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THE MARKET VALUE OF PATENTS AND R&D

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Abstract

This paper studies how R&D, patents and patent value indicators affect the market valuation of European firms. The information on individual patents from these firms is used to create portfolio averages, so called patent value indicators, which are linked to the firm data. The firm data consists of Tobin's Q, age, employees, R&D expenditures, physical assets and patent publications. A non-linear least squares regression is run to estimate the contribution of R&D, patent publications and the patent value indicators to the market valuation of European firms during the period 2011-2017. The results indicate that R&D and several value indicators, in particular the average number of claims, have a positive and significant effect on firm market value. This effect is especially notable for large firms and firms in West-Europe and Scandinavia. In addition, the results show that the inclusion of R&D and patents adds explanatory power to the market value equation.

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1. Introduction

Innovation is generally considered to be a major cause of economic wealth and growth for developed countries (Czarnitzki, et al., 2006). A necessary condition for private innovative activity is that it has a positive impact on the profits of a firm (Czarnitzki, et al., 2006). For this reason, there have been numerous studies on the expected gains for firms from investing in innovation assets. In the literature these assets are called knowledge capital or knowledge assets. Interest in valuing knowledge assets has come from different areas. First of all, firms want to be able to value innovation assets, either for strategic decision making or for transfer pricing (Hirschey, et al., 2001). Second, financial economists and investors often try to construct measures of the fundamental value of publicly traded firms as a guide for investment (Czarnitzki, et al., 2006). They therefore need to be able to value knowledge assets. Third, policy makers and economists wish to quantify the private returns to innovative activity in order to increase understanding of its contribution to economic growth (Czarnitzki, et al., 2006).

Expenditure on R&D is the most commonly used proxy for innovative activity. The part of the available funds that a firms dedicates to R&D, signals the firm's strategic choice and commitment to innovation (Vithessonthi & Racela, 2016). The OECD defines R&D as creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications (OECD, 2015). For large firms, R&D expenditures can amount to billions of euros. This is particularly true in the industrial, technological, health care and pharmaceutical sectors, which are all fast developing industries. Often, a significant portion of profits is reinvested in R&D to contribute to the firm's continued growth. In addition, firms can conduct R&D through acquisition. Typical for R&D activities is that they are not performed with the goal of immediate profit, but rather contribute to the long-term profitability of a company. R&D can therefore be a risky investment, since there is no immediate payoff and the return on investment is, to an extent, uncertain. Innovative activity is of big importance to firms, because it allows them stay ahead of other market participants (Legler & Krawczyk, 2006). Increased innovative activity can lead to a competitive advantage, especially at the beginning of a product cycle (Oostendorp & Kleinknecht, 2002). However, it is not enough to merely invest in innovation and reap the benefits. It is also necessary to prevent others from imitating by setting effective protection mechanisms. At this point formal intellectual property (IP) rights, in particular patents, play an important role (Neuhäusler, et al., 2011). Because the results from R&D investments are uncertain, some R&D projects will have more success in creating valuable knowledge assets than others. Intellectual property can serve as an observable proxy for R&D success, since only profitable R&D projects will be protected with intellectual property rights by the firm. The most important categories of intellectual property are copyright, patents, trademarks and industrial design. The concept of intellectual property is built on the idea that products of human intellect should be granted the same protective rights of ownership as physical property. IP rights have become increasingly more valuable in the modern knowledge-based economy. While all forms of IP can hold value and contribute to the stock price of a firm, this research will be restricted to patents. Patents are a form of intellectual property which provide its owner the legal right to exclude others from making, using, selling and importing an invention for (usually) 20 years in the country where the application is granted. It is important to note that a granted patent only provides protection in one country. For a patent application to be granted, the invention must satisfy three criteria: it has to be novel, it has to be non-obvious and it has to be suitable for industrial application. These requirements are used in almost every country in the world, although there are slight variations in the interpretation of the requirements per country. Discussing the details of the requirements of patentability is beyond the scope of this paper. To keep the protection in place the applicant needs to pay annual taxes, which are called renewal fees. Typically, a patent application consists of a description and claims. The claims determine the scope of the protection. Infringement of any one of the patent claims is enough for patent infringement. One invention is often patented in multiple countries, to obtain larger protection.

There are several ways in which patent rights can promote innovation (Blit, et al., 2017). First of all, they facilitate knowledge diffusion. Applicants are required to describe the technology in sufficient detail so that someone skilled in the same field can reproduce the invention. This is a crucial condition for patent applications. Second, patents rights create a market for ideas and innovation, and therefore facilitate transactions such as sales or licensing of inventions. The patent system provides an efficient allocation of ideas and technology. Where some firms might focus on production, distribution or marketing, other can focus on innovation (Gans & Stern, 2003). Most importantly, patents increase the incentive for innovation by providing a higher return to innovation (Grupp & Schmoch, 1999). Because applicants obtain a monopoly on their invention, it is beneficial for them to invest in R&D. Patent are necessary because knowledge itself is non-rivalrous, meaning that the use of a particular piece of knowledge by one firm does not prevent another firm from using that same particular piece of knowledge. Where the inventor probably has made development costs, the additional costs for other parties are zero. Once knowledge is created, it is difficult to be kept secret. Especially so when it is used for the production of consumer goods. In addition, they are a signaling device to consumers, competitors and (possible) investors. Patents contribute to an enterprise's research and development results, revenue, reputation and stock performance. While it is difficult to accurately value a patent, they are recognized as assets and can be used as collateral (Lin Min, 2017).

Over the years, numerous studies have been conducted to measure the value of knowledge assets. In the vast majority of these studies, R&D expenditures and patent counts (the number of patents which are owned by a firm) were used as proxies for knowledge assets. A large group of this research focuses on the question which impact R&D and patents have on the market value of a firm. For R&D this impact has been found positive and significant, although the size of the impact is dependable on numerous firm and sector characteristics. Patents also show a significant positive impact, although smaller and less significant than R&D. The patents in this strand of research are often weighted by the citations they received as a proxy for patent quality. Hall found a statistically significant and positive evaluation of the R&D capital by the stock market for German, Italian and French firms in 2006 (Hall & Oriani, 2006). The results were similar for these three countries. However, the estimated coefficients of R&D were considerably smaller than the coefficients reported by previous studies on the U.S. and the UK. Rahko did a similar research on Finnish firms and found significant positive relations for R&D and patent citations (Rahko, 2014). The simple patents count however, were not always significant. Simeth found positive relationships between patent publications and firm value, after controlling for forward citations and the average number of claims (Simeth & Cincera, 2016). Kim recently found remarkable results in the renewable energy sector for the period 1980 to 2014, showing simple patent counts do not have an impact on firm market value (Kim, et al., 2018). In contrast, the level of protection for patent portfolios, proxied by backward citations and patent family members, showed a positive and significant effect on firm market value. Hirschey and Richardson showed that patent-count data has a consistently positive influence on the market value of U.S. firms, but does not have such an effect on Japanese firms (Hirschey & Richardson, 2001). For both Japanese and U.S. firms, scientific measures of patent quality have robust influences on market values for actively patenting firms (Hirschey & Richardson, 2001). The (adjusted) R squared in the models in these papers varied between 15% and 40%, which means knowledge assets have significant explanatory power in regard to the market value of firms.

The central research question in this paper is: *What is the impact of R&D and patents on European firm value?* More specifically, this paper estimates the impact of R&D expenditure, the number of patent publications and various patent portfolio characteristics on Tobin's Q. The goal is to estimate how valuable R&D and patents are to European firms. Various patent portfolio characteristics (value indicators) are included to give more insight in which patents are the most valuable. The value indicators, which are explained more deeply in the next section, are very important in the research on patents. Because patents are hard to valuate, research focuses on determining characteristics of patents which signal a high value. By doing so, firms can learn which patents they optimally want to have in their portfolio. This paper will include several value indicators which have not been used before in a market value regression. In contrast to most studies in this topic, this paper will be based on very recent data, giving the results more current value. Since this topic is very sensitive to technological advancements, the new data might prove a big difference with other studies, which often rely on old datasets. This paper aims to provide research on European firms, so they may be compared to the results in the previous studies. Most of the existing research on R&D and patents focuses on American, Japanese or German firms. This paper will give an opportunity to estimate the impact of R&D and patenting on European firms. The effect of R&D and patenting activity on the market value of firms might be less significant in Europe, since the financial structure in European countries is strongly bank-based (Langfield & Pagano, 2015). It is often argued that a bank-based system could hinder innovation because banks, in the role of financier, favor conservative investments and established firms (Langfield & Pagano, 2015). Market-based systems, with the US and the UK as prime examples, tend to provide better financing of innovation (Allen & Gale, 1999). Historically, technological innovations have tended to occur in countries with market-based financial structures (Allen, 1993). If European firms are indeed bank-based, investors in European firms will attach less value to innovation and the market value of the firm will be less impacted by the signaling function of R&D expenditure and patenting. This theory has already been noted by Hall & Oriani (Hall & Oriani, 2006). Because patenting is expensive, the results of this research could prove valuable to firms. More in general, the results of this study could provide evidence that patent protection is indeed worth pursuing for firms. It has been noted that patent value can fluctuate highly between different industries (Acs & Audretsch, 1988). This paper, however, considers firm data from all available industries, which guarantees a large dataset. All the used data is provided by the database Orbis IP. The results in this paper are in line with previous research. Most notably, R&D and the average number of patent claims have a large and significant effect on firm market value. The impact of patent publications, forward citations, backward citations and family members is smaller, but still significant. Overall, the results show that knowledge assets can be used to explain change in Tobin's Q and add explanatory power to the market value equation. These results hold true for various subsamples and after several robustness checks.

The next chapter of this paper will give an overview of the existing literature on the relevant subjects. Based on the literature, hypotheses about the tested variables will be formulated. In chapter three the methodological approach and data collection procedure are outlined. The methodological approach is based on several previous studies in this field which all use the same model, popularized by Hall (Hall, et al., 2005). Chapter four will present the results from the regression analysis and chapter five contains the conclusion. The bibliography and appendices are included at the end.

2. Literature review

Literature provides several reasons on why the innovative activities of firms have an effect on the firm's market value. First of all, firms engaging in research may develop superior capabilities, and therefore create inventions which are more valuable than those created by other firms (Simeth & Cincera, 2016). However, basic research findings do not automatically lead to high commercial success since translating findings into concrete products is a difficult process (Pisano, 2006). In addition to product development, research by firms can create value through knowledge exchange. Scientific publications can be leveraged as a human resource instrument with regard to PhD graduates (Simeth & Cincera, 2016). Scientists who consider the private sector as a career option may seek out firms engaging in the practice of publishing research (Stern, 2004); (Sauermann & Roach, 2012). Publication of research however also has costs, because unintended knowledge spillovers may enable competing firms to learn from the disclosed knowledge (Arrow, 1962). Knowledge spillovers reduce the cost of imitation and offer insights into future trends, which could be very profitable for competitors (Simeth & Cincera, 2016). Employed scientists who publish research are more visible to competing firms, which may impose the need for retention strategies as their external employment options increase (Liu & Stuart, 2014).

2.1. Research and Development

Research and Development (R&D) are the activities undertaken by firms and other entities in order to create new or improved products and processes (Hall, 2006). It covers activities from basic scientific research performed in universities and laboratories to testing and refining products before commercial sale or use (Hall, 2006). R&D can be divided into three main activities or phases: basic research, applied research, and development. Basic research is research undertaken primarily to acquire new knowledge, without a specific application in mind. Applied research is research directed towards a specific objective. Finally, R&D in the development phase draws on results from the other two phases and works on new and improved products and processes. The goal of R&D investments is to create a competitive advantage and, by doing so, increase firm performance (Jaffe, et al., 1986). Many studies on the impact of R&D on firm performance have been conducted and most of the times a significant positive relationship was found. The effect of R&D investment has been tested on sales growth rates (Filatotchev & Piesse, 2009) (Chan, et al., 1990), investment opportunities (Borisova & Brown, 2013), stock returns (Eberhart, et al., 2004) and firm market value (Bae & Kim, 2003) (Ehie & Olibe, 2010) (Connolly & Hirschey, 2005). A large number of studies have used variations of the market value equation introduced by Griliches in 1981. In these studies, the impact of R&D expenditures on firm market value is measured. The firm market value is hereby often proxied by Tobin’s Q, which equals the market value of a firm divided by the firm’s assets' replacement cost. The majority of these studies confirm that stock markets generally value R&D positively. However, they also confirm that market valuation of R&D has progressively decreased over time (Grandi, et al., 2009). One of the main explanations for this result is the shortening of technology cycles, which makes past R&D expenditures less valuable to investors (Grandi, et al., 2009). A second possible reason is the increased number of firms that are pursuing R&D strategies, which drives the returns down (Grandi, et al., 2009). R&D is a risky undertaking by its nature because returns are not guaranteed. Even if there are returns, it can be difficult to attribute them to specific R&D processes. This often leads to an asymmetric information problem between the conductors of R&D and those who finance it, which can lead to underinvestment. Several authors have proposed that financial markets are not always efficient in evaluating R&D investments, mainly because of these information asymmetries (Grandi, et al., 2009).

Literature on the topic of R&D points out that various firm characteristics significantly affect the relation between firm valuation and R&D investments (Pindado, et al., 2010). Bae found that the relationship between R&D and firm performance for U.S. multinational firms is negative at a low level of internationalization, positive at an intermediate level of internationalization and negative at a high level of internationalization (Bae, et al., 2008). This is in accordance with the internalization theory for firms. The internalization theory states that the value of intangible assets of a firm increases in direct proportion to the scale of the firm’s markets (Merck & Yeung, 1992). When firms expand abroad, shareholders’ wealth increases due increased scale over which such intangible assets are applied (Merck & Yeung, 1992). Chan found that R&D expenditure announcements by low-tech firms are typically associated with negative abnormal stock-market returns (Chan, et al., 1990). Sundaram showed that the positive valuation effects of R&D spending announcements are less significant in aggressively competitive settings (Sundaram, et al., 1996). The rate of return for R&D announcements is greater for firms operating in highly concentrated industries (Doukas & Switzer, 1992). The market response to R&D has been found favorable for firms with a lower level of ownership concentration in Europe (Hall & Oriani, 2006). In addition, (Booth, et al., 2006) found that the stock market valuation of R&D investments is influenced by the relative size of the equity and private loan markets. If a firm is financed by equity rather than debt, the market valuation of R&D expenditure becomes stronger. Multiple papers have found evidence of size advantages for the valuation effects of R&D expenditure (Connolly & Hirschey, 2005). R&D activity of larger firms appears to be more impactful for market value than that of smaller firms (Chauvin & Hirschey, 1993). The economies of scale, the easier access to capital markets, and the R&D cost spreading are commonly cited reasons for the size effect (Cohen, et al., 2000). These assumptions were confirmed by Pindado in 2010 (Pindado, et al., 2010). The majority of firms in the used dataset can be labeled as big sized firms. Based on the dataset and on the positive relationship between R&D and firm value which generally has been documented in the literature, the first hypothesis is formulated. In the used model, all variables are introduced as ratios, which is explained in the next section of this paper.

- *H1: The relationship between R&D and firm market value is positive*

2.2. Patents

Patent publications are one of the most important visible indicators of successful R&D processes (Blind, et al., 2006). They are often used to assess the technological performance of firms, technology fields and economies as a whole. Patents can be seen as codified knowledge and are therefore considered reflectors of innovative activities for patenting firms and even for countries (Blind, et al., 2006). Even if a patent has no direct value, it is part of a technological trajectory from which the firm expects to generate an economic or strategic value (Neuhäusler, et al., 2011). Because patents disclose all the information behind the patented invention to the public, a published patent document also has social benefits, since others can build their own R&D upon this codified knowledge (Neuhäusler, et al., 2011). So both patents and the R&D expenditures leading to developing the patented inventions have spill-over benefits (Jaffe, et al., sd). Large patent portfolios are strategically useful, because they block competitors from innovation or even prevent them from entering relevant markets (Neuhäusler, 2012). A granted patent application provides a competitive advantage over other firms that operate within the same industry. The competitive advantage can result in profits through various ways. Patented inventions can lead to more effective production. Firms can gain profits via lower costs of production if they continue to sell at the same price. Alternatively, a firm can sell at a lower price and increase its market share by driving out competitors, leading to later returns from increased product monopoly (Greenhalgh & Rogers, 2007). If patented inventions lead to product novelty, the firm gains profitability from increasing its market share and gaining customer loyalty (Greenhalgh & Rogers, 2007). In addition, higher prices can be charged for a higher quality product. Patented inventions could also be used for licensing to other firms, which results in direct revenues without necessarily having to engage in production (Greenhalgh & Rogers, 2007). In addition to a competitive advantage, patents can be a useful signal to investors indicating a firm has valuable knowledge assets, even in the absence of a current profit stream (Hall & Harhoff, 2012). This is necessary when there is an informational asymmetry between the firm and outsiders. Patents are costly to acquire and are subject to an external quality check by the patent granting authority. Therefore, they act as good signal, allowing firms to raise finance or attract talented employees (Appio, et al., 2019). Although patenting firms can establish a competitive advantage and reinforce their market position, patenting remains an expensive practice for firms (Appio, et al., 2019). The potential benefits do not always exceed the high expenses. Other negative aspects appear when the invention is easy to reverse engineer or the ease of inventing around makes it vulnerable in the face of the competition (Blind & Gauch, 2009). In those cases, the choice to keep inventions secret is preferred over patenting to protect innovation (Cohen, et al., 2000). Overall, patent portfolios can have a strong and robust effect on a firms' market value since it can lead to sales revenue maximization or cost reduction (Czarnitzki & Kraft, 2010) (Appio, et al., 2019).

In 1981 a significant relationship was found between the value of large U.S firms and R&D expenditures and patent count (Griliches, 1981). A positive relationship was also found between the economic performance of fifty German firms and the patent count of their international patent applications, the rate of valid patents and the received citations for their patents (Ernst, 1995). Other research analyzed the value of large Australian firms and found that R&D expenditure and patent count are positively and significantly associated with market value as measured by Tobin's Q (Bosworth, et al., 2001). A positive relation was also found in the pharmaceutical industry (Chen & Shih, 2011). Therefore, the second hypothesis is formulated:

- *H2: The relationship between patent publications and firm market value is positive*

The earliest research on patents mainly focused on simple patent counts as indicators of valuable output. They estimated the economic value of patents based on various patent characteristics within patent databases or through field surveys. These approaches mostly made use of patent families, renewals and inventor surveys (Harhoff, et al., 1999). The main common observation of this literature was the severe skewness in patent value distributions, with a very long right tail and a majority of patents associated with no or very little value (van Zeebroeck, 2011). The task of assessing the value of patent rights is a particularly difficult one because patents exist in a blind market with high information asymmetry (Lemley & Myhrvold, 2007) and their value depends on highly idiosyncratic details, including the strategic function they have in a competitive environment (Cohen, et al., 2000). A simple patent count is not satisfactory in determining what value a patent adds to a firm, because it assigns a value of one to all patents by construction, whereas their true values exhibit a very large variance (van Zeebroeck, 2011).

2.3. Patent value indicators

In order to address the issue of skewness, most patent research includes one or more patent value indicators. Modern research often includes R&D expenditure, patent count and one or more patent value indicators as independent variables, which are regressed against the market value of the firm. In general, five different value indicators have consistently found to be positively correlated with firm or patent value: the number of claims, forward citations, backward citations, number of family members, and oppositions (van Zeebroeck, 2011). These are all important characteristics of patent applications and will be used in this paper to address the skewness of the patent publications. Citations are references made to other patents or non-patent research. Forward citations are the references that a patent receives from other patents, which were filed later. Backward citations are the references that a patent application makes in its filed text. The number of family members is the number of countries in which patent protection for the same invention is obtained. The claims, which were described in the introduction, are the most important part of the patent application and define the scope of protection. When a patent application receives an opposition, it means is a third party chose to formally challenge the validity of a patent application. They might argue the new patent infringes on their earlier patent or argue the new patent does not meet the grant criteria.

The first indicator which is discussed is the average number of claims. The purpose of the patent claims in a patent application is to define the scope of what is being claimed as the invention. When the patent application is granted, it is the granted patent claims that define the boundaries of patent protection which is afforded under the patent. Claim counts have been widely available to researchers for many years (Marco, et al., 2019). The scope of a patent determines the amount of monopoly power the patent grants on the owner. Research has shown that the scope and the clarity of patent claim language are significant concerns for patent quality (Wagner, 2009). Overly broad or vague claims can be exploited for the purpose of rent seeking, particularly by non-practicing entities (NPE's) (Schwartz & Kesan, 2014). Legally invalid, overly broad, or vague claims are thought to impose deadweight losses, as well as to reduce sequential innovation in various industries, particularly with regard to software (Rai, 2013). Research has shown that narrower claims at publication are associated with a higher probability of grant and a shorter examination process than broader claims (Marco, et al., 2019). In various papers a significant impact by the claim count on firm value was found (Lanjouw, et al., sd). There are however also papers who challenge the commonly accepted idea that more claims reflect a broader scope of protection (van Zeebroeck, et al., 2009). Based on the theory that a broader patent grants more protection and is therefore more valuable, the following hypothesis is formulated:

- *H3: The relationship between the average number of claims and firm market value is positive.*

Patent citations play an important role in patent analysis. If patent A cites patent B, it implies that patent B contains knowledge on which patent A builds and over which patent A cannot have a claim (Hall, et al., 2005). Patent citations are presumed to represent information on two aspects of innovation trough patenting. The first is that patent citations signal the linkages between inventions, inventors and assignees. Patent citations are an indication of the knowledge spillovers which result from our patent system. As a consequence, the number of citations a patent receives can be used as an indicator of its importance to future research.

The number of citations a patent receives from subsequent patent applications are seen as a measure of the technological value of a patent. The basic assumption is that the number of forward citations measures the degree to which a patent contributes to further developing advanced technology and therefore is an indicator of technological significance (Neuhäusler, et al., 2011). Patented innovations are for the most part the result of costly R&D conducted by profit seeking organizations. This means that if firms invest in further developing an innovation disclosed in a previous patent, then the resulting (citing) patents presumably signal that the cited innovation is economically valuable (Hall, et al., 2005). Many researchers have argued that forward citations are able to indicate the economic as well as the technological value of a patent (Trajtenberg, 1990). Forward citations are seen as the most important determinant of patent value for market-based measures, and are even used as dependent variable in some studies (Zeebroeck & Pottelsberghe, 2008). Hall et al. (2005) showed that citation weighted patents are more highly correlated with US firm's value than unweighted patents, after controlling for the firm's R&D expenditure. Hall's research used a sample of over six thousand publicly traded manufacturing firms with data on patents and citations from 1963 to 1999. Hall defined the value of the firm as the value of equity plus debt, which is related to tangible and intangible assets. She used the ratios of R&D to assets, patents to R&D, and citations to patents as proxies for knowledge assets, and found that the firm market value is positively related to these ratios (Hall, et al., 2005). The results showed that R&D expenditure has the most impact out of these factors. Citation-weighted patents are more informative about the market value of innovation than just the number of patents. Firms with often cited patents show significant large Tobin's Q values. These values are on average 50% higher than for firms with the same R&D and patent stocks, but with only the median numbers of citations. Various studies on R&D, patents and patent citations have confirmed these findings (Hall, et al., 2007).

Firms that hold much cited patents in their portfolio show very high Tobin's Q values. Of course, when Tobin's Q is measured, the amount of citations a patent will receive is not known yet. This indicates that patent citations are a good proxy for innovation quality that is already known to the stock market, before the citations are received (Greenhalgh & Rogers, 2007). A difficulty with using forward patent citations as a variable, is that they can come at any point in time after the patent is published. Even long after a patent has expired, they can still be cited in other applications. Therefore, this time-sensitive variable is likely to be biased, because ‘old’ patents are likely to have received more forward citations than ‘new’ patents (van Zeebroeck, 2011). Therefore, it is recommended not to use the forward citations variable for brand new patents, since they simply have not had the time yet to get cited by future references. Based on the literature, the following hypothesis is formulated:

- *H4: The relationship between the average number of forward citations and firm market value is positive.*

The third indicator is the average number of backward citations. Backward citations (citations a patent makes) refer to previous patents and are mostly used as an indicator of technological width or background of a patent. The cited patents are listed as prior art in the search report, which is produced as part of the grant procedure for each patent application. Backward citations have been called ambiguous as a value indicator (Neuhäusler, et al., 2011). One could argue that more prior art means a larger scope for the patent application. A larger scope would make the patent more valuable. Patents with a large number of backward citations can be assumed to build on a broad basis of already existing knowledge, whereas patents with only few backward citations only have a small existing knowledge stock to build upon (Fernández-Ribas, 2010). On the other hand, having a large number of backward references could mean that a patent application relies too much on previous research and therefore adds relatively little new innovation. In that is true, the patent scope is narrower if a patent has a high number of backward citations. Not just previous patents, but other scientific publications can be cited in a patent application. These references to non-patent literature (NPC’s) can be used to indicate the closeness to science or basic research of a patent applicant's R&D activities (Deng, et al., 1999). In general, research has found a positive influence of backward citations, to both patent and non-patent literature, on patent value (Neuhäusler, et al., 2011) (Harhoff, et al., 2003). In a similar research to Hall, Yi Deng looked at the effect of forward and backward citations on Tobin’s Q for semiconductor firms during the 1980s and 1990s. Deng found that backward citations have a clear positive effect on Tobin’s Q. However, the value of backward citations declines when the size of the firm’s patent portfolio increases. Based on existing literature, the hypothesis regarding backward citations is:

- *H5: The relationship between the average number of backward citations and firm market value is positive.*

The fourth indicator is the family size. The family size of a patent is defined by the number of countries in which patent protection is obtained for the same invention. This indicator has been examined and found positively correlated with patent or firm value by many authors (Lanjouw & Schankerman, 2004); (Lanjouw, et al., sd) (Harhoff, et al., 2003). Kim found that the average family size of a patent portfolio has a positive and significant effect on a firm's market value for firms in the renewable energy sector (Kim, et al., 2018). A similar effect was found by Neuhausler on a panel dataset including 479 firms from 1990 to 2007 (Neuhäusler, et al., 2011). This is logical, given the costs required to file and enforce patents in many countries. Only those with sufficient expected value to their owners will be extended abroad, denoting an expected market for the patented technology (van Zeebroeck, 2011). It is imported to note that patent applications are often filed as international PCT applications, in accordance with the Patent Cooperation Treaty (PCT), to which 153 countries are a party. A PCT application itself does not result in an actual patent. It is required to follow up the PCT application with a national or regional phase to receive an actual grant of patent. Given the previous findings on family size, the following hypothesis is formulated:

- *H6: The relationship between the average family size and firm market value is positive.*

The fifth and last indicator is the average number of oppositions. An opposition proceeding is an administrative process available under the patent law of many jurisdictions which allows third parties to formally challenge the validity of a pending patent application or a granted patent. Oppositions are relatively easy to measure, since in many countries they have to be filed within a certain time period from the grant date. In contrast to forward citations, they are not time-sensitive. When a patent application is opposed, it can either be revoked, maintained in amended form, or maintained as granted. For European patents, these three options happen with a similar frequency (van de Kuilen, 2013). On average, opposed patents which survived the opposition were maintained about two years longer than undisputed patents (van Zeebroeck, 2011). It has been noted that patents in the medical field are more likely to be opposed (van de Kuilen, 2013). Opposition cases provide a very interesting signal of a patent's value on the market as perceived by a third party, since they designate patents whose importance justified to the opponent the cost and risks associated with the dispute, clearly establishing the existence of a market for the patented invention (Lanjouw & Schankerman, 1997) (Hall & Harhoff, 2012). In addition, an appeal against a patent means that at least two parties conduct research for the same piece of technology. Therefore, the cost and risks associated with the dispute signal the existence of a market for the patented invention (van Zeebroeck, 2011). Opposition or litigation history has been well established as an indicator of patent value (Harhoff & Reitzig, 2004) (Harhoff, et al., 2003). This might feel contradictory, since one can argue that patents are opposed when opponents consider it weak. Therefore, the argument can be made that opposed patents should be less valuable. In practice, oppositions are rarely filed. For instance, only three to four percent of EPO patents applications are challenged (EPO Annual Report 2018). This number has been decreasing for a long time. This decline can be interpreted in various ways. A lower percentage of oppositions could indicate that patents hold less and less threatening power and are therefore not worth the time and money to oppose. On the other hand, patents might be stronger, which would discourage other parties to challenge them. A third possibility is that rival parties settle their arguments out of court (van Zeebroeck, 2011). These settlements might have the same effect as oppositions, but they cannot be observed in the data. Based on the literature, various hypothesis could be formulated. I, personally, think that a filed opposition indicates a patent is weak, and therefore less valuable. This is evidenced by the regressing number of oppositions that are filed. In addition, the statistics show that two thirds of the opposed patents are changed in some way (either amended or revoked), which would diminish their value. Therefore, the hypothesis is formulated:

- *H7: The relationship between the average number of received oppositions and firm market value is negative.*

It has already been established that firm size influences the impact of R&D on firm market value. High R&D expenditures are relatively concentrated among large firms. This fact suggests size advantages through economies of scale or economies of scope in R&D. Because this paper views patent publications and patent value indicators as proxies of successful R&D, it is expected that the size effect is noticeable for all knowledge assets of interest. The last hypothesis is:

- *H8: The relationship between the knowledge assets and firm market value is stronger for large firms.*

3. Method & Data

Research which focuses on patent valuation can be divided in two categories. It is either conducted on patent-level or conducted on market-level. Studies on patent level usually look at patents which were part of acquisition and use the acquisitions price as dependent variable. The obvious downside to this strand of research is that patent acquisitions are limited in number, and the prices are not always publicly available. Other studies on patent-level focus on renewals. This approach is based on the theory that patents which are renewed, are more valuable. The downside to this approach is that it can only differentiate value between patents up to a certain boundary. There is a large group of patents which are renewed for 20 years, which is the maximum lifespan of a patent. In this group, there is no way of telling which patents are more valuable than others. Due to the limitations of patent-level research, this paper will be conducted on market-level, which is known as the market value approach. The choice for the market value approach was made because it provides more economic meaning than research on patent level. Market value approach results show directly what impact R&D and patents have on firm market value.

This approach is based on the assumption that the market value reflects all future expectations in the market, in accordance with the Efficient Market Hypothesis (EMH). According to the EMH all available information is included in stock prices. Financial markets are assumed to assign a valuation to the firms' assets that is equal to the present discounted value of their future cash flows (Hall, et al., 2007). Therefore, valuable knowledge assets are taken into account by a company's stock price (Gogoris & Clarke, 2001). Previous market-level studies on R&D and patents have made use of a wide variety of models, including ordinary least squares (OLS), fixed effect or random effect models. This paper will use a nonlinear least squares (NLLS) model. The regression is a specification of the market value function which was first introduced by Grilliches in 1981 and has been predominantly used in literature. This function makes use of Tobin's Q as the dependent variable, which is defined as the ratio of market value of the firm divided by the book value of the physical assets. Tobin's Q captures the financial performance of a firm, in both short-term performance and long-term prospects (Chung, et al., 2014). In addition, it is forward-looking, risk adjusted, and not prone to changes in accounting practices (Chung, et al., 2014). The dependent variables of interest will be ratios of R&D expenditure, patent publications count and patent value indicators.

3.1. Model

The market value approach is based on the idea that firms are bundles of assets, which are difficult to disentangle and to price separately on the market. The bundle of assets consists of both physical assets and knowledge assets. This approach assumes that the financial markets are efficient and therefore assign a valuation to the firm's assets which is equal to the present discounted value of the firm's future cash flows. The firm value incorporates all the information currently available about the likely success or failure of the R&D expenditures in generating future profits for the firm (Hall, 2007). The market value equation can take a linear or log-linear form in which the assets enter additively. The market values of a set of firms are regressed on their respective bundle of assets. The slope coefficient of any particular type of asset can be interpreted as its marginal shadow value. This model, introduced by Griliches in 1981, is the predominant one employed for researching the market value and knowledge assets of firms (Griliches, 1981). It is derived from the following equitation, which expresses the market value of a firm as a multiple of the sum of its assets:

$$V_{it} = q_{it}\,(A_{it} + \beta K_{it}) \tag{1}$$

V_{it} denotes the market value of firm *i* at time t. q_{it} denotes the market valuation coefficient of the firm's total assets. The market valuation coefficient includes an individual effect, time differences and industry and firm-specific components and denotes the difference between the market value of a firm and the replacement value of its assets. A_{it} denotes the physical assets of the firm and K_{it} denotes the knowledge assets of the firm. β denotes the shadow value of a firm's knowledge assets, which reflects the possibility that knowledge assets are valued differently by the market than physical assets (Simeth & Cincera, 2016). The shadow value represents the contribution of knowledge assets to the firm's market value when the firm spends one additional unit on knowledge capital (Rahko, 2014). In accordance with research by Hall (Hall, et al., 2005), Kim (Kim, et al., 2018), Rahko (Rahko, 2014) and Simeth (Simeth & Cincera, 2016), logarithms are applied on both sides and physical assets are moved to the left-hand side of the equation. This gives the following equation:

$$log(\frac{V_{it}}{A_{it}}) \;=\; log\;Q \;=\; log\,q_{it} \;+\; log(1 + \beta\left(\frac{K_{it}}{A_{it}}\right)) \tag{2}$$

On the left side is the natural logarithm of the ratio of the firm's market value to the book value of its physical assets. This ratio is known as Tobin's Q. The market value is the stock market value of the firm at the end of the year plus the market value of its debt. The book value of the firm is the total value of its physical assets reported on the balance sheet. On the right side, β is the shadow value of the ratio of knowledge capital to tangible assets at a given point in time. β reflects the expectations of the investors over the effect of the knowledge capital relative to tangible assets on the discounted future profits of the firm (Hall, et al., 2007). The market valuation coefficient, $log\, q_{it}$, is the intercept and represents the firm's monopoly power and market structures (Griliches, 1981). This coefficient can vary across time, industries, and countries. To control for this, industry, country and year dummies are added to the model, as well as a control variables for firm-specific effects.

This paper aims to measure the effect of knowledge assets on Tobin's Q. Therefore K_{it} needs to be specified. As concluded from the literature, R&D expenditures are a sensible proxy. R&D expenditures measure the past efforts the firm has made in inventive activities. Even if some R&D projects do not yield protectable intellectual property, those projects still increase the firm's knowledge assets by expending the firm's know-how (Deng, 2005). However, this paper also aims to measure the success of the R&D process of firms. Therefore, the number of patent publication is included as a proxy for R&D success. Patent publications indicate the success of R&D projects and therefore the patent/R&D ratio indicates the R&D productivity (Deng, 2005). However, as can be learned from previous research, the quality and value of patents vary a lot. Simply looking at just the number of patent publications is unsatisfactory, because it does not necessarily mean these patents are important to the firm. To control for this heterogeneity, five patent value indicators are included, which were all discussed in the literature section. Following the literature review, the knowledge assets of firms are separated into R&D expenditure ($R\&D_{it}$), patent publication count (PAT_{it}), claims ($CLAIMS_{it}$), family members (FAM_{it}), forward citations ($CITFWD_{it}$), backward citations ($CITBWD_{it}$) and oppositions ($OPPS_{it}$). Since patent publication count can be regarded as a direct outcome of R&D it is introduced as a ratio, denominated by R&D expenditures (Hall, et al., 2005). Because the patent value indicators are outcomes of the patenting process, they are introduced as ratios denominated by the number of patent publications. It is very well possible that the five patent value indicators are correlated, which would cause multicollinearity if they were regressed together. Therefore, five different regression models are formulated. All these models are identical, except for the patent value indicator.

$$log\left(\frac{V_{it}}{A_{it}}\right) = log\,Q = \ log\,q_{it}\ +\ log(1\ +\ \beta_1(\frac{R\&D_{it}}{A_{it}})\ +\ \beta_2(\frac{PAT_{it}}{R\&D_{it}})\ +\ \beta_3\left(\frac{CLAIMS_{it}}{PAT_{it}}\right) +\ \varepsilon_{it} \quad (3)$$

$$log\left(\frac{V_{it}}{A_{it}}\right) = log\,Q = \ log\,q_{it}\ +\ log(1\ +\ \beta_1(\frac{R\&D_{it}}{A_{it}})\ +\ \beta_2(\frac{PAT_{it}}{R\&D_{it}})\ +\ \beta_3\left(\frac{FAM_{it}}{PAT_{it}}\right) +\ \varepsilon_{it} \quad (4)$$

$$log\left(\frac{V_{it}}{A_{it}}\right) = log\,Q = \ log\,q_{it}\ +\ log(1\ +\ \beta_1(\frac{R\&D_{it}}{A_{it}})\ +\ \beta_2(\frac{PAT_{it}}{R\&D_{it}})\ +\ \beta_3\left(\frac{CITFWD_{it}}{PAT_{it}}\right) +\ \varepsilon_{it} \quad (5)$$

$$log\left(\frac{V_{it}}{A_{it}}\right) = log\,Q = \ log\,q_{it}\ +\ log(1\ +\ \beta_1(\frac{R\&D_{it}}{A_{it}})\ +\ \beta_2(\frac{PAT_{it}}{R\&D_{it}})\ +\ \beta_3\left(\frac{CITBWD_{it}}{PAT_{it}}\right) +\ \varepsilon_{it} \quad (6)$$

$$log\left(\frac{V_{it}}{A_{it}}\right) = log\,Q = \ log\,q_{it}\ +\ log(1\ +\ \beta_1(\frac{R\&D_{it}}{A_{it}})\ +\ \beta_2(\frac{PAT_{it}}{R\&D_{it}})\ +\ \beta_3\left(\frac{OPPS_{it}}{PAT_{it}}\right) +\ \varepsilon_{it} \quad (7)$$

The resulting equation explains the knowledge flow in a technology development process, where R&D expenses, patent publication count and the patent value indicators are regarded as different stages (Kim, et al., 2018). When firms seek to develop new technology, they start by investing in R&D. Their emphasis on R&D is measured by the ratio of R&D expense to assets. As a consequence of R&D expenses, new technology is developed and protected by patent application. The successfulness of R&D is measured by the ratio of patents to R&D. Finally, the other five independent variables serve as proxies for patent quality. Ordinary least squares (OLS) can be applied for the regression if log(1+x) is regarded as x. However, this approximation is not preferable because it becomes inaccurate as the ratio of knowledge assets to total assets grows (Rahko, 2014). This paper therefore will use nonlinear least squares (NLLS) for the regression analysis. Because of the non-linearity of the used model, the estimated coefficients cannot easily be interpreted. If, for example, the beta for R&D/Assets is one, it does not simply mean that Tobin’s Q goes up with one if R&D/Assets goes up with one. This is also caused by the fact that the various dependent variables are measured in different units. R&D is measured in millions of euro’s, but the patent publications variable is measured in number of publications and forward citations is measured in forward citations per publication. Therefore, it impossible to directly compare the coefficients with each other. If R&D/Assets has a larger coefficient than publications/R&D, it does not necessarily mean a million extra in R&D expenses is more valuable than one extra patent publication. To provide more clarity, it is necessary to calculate the elasticity of Tobin’s Q with respect to the independent variables. Elasticity is the percentage change of one economic variable in response to a change in another. More specific, this research will use the semi-elasticity:

$$dyex = \frac{dy}{dx} \times (x) \quad (8)$$

Which can be interpreted as the change in y for a proportional change in x. In other words, this semi-elasticity represents the increase in Y measured in units from a one percent increase in X (Holmes, et al., 2018). For example, an elasticity value of 0,50 for the R&D/Assets variable means that Tobin's Q, on average, goes up with 0,50 if the R&D/Assets ratio goes up with 1%. If the elasticity of R&D/Assets is higher than for Publications/R&D, we can say that a percentual increase in R&D/Assets has a larger effect than the same percentual increase in Publications/R&D. This elasticity is often used for R&D and patenting research (Cameron & Trivedi, 2005).

In addition to the independent variables, a number of dummies and control variables will be included in the model, which enter through the current valuation coefficient. The dummies account for differences between years, sectors, and countries. The number of employees per firm and the age of the firms are added as control variables for firm size and firm age. Firm size is important because larger firms are thought to have above-average resources and capability for innovation (Wang, 2011). Firm size is best measured as a logarithmic function of the number of employees (Wang, 2011). Firm age is also controlled for, because younger high-tech firms might pursue more innovations than older firms (Wang, 2011). Additionally, total sales divided by employees and R&D expenditures divided by total sales are added to the dataset as control variables. These variables are used as proxies to measure how efficiently firms generate sales and how well a firm converts results of R&D processes into revenues (Neuhäusler, et al., 2011).

3.2. Data collection

All the used data is gathered from Orbis IP, a patent database which also provides key financial information on firms. Orbis IP currently provides data on 360 million firms and 115 million patents. Because of the need for extensive financial data, only publicly listed companies are included. This research will focus on the geographical region West-Europe. The countries included are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, and the UK. The examined years are 2011 up to and including 2017. This time frame is chosen because most of the economic firm data in Orbis is only available from 2011 and later. 2017 was chosen as the last year, because of the time-sensitivity of the forward patent citations. Patents that are relatively older have had more time to receive forward citations. To prevent bias all examined patents should be at least several years old (Neuhäusler, et al., 2011). To make sure the data is complete, only firms which reported R&D expenses from 2011 to 2017 are included. Because there are many firms who choose not to report their R&D investments, this could cause a sample selection bias. Hall et al. (2004) and Toivanen et al. (2002) discussed this issue extensively and found that excluding firms without R&D expenses does not form a significant sample selection bias. This results in a data collection of seven years for 1.002 companies. After deleting observations which have negative R&D expenses and negative sales, 6.987 firm-year observations remain. The book value of the physical assets and market value of the firm are used to construct Tobin's Q. As explained, R&D expenditure are also available for the selected firm-years. This is also the case for the intended control variables. All data is measured in millions of euro's, except of course the variables which are not expressed in currency, such as age, patent count and employees. The sectors in which the firms operate are indicated with the NACE Rev. 2 statistical classification of economic activities in the European Community.

For every firm-year, the number of patent publications is provided. Patents are published 1,5 year after the application is filed. In other words: published patents are the result of patent applications made in the year before. Therefore, a lag of one year is used for all the patent-level data. This means that a firm's financial data for year t will be coupled with the patent data for the publicized patents in year t+1. Orbis provides the data for number of claims, citations, family members and oppositions for every individual publicized patent. A first look at the publications reveals that some publications have zero claims, which is impossible. These publications are excluded from the data. There are also publications which are not 'alive' anymore. This means they have expired because of nonpayment of the maintenance fees by their owners. Since their owners did not think they are worth the maintenance fees they are presumably in general worth less than patents which have not expired. Removing them would cause a bias, since just the most valuable patents would be kept in the dataset. However, this paper also aims to measure the impact of less successful patent publications, to give an accurate assessment of the overall value of patent publications. The patent level data needs to be transformed to firm level (portfolio averages) before it can be used in the regression analysis. For every firm-year, the average number of claims, back- and forward citations, family members and oppositions are calculated. This provides the portfolio average for every firm in every year.

3.3. Descriptive statistics

Appendices C to G show the descriptive statistics for the final data sample. The firm variables are Tobin's Q, sales, tangible assets, employees, age and R&D expenditures. These are used to construct ratios which, in addition to the firm variables, function as control variables: sales/employees, R&D divided by sales and R&D divided by physical assets. Finally, the patent variables are number of publications, publications divided by R&D, average number of claims, average number of family members, average number of forward citations, average number of backward citations and average number of oppositions .

The data on the firm variables is balanced. 89% of the observations have a recorded value for Tobin's Q and 96% have a recorded value for R&D expenditure, sales, employees, and tangible assets. In contrast, just 70% of the observations have recorded patent data. This means that in 70% of the firm-years at least one patent was filed. The firms in the sample are, as expected, very large with 1.447 employees and 277 million total sales as median numbers. It is also clear that the data is very skewed to the right, so the medians will be used to compare differences between the firms. The values of skewness are all far outside the acceptable interval between -2 and +2 (Yousef Obeidat, et al., 2017). All the mean values of the variables are larger than the median values. Variables that are especially skewed are Tobin's Q and the ratios sales/employees, R&D/sales and publications/R&D. The age of the firms, which is the only variable that is not skewed, is on average 56. The median of Tobin's Q is 1,2, which is very close to unity, and the average is 2,2. These values are below the estimated values of Tobin's Q in similar research on European firms in the period from 1991 through 2002 (Hall, et al., 2007). This research recorded a mean of 2,99 and median of 1,71 for Tobin's Q. R&D is on average around 6% of tangible assets. The median of publications is 8, which means most companies publicize eight patents per year, the most in one year being 9.521. The data tells us that an average patent publication has 16,5 claims, 12 family members, 5,4 backwards citations and receives just one forward citation. These values are in line with previous research. The patent value indicators are even more skewed than the firm variables. Family size, forward citations, backward citations and oppositions have skewness values of 11, 13, 16 and 14 respectively. Claims are the exception, with a skewness value of just 4,26 and a mean and average that are very close to each other. It is notable that less than 1% of all patents is opposed, which is far less than the number of oppositions an average EPO patents receive, as mentioned in the literature. The problem of skewness is solved after log transforming the variables. The transformed variables of interest show skewness values between -1,22 and 0,86. The mean and median values of the transformed variables are very close to each other and there are no more extreme minimum or maximum outliers.

Appendix E shows the difference in the median of our variables for various sectors. Firms in sectors M (Professional, Scientific and Technical Activities), N (Administrative and Support Service Activities) and R (Arts, Entertainment and Recreation) often have a high Tobin's Q. Also interesting is that publications from firms in sector D (Electricity, Gas, Steam and Air Conditioning Supply) are far more likely to be opposed than those in other sectors. Sector N receives 0,829 forward citations on average, which is very high. Appendix F shows that the Netherlands has a very high average of publications. The reason for this is that The Netherlands has some extreme patenting outliers, such as Philips and ASML. Although Italy and Poland do not have a higher number of publications, they have a high ratio of publications to R&D, meaning their R&D processes are relatively effective in generating IP. None of the patent value indicators show significant correlation with each other, which indicates there is no multicollinearity.

4. Results

The model described in the previous sections will be regressed in various forms, which all represent a different stage in the innovation process. The first estimated model is called the baseline model (model 0), excluding all knowledge assets. This model explains Tobin's Q with just the dummy and control variables. Note that if the knowledge assets are not included, the last term in the equation becomes ln (1), which equals 0. In that case the equation simply becomes a linear sum of the dummies and control variables. Model 1 adds the R&D expenditures divided by physical assets to the baseline model, as a proxy for innovation. In model 2, the number of publications divided by R&D expenditures is added to the equation as a proxy for successful R&D projects. For models 3.1 until 3.5, each one of the five patent value indicators are added individually, to create five different regressions. The additional steps represent the innovation process in a firm: successful R&D expenditures lead to patent publications and successful patents are measured by the value indicators. Each regressor adds further information on top of what could be predicted on the basis of the previous regressor. This procedure facilitates the examination of the significance and the marginal contribution of each regressor (Deng, 2005). Finally, the model is estimated with all patent value indicators included simultaneously.

4.1. Baseline model, R&D and Publications

The baseline model was tested with several different (combinations of) control variables. The tests showed that age and number of employees are the best control variables. Adding total assets or sales as control variables does not influence the results. This does not change for models 1, 2, 3 and 4. With age and employees as control variables, the R-squared and R-squared adjusted ratio are 0,37, which is a significant increase from the baseline model. This implies that 37 percent of the variance in Tobin's Q is explained by the dummies, control variables and the R&D to physical assets ratio. The coefficients for the control variables are both slightly negative but significant. The coefficient for R&D/Assets has a positive value of 3,468 and is significant. These results improve when the outliers for all the variables are filtered out. To do so, all variables are winsorized at the 1 percent and 99 percent percentiles. The winsorized variables show a R-squared of 0,38 and the coefficient of R&D goes up to 3,696. The semi-elasticity coefficient for R&D/Assets is positive and significant, with a value of 0,116. The semi-elasticity remains the same if it is computed for the winsorized regression.

Model 2 adds the ratio of publications to R&D to the regression. Again, age and employees are used as control variables. Very noticeable is the difference in the coefficient for the R&D/Assets ratio in comparison with the first model. The coefficient is still significant and increases to 6,093. The R-squared value also increases to 0,41, meaning that the added publications regressor helps to explain the variance in Tobin's Q. The coefficient for Publications/R&D is positive and significant, although very small. Winsorizing the variables in this model has a lot more effect on the results than in the previous model. R-squared only goes up slightly, but the coefficient for R&D/Assets goes up to 7,371. Even more notable is the change in the coefficient of the publications, which becomes ten times bigger after winsorizing. The elasticities for R&D/Assets and Publications/R&D in model 2 are both positive and significant, with values of 0,248 and 0,005. The elasticity for R&D/Assets doubles in size in comparison to model 1 and increases slightly more after winsorizing. The elasticity for Publications/R&D becomes more than seven times as big when it is computed for the winsorized regression.

Table 1: Results from the NLLS Regression for the baseline model, model 1 and model 2

Dependent variable:	**0.**	**1.**	**2.**
Ln (Tobin's Q)	**Baseline model**	**R&D/A**	**R&D/A and Pub./R&D**
Constant	1,093***	0,507**	-0,343**
	(0,156)	(0,143)	(0,156)
Age	- 0,222***	-0,158***	-0,075***
	(0,017)	(0,017)	(0,019)
Employees	-0,074***	-0,057***	-0,023**
	(0,005)	(0,005)	(0,007)
R&D/Assets		3,468***	6,093***
		(0,272)	(0,483)
Publications/R&D			0,002*
			(0,001)
R^2	0,336	0,375	0,411
Adjusted R^2	0,331	0,370	0,405
Observations	6.041	6.041	3.955
Elasticities			
R&D/Assets		0,116***	0,248***
		(0,005)	(0,011)
Publications/R&D			0,005**
			(0,002)

All equations include full sets of year, country and industry dummies. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively

Table 2: Results from the NLLS Regression for the baseline model, model 1 and model 2 with all variables winsorized at the 1 percent and 99 percent percentiles

Dependent variable: Ln (Tobin's Q)	**0. Baseline model**	**1. R&D**	**2. R&D/A and Pub./R&D**
Constant	1,114***	0,468**	-0,426***
	(0,157)	(0,139)	(0,150)
Age	-0,226***	-0,160***	-0,074***
	(0,017)	(0,017)	(0,020)
Employees	-0,074***	-0,056**	-0,013**
	(0,005)	(0,005)	(0,007)
R&D/Assets		3,696***	7,371***
		(0,263)	(0,548)
Publications/R&D			0,026***
			(0,004)
R^2	0,336	0,382	0,427
Adjusted R^2	0,332	0,377	0,421
Observations	6.041	6.041	3.955
Elasticities			
R&D/Assets		0,120***	0,270***
		(0,006)	(0,011)
Publications/R&D			0,036***
			(0,005)

All equations include full sets of year, country and industry dummies. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively.

4.2. Patent value indicators separately

Model 3 adds the patent value indicators to the equation. This model is run five times, each time in which a different patent value indicator is used. These added value indicators do not provide a significant increase in the ability to explain the variance in Tobin's Q. R-squared decreases slightly in comparison with model 2. The R&D/Assets coefficient increases in the models which include claims, backward citations and family members. It decreases in the models which include forward citations and oppositions. In all the models R&D/Assets stays significant and the coefficients increase a lot after winsorizing. The elasticities have the same values as in model 2 and stay significant. The coefficients and the elasticities for Publications/R&D remain as small as in model 2. They also remain significant.
The elasticities for R&D/Assets and Publications/R&D in all five models are positive and significant, and show more or less the same values. Winsorizing has an even bigger effect on Publications/R&D as in model 2, for both the coefficients and elasticities.

The coefficients for all value indicators are about the same size and significant, except for oppositions which is larger but insignificant. The elasticity of claims, however, is significantly larger than the elasticity of the other indicators. This increases after winsorizing. Forward citations have overall a weaker effect on the model. The elasticity for forward citations is also positive, but smaller and less significant. To control better for the time sensitivity of forward citations, the regression is performed again, including only the years 2011-2014. This does not gain different results. The models which include backward citations and family members show similar results, which are not as good as claims, but better than forward citations. Oppositions is the only patent value indicator whose coefficient and elasticity are not significant. The value of the coefficient however is positive and very large in comparison with the other models. After winsorizing the coefficient is estimated to be 0,95. The elasticity for oppositions is very low and insignificant.

Table 3: Results from the NLLS Regression for model 3

Dependent variable: Ln (Tobin's Q)	**3.1. Claims**	**3.2. Fwd. Cit.**	**3.3. Bwd. Cit.**	**3.4. Fam.**	**3.5. Oppositions**
Constant	-0,516**	-0,173	-0,203	-0,225	-0,155
	(0,178)	(0,162)	(0,161)	(0,157)	(0,161)
Age	-0,069***	-0,075***	-0,076***	-0,077***	-0,076***
	(0,022)	(0,023)	(0,022)	(0,022)	(0,023)
Employees	-0,026***	-0,028***	-0,027***	-0,028***	-0,028***
	(0,008)	(0,008)	(0,008)	(0,008)	(0,008)
R&D/Assets	7,561***	6,071***	6,585***	6,285***	5,978***
	(0,845)	(0,564)	(0,634)	(0,606)	(0,552)
Publications/R&D	0,002**	0,002*	0,002*	0,002*	0,001*
	(0,001)	(0,001)	(0,001)	(0,001)	(0,001)
Claims	0,018***				
	(0,005)				
Forward Citations		0,025**			
		(0,012)			
Backward citations			0,022***		
			(0,005)		
Family members				0,010***	
				(0,002)	
Oppositions					0,076
					(0,366)
R^2	0,405	0,401	0,406	0,407	0,400
Adjusted R^2	0,397	0,393	0,399	0,400	0,393
Observations	3.075	3.075	3.075	3.075	3.075
Elasticities					
R&D/Assets	0,245***	0.248***	0,248***	0,240***	0,250***
	(0,013)	(0,013)	(0,013)	(0,013)	(0,013)
Publications/R&D	0,005**	0,005**	0,006**	0,005**	0,005**
	(0,002)	(0,003)	(0,003)	(0,002)	(0,002)
Claims	0,166***				
	(0,037)				
Forward Citations		0,017**			
		(0,008)			
Backward citations			0,074***		
			(0,014)		
Family members				0,078***	
				(0,014)	
Oppositions					0,001
					(0,002)

All equations include full sets of year, country and industry dummies. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively.

Table 4: Results from the NLLS Regression for model 3 with all variables winsorized at the 1 percent and 99 percent percentiles

Dependent variable: Ln (Tobin's Q)	**3.1. Claims**	**3.2. Fwd. Cit.**	**3.3. Bwd. Cit.**	**3.4. Fam.**	**3.5. Oppositions**
Constant	-0,779***	-0,393**	-0,441***	-0,478***	-0,379**
	(0,184)	(0,162)	(0,083)	(0,157)	(0,161)
Age	-0,062***	-0,068***	-0,067***	-0,069***	-0,068***
	(0,022)	(0,022)	(0,022)	(0,002)	(0,022)
Employees	-0,012	-0,013	-0,012	-0,013*	-0,012
	(0,008)	(0,008)	(0,008)	(0,008)	(0,008)
R&D/Assets	10,557***	8,266***	9,135***	8,810***	8,191***
	(1,260)	(0,753)	(0,883)	(0,847)	(0,742)
Publications/R&D	0,034***	0,026***	0,029***	0,029***	0,026***
	(0,007)	(0,005)	(0,006)	(0,006)	0,005)
Claims	0,024***				
	(0,007)				
Forward Citations		0,034**			
		(0,016)			
Backward citations			0,032***		
			(0,007)		
Family members				0,015***	
				(0,003)	
Oppositions					0,954
					(0,866)
R^2	0,412	0,408	0,414	0,416	0,408
Adjusted R^2	0,404	0,400	0,406	0,408	0,400
Observations	3.016	3.016	3.016	3.016	3.016
Elasticities					
R&D/Assets	0,272***	0,280***	0,277***	0,270***	0,282***
	(0,014)	(0,013)	(0,013)	(0,013)	(0,013)
Publications/R&D	0,044***	0,046***	0,045***	0,045***	0,047***
	(0,007)	(0,007)	(0,006)	(0,007)	(0,007)
Claims	0,183***				
	(0,040)				
Forward Citations		0,020**			
		(0,009)			
Backward citations			0,090***		
			(0,016)		
Family members				0,095***	
				(0,014)	
Oppositions					(0,004)
					(0,004)

All equations include full sets of year, country and industry dummies. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively.

4.2.1. Small and large firms

The data sample is divided in a group of small firms and a group of large firms. The first group consist of firms which employ an equal or smaller amount than the median value of 1459 employees. The second group of firms has 1459 employees or more employed. Based on the reviewed literature on the effects of firm size, it is expected that the knowledge assets have a larger impact on the group of big firms in comparison with the small firms. This expectation is confirmed by the results. The group of small firms shows a substantial smaller impact from knowledge assets on Tobin's Q than in the base regression for model 3. The coefficients for R&D/Assets are twice as small. The elasticity is also smaller although the difference is not as big as for the coefficients. Publications/R&D almost has no impact, with very low insignificant values for both the coefficients and the elasticities. The coefficients and elasticities for the value indicators do not change substantially. One notable change is that the coefficient and elasticity for oppositions are negative. The coefficient shows a very large and significant negative value. The group of large firms show a larger impact from knowledge assets on Tobin's Q. The coefficients for R&D/Assets are almost four times as high as for the small firms. The elasticities are also larger, but the difference is less big. The impact of Publications/R&D is not notably different from the impact in the base regression of model 3. The same can be said for the coefficients and elasticities of the value indicators. One very interesting difference is that oppositions shows a large positive and significant coefficient. The elasticity is also positive and significant.

These results are in line with expectations based on the literature. R&D and knowledge assets have indeed a bigger impact on the market value of large firms. One thing that is very noteworthy is the changing sign of the oppositions variable between the two groups. This indicates that oppositions have a negative impact on firm value for small firms, but a positive impact on firm value for big firms.

Table 5: Results from the NLLS Regression for model 3, subsample small (employees ≤ 1459) firms

Dependent variable: Ln (Tobin's Q)	**3.1. Claims**	**3.2. Fwd. Cit.**	**3.3. Bwd. Cit.**	**3.4. Fam.**	**3.5. Oppositions**
Constant	-0,117	0,201	0,157	0,089	0,215
	(0,451)	(0,439)	(0,430)	(0,438)	(0,440)
Age	-0,251***	-0,264***	-0,270***	-0,240***	-0,270***
	(0,055)	(0,055)	(0,055)	(0,054)	(0,055)
Employees	-0,058**	-0,067***	-0,059**	-0,055**	-0,066***
	(0,023)	(0,023)	(0,023)	(0,023)	(0,023)
R&D/Assets	3,352***	2,823***	3,033***	2,951***	2,713***
	(0,585)	(0,444)	(0,489)	(0,482)	(0,425)
Publications/R&D	0,000	0,000	0,013**	0,000	0,000
	(0,000)	(0,000)	(0,006)	(0,000)	(0,000)
Claims	0,012**				
	(0,005)				
Forward Citations		0,028			
		(0,021)			
Backward citations			0,013**		
			(0,006)		
Family members				0,011***	
				(0,003)	
Oppositions					-0,541*
					(0,295)
R^2	0,426	0,423	0,426	0,430	0,424
Adjusted R^2	0,408	0,405	0,408	0,413	0,406
Observations	1.196	1.196	1.196	1.196	1.196
Elasticities					
R&D/Assets	0,236***	0,236***	0,240***	0,224***	0,234***
	(0,022)	(0,022)	(0,022)	(0,023)	(0,022)
Publications/R&D	0,002	0,001	0,001	0,001	0,001
	(0,002)	(0,002)	(0,567)	(0,002)	(0,002)
Claims	0,124***				
	(0,045)				
Forward Citations		0,019			
		(0,013)			
Backward citations			0,049***		
			(0,018)		
Family members				0,088***	
				(0,020)	
Oppositions					-0,005
					(0,004)

All equations include full sets of year, country and industry dummies. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively.

Table 6: Results from the NLLS Regression for model 3, subsample big firms (employees ≥ 1459)

Dependent variable: Ln (Tobin's Q)	3.1. Claims	3.2. Fwd. Cit.	3.3. Bwd. Cit.	3.4. Fam.	3.5. Oppositions
Constant	-0,647***	-0,392**	-0,423**	-0,429**	-0,385*
	(0,211)	(0,088)	(0,198)	(0,194)	(0,197)
Age	-0,008	-0,010	-0,010	-0,013	-0,010
	(0,026)	(0,026)	(0,025)	(0,026)	(0,197)
Employees	-0,043***	-0,045***	-0,045***	-0,046***	-0,044***
	(0,015)	(0,014)	(0,015)	(0,015)	(0,015)
R&D/Assets	12,772***	10,720***	11,552***	11,513***	10,779***
	(1,713)	(1,130)	(1,296)	(1,266)	(1,135)
Publications/R&D	0,004	0,003	0,003*	0,003*	0,003
	(0,002)	(0,002)	(0,002)	(0,002)	(0,002)
Claims	0,015**				
	(0,007)				
Forward Citations		0,015			
		(0,016)			
Backward citations			0,027***		
			(0,008)		
Family members				0,008***	
				(0,003)	
Oppositions					1,017*
					(0,558)
R^2	0,353	0,351	0,358	0,355	0,352
Adjusted R^2	0,340	0,338	0,346	0,343	0,339
Observations	1.880	1.880	1.880	1.880	1.880
Elasticities					
R&D/Assets	0,259***	0,261***	0,254***	0,262***	0,263***
	(0,017)	(0,016)	(0,016)	(0,016)	(0,016)
Publications/R&D	0,005*	0,005*	0,004**	0,005**	0,005*
	(0,002)	(0,003)	(0,002)	(0,003)	(0,003)
Claims	0,135**				
	(0,055)				
Forward Citations		0,010			
		(0,011)			
Backward citations			0,086***		
			(0,020)		
Family members				0,059***	
				(0,018)	
Oppositions					0,006**
					(0,003)

All equations include full sets of year, country and industry dummies. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively.

4.2.2. West-Europe and Scandinavia

To take a closer look at the effects, the data is divided in the subsamples. West-Europe (Germany, Netherlands, France, Belgium, Luxemburg, Switzerland) and Scandinavia (Denmark, Finland, Norway, Sweden). These are the largest distinct geographical subgroups in the data sample. Because firms in these countries are more innovation oriented than firms in East and South-Europe, it is expected that the coefficient and elasticity values of the knowledge assets go up in comparison with the full sample. For West-Europe, the coefficient for R&D/Assets increases further, most notably in the model which includes claims as patent value indicator. The coefficient for claims itself also increases and stays significant. The same is true for the elasticity of the claim's coefficient. The coefficient and elasticity for forward citations also increases, although less than for claims. The coefficient and elasticity for family members decrease slightly. In all regressions for West-Europe the publications/R&D coefficient and elasticity are small and insignificant.

A different effect is noticeable in the Scandinavia subsample. The coefficient for R&D/Assets increases in the claims model as well, but not nearly as much as for West-Europe. The coefficient and elasticity for claims are smaller and insignificant. In contrast, the coefficient and elasticity of publications/R&D are higher and significant. The same effect can be noticed from the models with forward citations and family members. The coefficients and elasticities for the patent value indicators are smaller and insignificant than for West-European countries. The coefficients and elasticities for publications/R&D are however larger and significant. The model with backward citations as value indicator is the only model which gives significant coefficients and elasticities for both regions, with similar values. One interesting result is that oppositions has a significant high negative coefficient and elasticity. The model with all patent value indicators does not gain meaningful results for both regions. In addition, the constant value becomes really big. This is probably because Scandinavia has some outliers in sector A, which functions as the base category for the sector dummy variables.

Table 7: Results from the NLLS Regression for model 3, subsample West-Europe

Dependent variable: Ln (Tobin's Q)	**3.1. Claims**	**3.2. Fwd. Cit.**	**3.3. Bwd. Cit.**	**3.4. Fam.**	**3.5. Oppositions**
Constant	-1,081***	-0,225	-0,286	-0,219	-0,176
	(0,258)	(0,176)	(0,182)	(0,170)	(0,173)
Age	-0,041	-0,064**	-0,068**	-0,070**	-0,065**
	(0,030)	(0,030)	(0,030)	(0,030)	(0,030)
Employees	-0,023**	-0,022**	-0,017	-0,021**	-0,020*
	(0,010)	(0,011)	(0,011)	(0,011)	(0,011)
R&D/Assets	15,670***	8,713***	10,022***	8,796***	8,535***
	(3,144)	(0,951)	(1,206)	(0,986)	(0,917)
Publications/R&D	0,003	0,002	0,004	0,002	0,002
	(0,004)	(0,002)	(0,004)	(0,002)	(0,002)
Claims	0,072***				
	(0,023)				
Forward Citations		0,051**			
		(0,021)			
Backward citations			0,036***		
			(0,011)		
Family members				0,009***	
				(0,003)	
Oppositions					0,183
					(0,378)
R^2	0,324	0,310	0,314	0,314	0,307
Adjusted R^2	0,315	0,300	0,304	0,304	0,298
Observations	1.612	1.612	1.612	1.612	1.612
Elasticities					
R&D/Assets	0,280***	0,295***	0,299***	0,287***	0,297***
	(0,018)	(0,017)	(0,017)	(0,018)	(0,017)
Publications/R&D	0,004	0,005	0,008	0,005	0,005
	(0,004)	(0,004)	(0,007)	(0,005)	(0,004)
Claims	0,360***				
	(0,057)				
Forward Citations		0,030***			
		(0,011)			
Backward citations			0,097***		
			(0,023)		
Family members				0,066	
				(0,018)	
Oppositions					0,001
					(0,002)

All equations include full sets of year and industry dummies. Country dummies are not included. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively.

Table 8: Results from the NLLS Regression for model 3, subsample Scandinavia

Dependent variable: Ln (Tobin's Q)	**3.1. Claims**	**3.2. Fwd. Cit.**	**3.3. Bwd. Cit.**	**3.4. Fam.**	**3.5. Oppositions**
Constant	14,795***	0,766***	-37,763***	-35,560***	-116,606***
	(0,273)	(0,244)	(0,335	(0,241)	(0,232)
Age	-0,157***	-0,160***	-0,146***	-0,162***	-0,169***
	(0,043)	(0,044)	(0,044)	(0,044)	(0,043)
Employees	0,006	0,009	-0,003	0,011	0,008
	(0,019)	(0,019)	(0,018)	(0,019)	(0,657)
R&D/Assets	10,165***	9,177***	9,294***	9,279***	8,760***
	(2,284)	(1,746)	(1,930)	(1,798)	(1,647)
Publications/R&D	0,023	0,024	0,019	0,024	0,023
	(0,022)	(0,019)	(0,019)	(0,020)	(0,019)
Claims	0,013				
	(0,009)				
Forward Citations		0,025			
		(0,023)			
Backward citations			0,037**		
			(0,016)		
Family members				0,002	
				(0,004)	
Oppositions					-0,873***
					(0,052)
R^2	0,397	0,395	0,407	0,395	
Adjusted R^2	0,379	0,377	0,389	0,376	
Observations	671	671	671	671	
Elasticities					
R&D/Assets	0,310***	0,320***	0,299***	0,322***	0,319***
	(0,028)	(0,027)	(0,026)	(0,027)	(0,027)
Publications/R&D	0,035	0,042	0,031	0,042	0,042
	(0,026)	(0,026)	(0,025)	(0,026)	(0,026)
Claims	0,115**				
	(0,063)				
Forward Citations		0,016			
		(0,014)			
Backward citations			0,110***		
			(0,035)		
Family members				0,016	
				(0,029)	
Oppositions					-0,010***
					(0,002)

All equations include full sets of year and industry dummies. Country dummies are not included. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively.

4.2.3. Subsample excluding Germany

In Germany, the impact of knowledge assets on firm market value has already been proven in previous research. Germany is also one of the countries in the data sample with the highest number of observations. To control for the possibility that the German firms influence the results too much, model 3 is regressed excluding them. The remaining subsample shows smaller values for the coefficients and elasticities of the R&D/Assets variable. However, they remain significant. The values of the coefficients and elasticities for publications/R&D are also smaller and are not significant. The values of the coefficient and elasticity for claims, backward citations and family members remain positive and significant. The values of the coefficient and elasticity of forward citations and oppositions are no longer significant. These results seem to indicate that German firms indeed profit substantially from knowledge assets and this has an upward effect on the results from the whole sample. However, the results for R&D/Assets and the majority of the value indicators are still significant enough to conclude that the influence of German firms is not too strong.

Table 9: Results from the NLLS Regression for model 3, subsample excluding German firms

Dependent variable: Ln (Tobin's Q)	**3.1. Claims**	**3.2. Fwd. Cit.**	**3.3. Bwd. Cit.**	**3.4. Fam.**	**3.5. Oppositions**
Constant	-0,406**	-0,163	-0,190	-0,259	-0,153
	(0,187)	(0,178)	(0,180)	(0,171)	(0,177)
Age	-0,108***	-0,112***	-0,110***	-0,110***	-0,113***
	(0,026)	(0,026)	(0,026)	(0,026)	(0,026)
Employees	-0,030***	-0,032***	-0,031***	-0,031***	-0,032***
	(0,009)	(0,009)	(0,008)	(0,009)	(0,009)
R&D/Assets	5,807***	5,032***	5,438***	5,320***	4,990***
	(0,715)	(0,551)	(0,613)	(0,618)	(0,545)
Publications/R&D	0,001	0,001	0,001	0,001	0,001
	(0,001)	(0,001)	(0,001)	(0,001)	(0,001)
Claims	0,010**				
	(0,004)				
Forward Citations		0,009			
		(0,010)			
Backward citations			0,017***		
			(0,005)		
Family members				0,015***	
				(0,003)	
Oppositions					-0,140
					(0,572)
R^2	0,423	0,421	0,425	0,432	0,420
Adjusted R^2	0,413	0,411	0,416	0,423	0,411
Observations	2.447	2.447	2.447	2.447	2.447
Elasticities					
R&D/Assets	0,225***	0,227***	0,226***	0,212***	0,227***
	(0,015)	(0,015)	(0,014)	(0,015)	(0,015)
Publications/R&D	0,004	0,004	0,004	0,003	0,004
	(0,002)	(0,002)	(0,002)	(0,002)	(0,002)
Claims	0,110***				
	(0,039)				
Forward Citations		0,006			
		(0,007)			
Backward citations			0,061***		
			(0,013)		
Family members				0,107***	
				(0,015)	
Oppositions					-0,001
					(0,003)

All equations include full sets of year, country and industry dummies. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively.

4.2.4. Testing for endogeneity.

A firm's decision to spend money on R&D or on patenting may be influenced by a lot of factors, including its current and future performance. The firm performance is captured by Tobin's Q. It is therefore possible that the dependent variable in this research influences the independent variables, instead of the other way. In that case, the firm's R&D and patent publication variables are endogenous and the estimation results could be biased (Chung, et al., 2014). To control for this, the regressions are run with a lagged version of Tobin's Q. The values for Tobin's Q in year t are replaced by the values for Tobin's Q in year t+1. Table 7 shows the results for the lagged regression. The coefficient and elasticities for R&D/Assets stay positive and significant, although they are lower than in the non-lagged regression. The coefficients and elasticity for publications/R&D also decrease and are not significant. The values of the coefficients and elasticities for the patent value indicators stay significant and even increase in some cases. The one exception is oppositions, which stays insignificant and decreases even further.

It appears that the knowledge assets significantly influence next year's Tobin's Q. This indicates that there is no endogeneity, because in that case Tobin's Q in year T influences the knowledge assets in year T and not the other way around. In that case they would not have a significant impact on the Tobin's Q of next year. Because they also have an impact on Tobin's Q in the next year, it can be assumed the impact of knowledge stocks on Tobin's Q in the same year is not a result of endogeneity.

4.2.5. Ordinary Least Squares

As a last robustness check, model 3 is estimated with an OLS regression. The included variables are all log transformed. Although the coefficients are less high, they stay significant and show the same sign as the NLLS regression. There are two notable differences with NLLS. The first is that the coefficient for forward citations is negative and insignificant. The second is that the coefficient for oppositions is positive and significant. This confirms two notable results from this study. The first being that forward oppositions have not proven themselves as the value indicator best suited to estimate patent quality, which was expected beforehand. The second being that oppositions could be a good value indicator, but because they are so uncommon, a larger dataset is necessary to study their impact.

Table 10: Results from the NLLS regression for model 3 with lagged Tobin's Q

Dependent variable: Ln (Tobin's Q) L1	3.1. Claims	3.2. Fwd. Cit.	3.3. Bwd. Cit.	3.4. Fam.	3.5. Oppositions
Constant	-0,424**	0,025	0,003	-0,023	0,037
	(0,101)	(0,178)	(0,177)	(0,099)	(0,177)
Age	-0,082***	-0,090***	-0,090***	-0,094***	-0,091***
	(0,024)	(0,024)	(0,024)	(0,024)	(0,025)
Employees	-0,031***	-0,034***	-0,034***	-0,035***	-0,033***
	(0,008)	(0,008)	(0,008)	(0,008)	(0,008)
R&D/Assets	6,311***	4,774***	5,137***	4,789***	4,713***
	(0,853)	(0,542)	(0,599)	(0,579)	(0,530)
Publications/R&D	0,001	0,001	0,001	0,001	0,001
	(0,001)	(0,001)	(0,001)	(0,001)	(0,001)
Claims	0,025***				
	(0,007)				
Forward Citations		0,021*			
		(0,012)			
Backward citations			0,019***		
			(0,005)		
Family members				0,012***	
				(0,002)	
Oppositions					0,042
					(0,298)
R^2	0,380	0,374	0,379	0,383	0,374
Adjusted R^2	0,371	0,365	0,370	0,374	0,364
Observations	2.664	2.664	2.664	2.664	2.664
Elasticities					
R&D/Assets	0,213***	0,219***	0,218***	0,204***	0,221***
	(0,015)	(0,015)	(0,015)	(0,015)	(0,015)
Publications/R&D	0,004	0,004	0,004	0,003	0,004
	(0,003)	(0,003)	(0,003)	(0,003)	(0,003)
Claims	0,217***				
	(0,042)				
Forward Citations		0,018*			
		(0,009)			
Backward citations			0,070***		
			(0,016)		
Family members				0,093***	
				(0,015)	
Oppositions					0,000
					(0,002)

All equations include full sets of year, country and industry dummies. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively.

Table 11: Results from the OLS regression for model 3

Dependent variable: Ln (Tobin's Q)	3.1. Claims	3.2. Fwd. Cit.	3.3. Bwd. Cit.	3.4. Fam.	3.5. Oppositions
Constant	0,590**	1,276***	1,080***	0,776***	1,957***
	(0,202)	(0,194)	(0,172)	(0,151)	(0,327)
Ln Age	-0,094***	-0,145***	-0,122***	-0,098***	-0,180***
	(0,022)	(0,025)	(0,023)	(0,022)	(0,046)
Ln Employees	-0,024***	-0,026**	-0,024***	-0,023***	0,004
	(0,008)	(0,010)	(0,009)	(0,008)	(0,031)
Ln (R&D/Assets)	0,234***	0,232***	0,238***	0,237***	0,251***
	(0,012)	(0,014)	(0,013)	(0,013)	(0,034)
Ln (Publications/R&D)	0,060****	0,075***	0,063***	0,063***	0,128***
	(0,009)	(0,012)	(0,010)	(0,009)	(0,032)
Ln Claims	0,141***				
	(0,038)				
Ln Forward Citations		-0,016			
		(0,015)			
Ln Backward citations			0,042**		
			(0,019)		
Ln Family members				0,123***	
				(0,016)	
Ln Oppositions					0,106***
					(0,035)
R^2	0,416	0,415	0,414	0,423	0,421
Adjusted R^2					
Observations	3.075	2.280	2.897	2.995	586

All equations include full sets of year, country and industry dummies. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively.

4.3. Patent value indicators combined

The last model which is regressed contains all patent value indicators. The explanatory power of the model is somewhat enhanced, with R-squared increased to 0,416 and even 0,429 after winsorizing. The coefficient and elasticity for R&D/Assets go up in comparison with the base model 3. The coefficient and elasticity for publications/R&D are significant, and again increase a lot after winsorizing. All coefficients and elasticities for the value indicators are positive, except for oppositions. All coefficients and elasticities for the value indicators are also significant, except for oppositions and forward citations. The coefficient and elasticity for forward citations are very small and insignificant. After winsorizing all coefficients and elasticities increase, except forward citations, which remains the same. The coefficient for oppositions turns positive and is very large but remains insignificant. These results do not change significantly after winsorizing. Overall, the combined model does not gain different insights than the models that use separate value indicators.

Table 12: Results from the NLLS Regression for model 4, combining all value indicators

Dependent variable: Ln (Tobin's Q)	**4. Normal variables**	**4. Winsorized variables**
Constant	-0.542***	-0,815***
	(0,178)	(0,189)
Age	-0,071***	-0,067***
	(0,022)	(0,022)
Employees	-0,027***	-0,013*
	(0,008)	(0,008)
R&D/Assets	8,300***	12,433***
	(1,016)	(1,691)
Publications/R&D	0,002*	0,038***
	(0,001)	(0,008)
Claims	0,013**	0,014*
	(0,006)	(0,007)
Forward Citations	0,005	0,005
	(0,015	(0,024)
Backward citations	0,029***	0,045***
	(0,007)	(0,011)
Family members	0,013***	0,020***
	(0,003)	(0,004)
Oppositions	-0,032	0,448
	(0,521	(1,289)
R^2	0,416	0,429
Adjusted R^2	0,407	0,421
Observations	3.075	3.075
Elasticities		
R&D/Assets	0,234***	0,273***
	(0,013)	(0,014)
Publications/R&D	0,005**	0,042***
	(0,002)	(0,006)
Claims	0,106***	0,091**
	(0,036)	(0,040)
Forward Citations	0,002	0,002
	(0,002)	(0,009)
Backward citations	0,073***	0,089***
	(0,015)	(0,017)
Family members	0,072***	0,088***
	(0,014)	(0,015)
Oppositions	0,000	0,001
	(0,002)	(0,003)

All equations include full sets of year, country and industry dummies. Robust standard errors in parenthesis. *, **, *** Denote significance at the 10%, 5% and 1% levels, respectively.

5. Discussion and conclusion

The goal of this paper was to estimate which impact knowledge assets have on the market value of European firms. More specifically, it measured the impact of the ratios R&D/Assets, publications/R&D and various patent portfolio characteristics on Tobin's Q. This type of research had been conducted before, however not with the specific value indicators combined in a nonlinear market value regression. This research made use of a very recent data sample for European firms, which are well-studied in this strand of literature. Based on the literature, a positive impact was expected for R&D, patent publication count, average number of claims, forward citations, backward citations, and family members. It was expected that these effects are bigger for larger firms. A negative impact was expected from oppositions.

The results clearly show that R&D/Assets has a significant positive effect on the market value of European firms. This hypothesis cannot be rejected for all the estimated models in this paper. It is also clear that the impact of R&D/Assets increases when a model takes into account the patent publication count. The impact of R&D/Assets and the explanatory power of the model increases even further after adding the patent value indicators. The values of the elasticities for R&D/Assets for all estimated models fluctuate between 0,2 and 0,3. This means that, on average, Tobin's Q goes up with 0,2 - 0,3 when the R&D/Assets ratio increases with 1%. These values are a bit higher than the majority of results in similar research: 0,200 (Hall, et al., 2007); 0,063 (Rahko, 2014); 0,12 (Deng, 2005); 0,02 (Simeth & Cincera, 2016); 0,700 (Hall, et al., 2005). The difference is not substantially high and can be explained by the fact that this paper focuses on large publicly listed companies which should have a size effect on the results. Most of the previous literature focused on sectors or countries and often included private firms, which are generally smaller sized.

Publications/R&D also shows a positive significant effect on firm value. The results however are less convincing than for R&D/Assets. The coefficients for publications/R&D are lower than for R&D/Assets in every model. This of course could be attributed to the fact that publications are measured with different units of account. The elasticities for publications are, however, also very low. Furthermore, the coefficients and elasticities for publications are not significant in the subsamples for West-Europe and Scandinavia, and also when using the lagged Tobin's Q. The results for publications/R&D increase a lot after winsorizing the data. In general, the elasticities for Publications/R&D fluctuate between 0,005 and 0,035. Meaning that, on average, Tobin's Q goes up with 0,005-0,035 if Publications/R&D goes up with 1%. This result is in line with the average results in previous research: 0,030 (Hall, et al., 2007); 0,035 (Rahko, 2014); 0,070 (Deng, 2005); 0,020 (Simeth & Cincera, 2016); 0,018 (Hall, et al., 2005). Claims, backward citations, and family members all show a consistent positive and significant effect on the market value of European firms. However, they do not add any explanatory power to the model. In addition, their inclusion does not seem to affect the coefficient or elasticity for publications. The model which includes claims as value indicator shows the best results. According to the elasticity values, Tobin's Q goes up with 0,170 when the average number of claims goes up with 1%, which is a very big impact. Oppositions shows a changing sign between samples, sometimes accompanied by a very large or very small coefficient. This means oppositions could be a good value indicator, but because they are so uncommon, a larger dataset is necessary to study their impact. The elasticity for forward citations fluctuates around 0,020, which is comparable to the average values in previous research which focused on forward citations: 0,003 (Deng, 2005); 0,045 (Simeth & Cincera, 2016); 0,90 (Rahko, 2014) and 0,03 (Hall, et al., 2005). However, the values of the coefficient and elasticity of forward citations were not significant in a few robustness checks, including the OLS regression, the subsample with exclusion of German firms, and both the small firm and big firm samples. It can therefore be concluded that forward citations in this research had a smaller impact than what could be expected, based on the literature. One explanation for this is that the data is too recent, and patent publications simply need more time to receive forward citations. While it was attempted to control for the time-sensitivity in this research, it could not be done to the same extent as previous research, due to the limited availability of data. Claims, backward citations, and family members have not yet been used (enough times) in research which combine a market value approach with NLLS. Therefore, the values of their coefficients and elasticities cannot be directly compared against results in other papers. Their signs and significance, however, are the same as in previous research which used different models or estimations, and which were discussed in the literature section. The hypotheses regarding these value indicators cannot be rejected. The same goes for the hypothesis for the size effect, which was clearly evident in the results where big and small firms were separated.

For further research it is recommended to look in more detail to patent oppositions, since they show signs of great impact on firm market value, but this specific dataset is too small to obtain significant results. Since the Orbis IP database also contains info on the price of patents which were part of a transaction, this could be used in further research to check if opposed patents indeed are perceived as more valuable. More specific, further research could evaluate differences in the nationality of the patent, the nationality of the applicant (the firm) and the impact of the size of the applicant (firm). Furthermore, Orbis IP provides information on the financial dependence of firms, which also could influence the impact of knowledge assets, as explained in the literature section.

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Appendix A: Country codes

Country	Code
Austria	AT
Belgium	BE
Denmark	DK
Finland	FI
France	FR
Germany	DE
Greece	GR
Iceland	IS
Ireland	IE
Italy	IT
Luxembourg	LU
Netherlands	NL
Norway	NO
Poland	PO
Portugal	PT
Spain	ES
Sweden	SE
Switzerland	CH
UK	GB

Appendix B: Sector codes

Sector	Code
Agriculture, Forestry and Fishing	A
Mining and Quarrying	B
Manufacturing	C
Electricity, Gas, Steam and Air Conditioning Supply	D
Water Supply; Sewerage, Waste Management and Remediation Activities	E
Construction	F
Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	G
Transportation and Storage	H
Accommodation and Food Service Activities	I
Information and Communication	J
Financial and Insurance Activities	K
Real Estate Activities	L
Professional, Scientific and Technical Activities	M
Administrative and Support Service Activities	N
Public Administration and Defence; Compulsory Social Security	O
Education	P
Human Health and Social Work Activities	Q
Arts, Entertainment and Recreation	R
Other Service Activities	S
Activities of Households as Employers	T
Activities of Extraterritorial Organisations and Bodies	U

Appendix C: Descriptive statistics, unaltered variables

Variables	Obs	mean	Std. dev.	Min.	Median	Max.	Skew.
Tobin's Q	6243	2,214	4,427	0,011	1,2	176	17,655
Firm age	6987	56,5	48,9	6	34	355	1,699
Employees	6703	16445	48199	0,5	1459	642300	6,371
Sales*	6987	4747	16259	0	279	291218	8,327
Total assets*	6987	7022	24416	0	308	422193	7,181
Physical assets*	6987	5278	19737	0	254	358773	8,320
Sales / employees	6703	0,393	5,570	0	0,198	281	46,572
R&D / sales	6745	2,684	89	0	0,009	6991	72,066
R&D / physical assets	6984	0,064	0,181	0	0,009	5,343	10,233
Publications / R&D	4319	4,511	45	0	0,484	2000	29,058
R&D*	6987	135	645	0	1,797	10768	8,499
Publications	4869	121	613	1	8	9521	10,101
Average claims	4869	16,5	9,790	1	15	160	4,255
Average forward citations	4869	1,09	2,883	0	0,330	113	15,914
Average backward citations	4869	5,438	10,298	0	3,857	298	13,497
Average family members	4869	12	19,566	0	7	565	10,660
Average oppositions	4869	0,008	0,050	0	0	1	0,050

**in millions of euros.*

Appendix D: Descriptive statistics log transformed variables

Log transformed variables	Obs	Mean	Std. dev.	Min.	Median	Max.	Skew.
Tobin's Q	6243	0,19	1,09	-4,48	0,19	5,17	-0,03
Firm age	6987	3,71	0,79	1,79	3,53	5,87	0,31
Employees	6703	7,09	2,76	-0,07	7,29	13,4	-0,22
Sales	6745	5,43	3,25	-7,52	5,78	12,6	-0,64
Total assets	6984	5,78	2,85	-4,27	5,73	13	-0,03
Physical assets	6984	5,51	2,88	-4,52	5,54	12,8	-0,15
Sales / employees	6505	-1,7	1,06	-10,2	-1,6	5,64	-1,79
R&D / sales	4227	-3,29	2,13	-11,1	-3,42	8,85	0,7
R&D / physical assets	4318	-3,4	1,71	-10,7	-3,22	1,68	-0,66
Publications / R&D	3333	-0,22	1,9	-8,34	-0,08	7,6	-0,36
R&D	4319	2,71	2,43	-6,91	2,7	9,28	0,04
Publications	4869	2,36	1,89	0	2,08	9,16	0,86
Average claims	4869	2,66	0,56	0	2,71	5,08	-1,22
Average forward citations	3274	-0,32	1,29	-5,65	-0,24	4,73	-0,17
Average backward citations	4455	1,4	0,80	-3	1,4	5,7	0,09
Average family members	4650	2	1,04	-2,3	2,01	6,34	-0,16
Average oppositions	676	-3,93	1,48	-8,94	-3,88	0	-0,13

Appendix E: median values by sector, unaltered variables

Variables	B	C	D	G	J	M	N	R
Tobin's Q	0,674	1,248	0,381	0,952	1,777	2,25	2,118	2,311
Firm age	34	40	26,5	28,5	29	26	28	42
Employees	6503	1454	11543	500	1146	536	1006	814,5
Sales*	2643	293,3	4506	76,68	198,4	72,72	55,28	277,5
R&D*	0,894	3,739	1,15	0	2,032	0,352	0	0
Publications	6	10	6,5	3	6	7	5	1
Average claims	15,01	15	13,69	13	15	16,08	17	14,67
Average forward citations	0,391	0,333	0,280	0	0,407	0,375	0,829	0
Average backward citations	3,589	4	3,613	3,063	4,23	3,258	4,2	1
Average family members	8,764	7,743	5,507	6	4	7	4,639	3,333
Average oppositions	0	0	0	0	0	0	0	0

**in millions of euros. The eight sectors with the most observations are included*

Appendix F: median values by country, unaltered variables

Variables	BE	CH	DE	DK	ES	FI	FR	GB	IT	NL	NO	PL	SE
Tobin' Q	1,42	1,66	0,963	1,19	0,583	1,12	1,15	2,2	0,68	1,15	1,26	0,685	2,3
Firm age	56	67	44	34	51	52	32,5	28	58	50	24	30	24
Employees	2017	4900	1902	1781	6881	3981	1135	663	2567	10044	400	796	57
Sales*	348	938	410	247	1722	1193	176	106	450	2606	101	71,9	8,63
R&D*	12,9	22	8,34	0,912	0	12,2	1,62	1,2	0	33,6	0	0	0
Publications	13	14	14	12	4	13,5	10	4	9	8	12	2	5
Average claims	15,4	14,6	13,9	17	14	15	13,8	18,5	13,4	16,7	17,5	6,45	16
Average forward citations	0,333	0,405	0,429	0,586	0,105	0,467	0,3	0,242	0,551	0,2	0,457	0	0,25
Average backward citations	4,28	4,43	4,61	5	2,4	4	3,28	3,4	4,6	3,39	3,83	1	3,81
Average family members	9,93	8,37	6	10,4	6,5	7	7,09	8,6	6,03	7	10	1,77	7,15
Average oppositions	0	0	0	0	0	0	0	0	0	0	0	0	0

**in millions of euros. The 13 countries with the most observations are included*

Appendix G: Pearson's correlation matrix

Variables	1	2	3	4	5	6	7	8	9	10	11
Tobin's Q (1)	1,000										
Firm age (2)	-0,161 ***	1,000									
Employees (3)	-0,076 ***	0,157 ***	1,000								
Sales (4)	-0,076 ***	0,151 ***	0,694 ***	1,000							
R&D (5)	-0,020	0,114 ***	0,508 ***	0,529 ***	1,000						
Publications (6)	-0,037 **	0,178 ***	0,365 ***	0,335 ***	0,527 ***	1,000					
Average claims (7)	0,126 ***	-0,134 ***	-0,077 ***	-0,060 ***	-0,030 **	-0,024 *	1,000				
Average forward citations (8)	-0,012	-0,047 ***	-0,016	-0,008	-0,002	0,011	0,057 ***	1,000			
Average backward citations (9)	0,038 **	-0,035 **	-0,032 **	-0,030 **	-0,009	0,002	0,129 ***	0,249 ***	1,000		
Average family members (10)	0,064 ***	-0,038 ***	-0,030 **	-0,015	0,016	-0,020	0,129 ***	-0,044 ***	-0,029 **	1,000	
Average oppositions (11)	-0,015	-0,005	0,000	-0,014	-0,018	-0,008	-0,028 *	-0,006	0,013	0,010	1,000

, **, * denote significance at the 10%, 5% and 1% levels, respectively.*