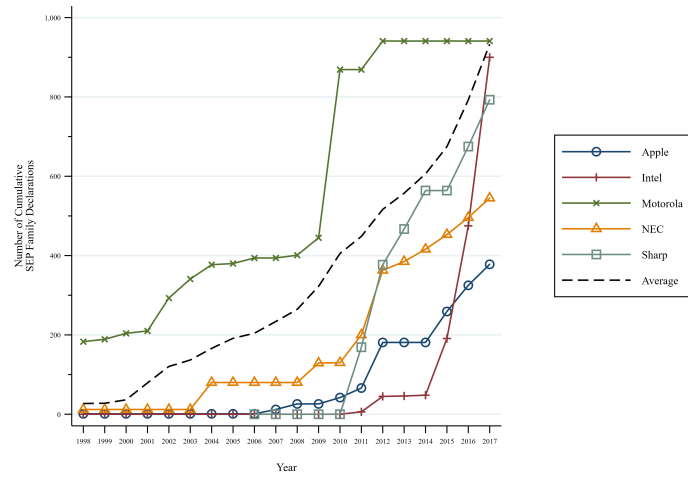


Figure 6: Yearly cumulative number of SEP family declarations by company (middle third).

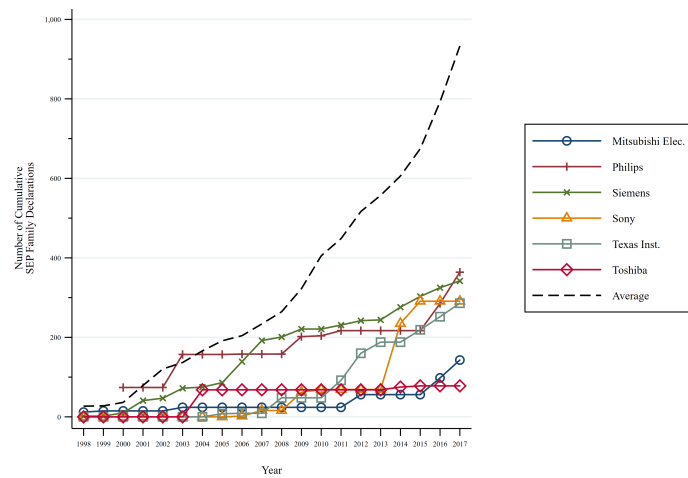


Figure 7: Yearly cumulative number of SEP family declarations by company (bottom third).

Table A3: Pairwise correlation matrix of log-transformed sample variables.

	1	2	3	4	5	6	7	8	9	10	11	12
1 log YATCPF - 0-Year Lag	1.00											
2 log YATCPF - 1-Year Lag	0.99	1.00										
3 log YATCPF - 2-Year Lag	0.98	0.99	1.00									
4 log YATCPF - 3-Year Lag	0.96	0.98	0.99	1.00								
5 log YATCPF - 4-Year Lag	0.94	0.96	0.98	0.99	1.00							
6 log YATCPF - 5-Year Lag	0.91	0.94	0.96	0.98	0.99	1.00						
7 log HHI of SEP Family Ownership	-0.01	-0.05	-0.09	-0.12	-0.13	-0.15	1.00					
8 log SEP Family Ownership	0.22	0.23	0.25	0.25	0.26	0.26	-0.49	1.00				
9 log Patent Family Applications	-0.62	-0.62	-0.62	-0.62	-0.62	-0.62	0.15	-0.18	1.00			
10 log Avg. # FW-Citations	0.06	0.09	0.12	0.14	0.15	0.16	-0.17	0.13	0.42	1.00		
11 log Avg. Family Size	0.57	0.55	0.53	0.50	0.48	0.45	-0.10	0.52	-0.37	0.11	1.00	
12 log Number of Employees	-0.21	-0.19	-0.17	-0.15	-0.12	-0.10	-0.01	-0.02	0.65	0.59	-0.23	1.00
13 log Total Assets	-0.04	-0.04	-0.04	-0.04	-0.05	-0.06	-0.02	0.02	0.59	0.62	0.01	0.78

Notes: This table presents the pairwise correlation matrix of all sample variables *after* undergoing a log-transformation and in accordance with the descriptive statistics in table A2.

Appendix B

6.1. Additional regression results

Table B1: Results of the multi-factor regression models using total assets as a firm size measure.

	(1) (No Lag)	(2) (1-Y. Lag)	(3) (2-Y. Lag)	(4) (3-Y. Lag)	(5) (4-Y. Lag)	(6) (5-Y. Lag)
HHI of SEP Family Ownership	-0.057 (0.073)	-0.064 (0.075)	-0.114 (0.080)	-0.149* (0.079)	-0.135* (0.075)	-0.141* (0.073)
SEP Family Ownership	0.019 (0.026)	0.037 (0.026)	0.048* (0.025)	0.062** (0.025)	0.093*** (0.025)	0.113*** (0.025)
Patent Family Applications	-0.193*** (0.038)	-0.214*** (0.038)	-0.219*** (0.038)	-0.223*** (0.038)	-0.238*** (0.036)	-0.243*** (0.035)
Avg. # FW-Citations	-0.026 (0.112)	-0.009 (0.115)	0.035 (0.119)	0.080 (0.121)	0.079 (0.118)	0.048 (0.116)
Avg. Family Size	-0.880*** (0.225)	-1.143*** (0.229)	-1.373*** (0.235)	-1.597*** (0.244)	-1.870*** (0.254)	-2.041*** (0.267)
Total Assets	-0.045 (0.065)	-0.078 (0.065)	-0.123* (0.066)	-0.159** (0.067)	-0.172*** (0.065)	-0.170*** (0.064)
Constant	13.928*** (0.680)	14.315*** (0.709)	14.342*** (0.755)	14.329*** (0.764)	14.665*** (0.737)	14.915*** (0.710)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
F-Value	16.504	23.289	30.391	36.537	44.520	50.365
R ²	0.306	0.393	0.468	0.525	0.586	0.627
Observations	247	238	229	220	211	202

Notes: This table presents the main regression results using a log-log scale multi-factor model (see also equation 1). The models use *total assets* as a firm size measure. Standard errors are in parentheses. Significance levels are as follows: * p < 0.10, ** p < 0.05, *** p < 0.01.

6.2. Additional robustness checks

Table B2: Results of the multi-factor regression models using total assets as a firm size measure and with robust standard errors.

	(1) (No Lag)	(2) (1-Y. Lag)	(3) (2-Y. Lag)	(4) (3-Y. Lag)	(5) (4-Y. Lag)	(6) (5-Y. Lag)
HHI of SEP Family Ownership	-0.057 (0.092)	-0.064 (0.087)	-0.114 (0.079)	-0.149** (0.072)	-0.135** (0.061)	-0.141** (0.060)
SEP Family Ownership	0.019 (0.021)	0.037* (0.020)	0.048** (0.019)	0.062*** (0.018)	0.093*** (0.016)	0.113*** (0.017)
Patent Family Applications	-0.193*** (0.035)	-0.214*** (0.037)	-0.219*** (0.038)	-0.223*** (0.037)	-0.238*** (0.042)	-0.243*** (0.049)
Avg. # FW-Citations	-0.026 (0.104)	-0.009 (0.109)	0.035 (0.115)	0.080 (0.103)	0.079 (0.100)	0.048 (0.106)
Avg. Family Size	-0.880*** (0.230)	-1.143*** (0.214)	-1.373*** (0.191)	-1.597*** (0.186)	-1.870*** (0.182)	-2.041*** (0.201)
Total Assets	-0.045 (0.053)	-0.078 (0.054)	-0.123** (0.055)	-0.159*** (0.052)	-0.172*** (0.053)	-0.170*** (0.062)
Constant	14.449*** (0.743)	14.939*** (0.739)	15.071*** (0.733)	15.160*** (0.590)	15.598*** (0.580)	15.931*** (0.675)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
F-Value	508.134	408.314	358.486	338.934	356.835	407.016
R ²	0.895	0.900	0.907	0.913	0.923	0.930
Observations	247	238	229	220	211	202

Notes: This table presents the main regression results using a log-log scale multi-factor model (see also equation 1). The models use *total assets* as a firm size measure. Robust standard errors are in parentheses. Significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.