Innovation and Corporate Governance in the Firm - An Empirical Analysis with a Focus on Patents and Ownership Structure

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Contents

1 Acknowledgments

This thesis aims at contributing to the ongoing debate on the value of innovation for the firm. Ever since the seminal work of Schumpeter (1942), seeking new business opportunities on the firm-level has been identified by economists as a major source of overall welfare growth. Consequently, any way to understand and boost firm-level innovation will be beneficial for the economy in general. Policy makers should therefore provide innovation-friendly environments and eliminate harmful incentive schemes. Here I focus on Corporate Governance represented by ownership structure as a major driver of how manager's decisions to innovate or not are driven by aspects like the distribution of residual claims, external pressure and their individual skill set.

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Last I have to thank my parents and all my friends for constantly believing in my capabilities to successfully finish this thesis.

2 Introduction

2.1 The Innovation Value Chain

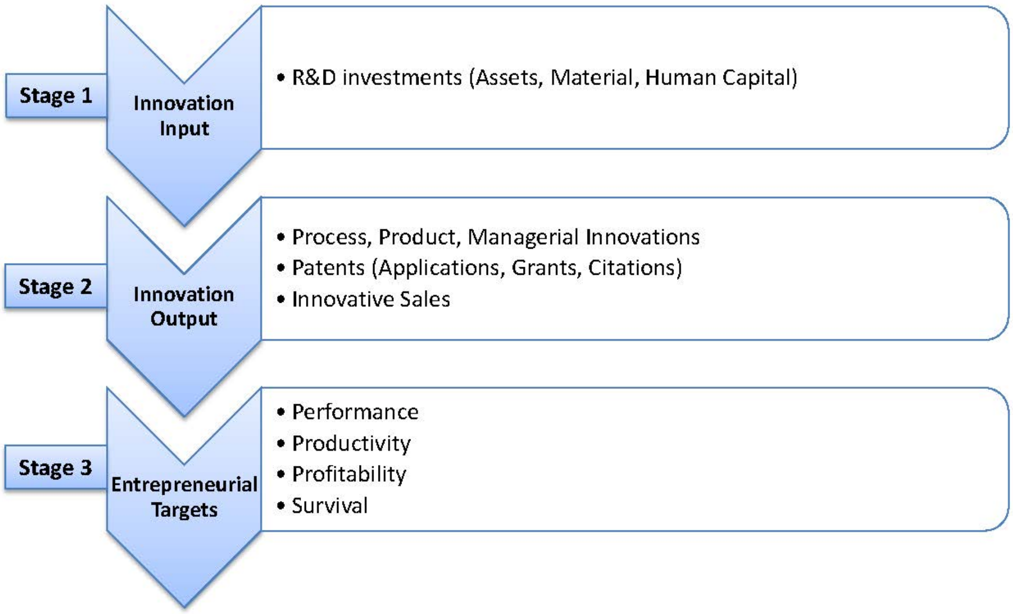
It is widely accepted that the level of technological progress within the firm shapes its productivity which in turn shapes performance, easily said to be a major entrepreneurial target (A. Jaffe & de Rassenfosse (2017); Hall & Sena (2017), Hall and Mohnen 2013; Griliches (1986)). Firms thus seek to enhance their knowledge stock to outperform competitors and strengthen their market position (Aghion et al. (2014); Klepper (1996); Ericson & Pakes (1995); Jovanovic (1982)). In the first place innovation requires a decision upon investments. As innovation usually competes with classical non-innovative investments like acquiring new machinery, more or higher quality material or human capital, innovation is from the very first idea up to notable shifts in performance driven by in-house decision processes. Economists have thus intensively sought to model the whole process of knowledge acquisition and transformation as a unified theoretical concept and furthermore conceived manifold techniques to empirically investigate it in order to identify structures common to most if not all companies (Crépon et al. (1998); Pakes & Griliches (1984)). Doing so has proven cumbersome in both theoretical frameworks and statistical methods, even though distinct progress has been made throughout the last few decades (Baum et al. (2017); Aw et al. (2011); Harhoff (1998); Olley & Pakes (1992)). The concept of technological process has even reached a more comprehensive level of including not only firms but customers, governmental authorities and especially regional patterns with endogenously determined channels, called innovation ecosystems, with a promising outlook (Oh et al. (2016); Autio & Thomas (2014)).

Figure 2.1 depicts a simple version of what I call the Innovation Value Chain (IVC), which is of major interest for this thesis[1]. The first stage is defined as finding firm-internal characteristics shaping the investment decision. There is merely consensus that R&D investments are the beginning of any knowledge-creating activity. Innovation can simplest be treated as any other investment – with the usual fragmentation into assets, material and human capital like in a Cobb-Douglas production function – but if so we miss crucial peculiarities, mainly risk and expected time until pay-off (Holmström (1989)). Standard investments are predictable for the firm and experience as well as deterministic production processes yield a certain output both in quantity and

[1] Here I will only shortly explain this process in order to motivate my upcoming analyses. I will offer a deeper discussion throughout this thesis at the point the stages are of particular interest. The general concept can mostly be attributed to the structural equation work of Crépon et al. (1998), who display a similar diagram. Here I drop external (non-innovative) factors for simplicity and to highlight the temporal structure of the process, even though each stage is surely affected by other internal and external forces.

quality. On the other hand innovation is defined as being new to the firm and at best new to the market. This offers a high variance output with substantial chances for success but also for failure. Firms should therefore consider carefully if they undergo innovation at all or stick to conventional production methods. The second peculiarity is the time lag between investment and innovation output which can but must not be severe (Artz et al. (2010), Ernst (2001); Hall et al. (1986)). The lag is nevertheless legally established via the patent system where reviews of applications usually take several years until a decision upon a grant is made by the patent office.

Figure 2.1: The Innovation Value Chain (IVC)



Here we are yet at the second stage of the IVC. The transition from investments to measurable and legally tangible (but in accounting manners intangible) innovative assets has been first described by Pakes & Griliches (1984). This process is worth a deeper look in order to motivate and legitimate our empirical investigation and is discussed more accurately in the next section. In a nutshell R&D investments largely determine a firm's knowledge stock (innovative output) but with significant stochastic disturbances. Furthermore empirical analyses often suffer from mismeasurement if only one specific aspect is observed. This is indeed true for patents, a measure of major interest in this thesis. This second stage of the IVC is often – contrary to the first stage – subdivided into deeper subsequent stages. This is actually what I will do to contribute to the debate of knowledge production and innovation management. Beside patents I here only mentioned the most important empirically tangible variables widely used in Industrial Organization (IO) literature. Data on the adoption of process, organizational or marketing innovations have been mainly gathered via surveys. The most influential is the Community Innovation Survey (CIS) for Europe, a survey usually conducted every two years with a repeating but also shifting topical questionnaire. There is an enormous body of literature making use of this very rich dataset for many different countries, such that only naming a few here would in any case prove inconclusive. The German contribution to this survey is the Mannheim Innovation Panel (MIP) conducted by the Leibniz Centre for European Economic Research (ZEW). Empirically Crépon et al. (1998) developed the first comprehensive model to estimate the channels of the IVC explicitly with CIS data. This model – often abbreviated the CDM-model – has been widely used and improved (e.g. by Aw et al. (2011)). A major caveat of this approach is its cross-sectional nature, an attribute having its base in the survey itself. Beside the fact that it is not conducted every year, participation is voluntary for firms such that it is hard to observe the same firm over multiple iterations. Due to the fact that the process from investment towards notable performance effects is lengthy by nature, dynamic approaches may offer substantial gains in statistical accuracy and visualizing temporal changes in firm behavior. Even this is taken into account by researchers who are still refining statistical techniques in order to estimate dynamic structural models (Baum et al. (2017); Peters, Roberts, & Vuong (2017); Peters, Roberts, Vuong, & Fryges (2017)). As the data I will use is of panel structure, I will make use of available lagged channels in order to first estimate dynamic decision processes within the firm and second to observe the lengthy process of generating tangible value out of R&D investments. Furthermore the sometimes tedious process of invention patenting can be analyzed carefully, a major improvement to earlier studies based on patent data.

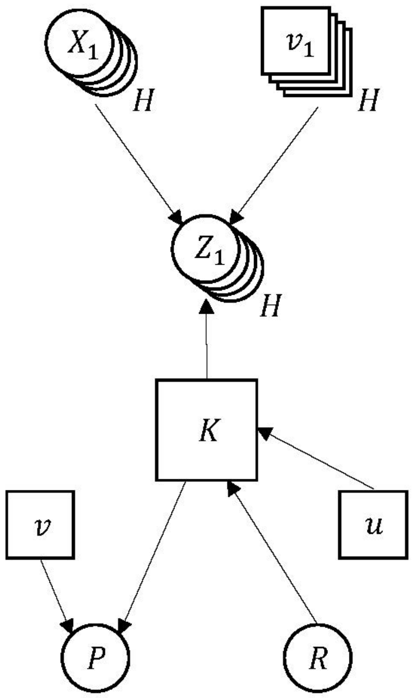
The third and last stage of the IVC is transforming (intangible) knowledge into (tangible) value for the firm. This process is multidimensional in both, input and output as depicted in figure 2.1. A firm might seek many entrepreneurial targets if it decides to undergo innovation. I therefore will also analyze the effect of generated knowledge in form of patents on several of those targets. Most of them are pooled under the term 'performance'. Similarly to the manifold and sometimes diffuse use of the term 'innovation', performance is also ambiguously applied as an output in many studies, not exclusively in the innovation literature context. Among others Tangen (2005) makes an attempt to disentangle and classify different output terms, namely performance, productivity and profitability. Sometimes these measures are highly correlated but sometimes they are not. So depending on the research question different measures might yield opposing results. It is thus of crucial importance to discuss their differences and empirically test more than one or at least to classify ones findings with the appropriate measure not to end up with misleading conclusions. Besides the three P's – performance, productivity and profitability – another possible target for the firm is pure survival, a dimension I will also pay attention to. There are indeed more aspects conceivable, but those are the most important and most common ones economists usually agree upon. Different innovation output indicators have proven to or to not influence such targets, such that there is not – and not to be expected any time soon – a simple conclusion like that innovation in general is beneficial for the firm. Economists rather seek to disentangle this complex process and to find ways to foster firm innovativeness both in quantity and effectiveness as a major driver of overall economic process in the sense of Schumpeter (1942).

In this thesis I will focus certain aspects, namely corporate governance, ownership, patents, innovation success, performance and survival. The conceptual framework of the IVC will shape the overall approach such that my results can fit the state of the art and contribute to the ongoing debate on how knowledge is created and exploited within the firm. Now I will explain my main measure of innovation, which will play a role throughout this whole thesis: patents.

2.2 Patents as a Measure of Innovation and their Value for the Firm

Since the 1980s, different patent measures have been used widely in empirical research to quantify firm innovative assets and to analyze how they interact with R&D investments and firm value. The first attempt to demystify the process of knowledge creation within the firm was made by Pakes & Griliches (1984) with a first application to patent statistics by Griliches (1990). They develop a theoretical model, the so-called Knowledge Production Function (KPF), depicted in figure 2.2.

Figure 2.2: The Knowledge Production Function



Notes: R – research expenditures
K – additions to economically valuable knowledge
P – patents, a quantitative indicator of the number of invention
$Z's$ – indicators of expected or realized benefits from invention
$X's$ – other observed variables influencing the $Z's$
u, v – other unobserved influences, assumed random and mutually uncorrelated

Source: Pakes & Griliches (1984)

The actual but unobservable knowledge stock K is affected by (mainly observable) R&D expenditures R. From this stock patents P are obtained. Thus patents as we observe them are only one aspect of a firm's knowledge, possibly inducing biased empirical estimations, but the same is also true for R&D investment. The latter has then an effect on economic values Z, which one can interpret as the performance indicators from figure 2.2, of which there is indeed more than just one. Of course there are also other non-innovative firm-level variables X, e.g. classical inputs like capital and labor if we refer to a Cobb-Douglas production function (which I later will). There is furthermore a set of random disturbance u and v. In fact u can be higher than most $v's$ as the prediction of knowledge creation is limited for the researcher and the firm, a key attribute of innovation. Especially at very early levels of knowledge creation, risk and uncertainty are very high as more and more residuals are added until any target is achieved. This is highly relevant for R&D investment as usually the first stage (Coad & Rao (2008)). Recently Hussinger & Pacher (2019) show that R&D increases information ambiguity about a firm's market value because the outcome is highly uncertain. Patents on the other hand represent an outcome with certain value and benefit the firm. Still the choice of an adequate performance measure prevails. Stock markets can be myopic and thus tend to undervalue innovation that has not yet led to the creation of tangible value (Hall (1993)).

Data availability and difficulties in disentangling different innovation and non-innovation measures still often prevent researchers from empirically testing theoretical models like the one explained here, such that they often are forces to stick to one or few indicators. However, significant positive effects of R&D investments on performance have already been found quite early (e.g. Griliches & Mairesse (1991); Griliches (1986); Griliches & Mairesse (1981)). There are also different ways to use R&D investment data. Very common is to construct an R&D stock via a perpetual inventory equation, which will then be able to not only value recent investments but also past accumulation of knowledge with a certain depreciation rate, initially created by the above cited work of Griliches and later on widely adapted[2]. Even though such studies tend to simplify the process of knowledge production by omitting intermediate steps, the fact that innovative firms in general tend to be more productive still prevails besides statistical and theoretical developments (Mohnen & Hall (2013)).

Relying solely on investments might be sufficient to capture a firm's innovative activity, but using them to estimate effects on the $X's$ misses out the intermediate stage K. The same is indeed true for patents (van Zeebroeck (2011)) such that measuring innovation is in all cases incomplete (Lhuillery et al. (2016)). Most of the work by Zvi Griliches is dedicated to making use of patent statistics to represent K as adequately as possible and thus to estimating a direct channel from P to the $Z's$. Even though several other innovative measures in use, there is still substantial value in patent data (Dang & Motohashi (2015); Harhoff et al. (2003)), all the more after recent data collecting developments allow us to move beyond pure counts. Some authors have even combined patents and R&D expenditures into one innovation measure (Hirshleifer et al. (2013)).

Innovation in general is extensively described by the Oslo Manual (OECD/Eurostat (2018)). Patents

[2]New evidence on the depreciation of innovation over time is given by De Rassenfosse & Jaffe (2018) who report a rate of 2-7% depending on the type of innovation.

are not addressed at all by the recent 4th edition of the Oslo Manual, which might seem surprising at first sight. Indeed a comparison between patents and other measures should not be dropped completely by an internationally approved guideline for defining innovation. Interestingly, the third edition of the manual still shortly discusses patents as a way of legal intellectual property protection and includes them in its portfolio of possible innovation indicators (OECD/Eurostat (2005)). Even more surprisingly, the even earlier second edition states:

"Patent data, whether applications or grants, are not indicators of innovation outputs; they are indicators of inventions, not necessarily leading to innovations. But questions about patenting are essential for a deeper understanding of the innovation process. The basic general series, of course, are the numbers of patents applied for and granted by firm, available from various national and international databanks. Questions on patenting have been included in a number of countries' R&D or innovation surveys" (OECD/Eurostat (1997))

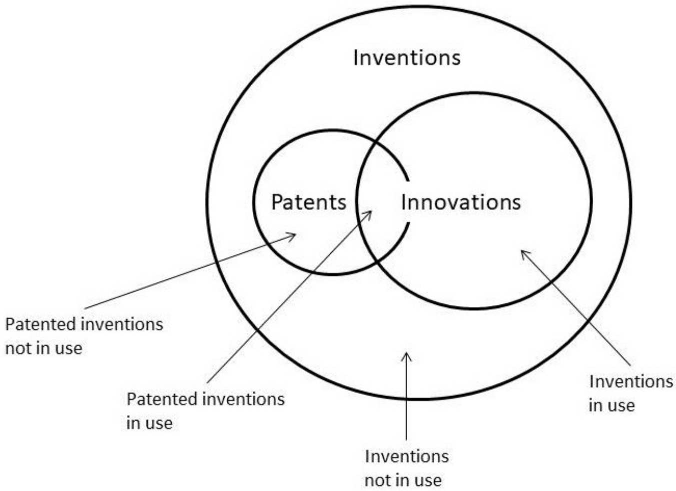
So the authors are aware of both, the value of patent data as well as their possible shortcomings in providing a complete picture of a firm's innovative efforts. However, the Oslo Manual's main goal is to provide guidelines to statistical offices and other authorities to decide if certain entrepreneurial activities are innovative or not. Patent data are easily available and have already proven to show significant correlation with other innovation measures (Artz et al. (2010)). Strictly speaking, patents are merely seen as inventions by the Oslo Manual, which are usually still far from being a commercially usable idea, than as innovations. The latter is defined as follows by the recent manual:

"An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)." (OECD/Eurostat (2018))

So in a narrow sense a patent might lack all these features and the Oslo Manual would classify patents merely as input in the Innovation Value Chain of figure 2.1. Considering the Knowledge Production Function depicted in figure 2.2, this is taken into account. Despite the fact that patents probably do not represent a firm's complete knowledge stock or innovative activities, they surely contribute to both and firms that patent can clearly considered innovative.

An attempt to clarify innovation measurement with a focus on patents has been made by Basberg (1987). Figure 2.3 illustrates his basic concept. We can see that patents are an incomplete measure of innovation. Inventions are basically ideas that may be new to the firm but not new to the market (if they were they could be patented) and might never spread a commercial use. On the other hand patented inventions have proven relevant to the firm such that they are worth paying fees and administrative efforts. R&D investments could also lead to non-patented inventions which are even less valuable. There is thus a debate on whether patents represent a firm's ability

Figure 2.3: A generalized picture of the relationship between patenting, invention and innovation



Source: Basberg (1987)

to foster economic progress in the sense of the Schumpeterian hypothesis (Moser (2013)) as well as on their actual value for the firm (Boldrin & Levine (2013)). They might even discourage innovation as some firms tend to decrease R&D efforts after being awarded the protective power of a patent (Bessen & Maskin (2009)). Furthermore patents are in all cases an incomplete measure of a firm's knowledge stock (see figure 2.2). This can indeed be true for all available data as firms have also the opportunity to never reveal their innovative capacity (Hall et al. (2014)). Therefore, one has to be cautious in interpreting the results as being driven by innovation alone. In this thesis I will focus on patents as a measure of (intermediate) innovative output, which makes a careful discussion on the consequences necessary. I attempt to provide new evidence on the value of patents for the firm and link them to inputs (R&D investment) and output (multiple entrepreneurial targets) to contribute to the literature. Several researchers have also attempted to create innovation indices consisting of various innovative measures in order to represent a firm's knowledge stock (Verhoeven et al. (2016); De Rassenfosse, Dernis, et al. (2014); Coad & Rao (2008))

If patents do not properly reflect innovation at the firm level, can we find arguments why firms use patents at all if not for introducing new products or cost-reducing processes? Critics of the current patent system in most industrialized countries argue that they are merely used to block competitors or generate cash flows from licensing (Motohashi (2008); Hall & Ziedonis (2001); Cohen et al. (2000)). This can be highly relevant for patents not in use. Thus even patents not resulting in marketable innovations have a value for the firm which should be observable in the effects on entrepreneurial targets. The steady increase in firms' patenting behavior as well as in lengthy and costly legal disputes on intellectual property point in this direction. For example, for China as an economy seriously challenging the technological supremacy of western industrialized countries, Dang & Motohashi (2015) show that patents are highly valuable as a measure of innovativeness. The reader must in every case keep in mind that – despite the fact that patents are usually innovative in nature – any correlation between patents and other firm or market variables can stem from non-innovative firm strategies that go with patents. On the other hand, observing any such effects can support patents as being able to represent a firm's knowledge stock. This thesis can thus be seen as contributing to the literature of the actual value of patents for the firm, besides its specific focus throughout the chapters.

Other measures of innovation besides patents and R&D investments are also well established and can offer a more detailed look on certain aspects of innovation but also can have drawbacks. According to the Oslo Manual, firms can undergo innovation through many activities, of which R&D is only one. Others are: engineering, design and other creative work activities; marketing and brand equity activities; IP-related activities; employee training activities; software development and database activities; activities related to the acquisition or lease of tangible assets; innovation management activities. Only few of them finally lead to patents, such that other measures can offer promising features. Most common are survey-based measures. One important data source is the CIS. Despite the fact that the questionnaire changes over time in order to widen and diversify gathered information as well as to picture latest developments in research, policy and business, the most important questions are included in every rotation. Those are – besides R&D investments – the introduction of product and process innovation as well as innovative sales[3].

A product innovation is the commercial introduction of a product which is usually new to the market. It must be new according to either technical features, intended usage, software or other fundamental characteristics, but not just design or aesthetics. Product innovations usually come from the manufacturing sector but are not restricted to it. Goods and services can also be innovative in nature and thus open new markets. A product innovation must not necessarily be new in every aspect. If it is, it creates its own market, basically offering monopoly power. If new only in certain aspects, it still competes with other similar products but has a comparative advantage.

A process innovation is a production technique for a given set of products which is able to significantly decrease production costs. This technique should be at least new to the firm and simple material or labor reallocations or the acquisitions of machinery common in the industry are not innovative. A process innovation capable to decrease costs such that it allows a firm to charge the monopoly (Cournot) price is usually called radical.

Innovative sales are calculated as the share of sales made with new or significantly improved products and are rather a measure of innovative success. If the firm declares innovative sales as an entrepreneurial target this can be achieved by innovating and there is still need to choose adequate

[3]There exists a huge amount of empirical studies applying those measures, such that I abstain from citing only a snippet.

measures for innovative inputs. Researchers often call innovations successful if they are capable of boosting firm's innovative sales, which might in some cases be misleading because non-innovative sales might simply decrease.

The Oslo Manual also classifies two more innovation output types: There are organizational innovations that distinguish from the former mentioned process innovations such that they do not involve patentable technical novelties but a restructuring of the production progress. This also involves new to the firm innovations like efficiency gains in organizing workflows, shortening value chains, exploiting existing resources or implementing new management practices. Next are marketing innovations, which involve any kind of new marketing methods like packaging, branding, advertisement or pricing. Such innovations are seldom patentable, such than patents usually fail in capturing such non-technical novelties. They probably make a big share of non-patented inventions in use referring to figure 2.3. Still the question remains which part of new organizational or marketing methods are innovations, such that especially for these measures the problem of subjectivity is big. This I will discuss now.

Defining an investment as falling into the R&D category as well as defining non-technological inventions as innovations is not always straightforward. For this purpose in 1963 the first Frascati Manual was developed to help practitioners as well as policy makers to define R&D and how to gather and publish necessary information. The recent version of the manual is of 2015, offering steady improvements which are necessary to keep up with technological developments (OECD 2015). Despite this well-conceived guideline, there are still plenty of innovative activities a firm can seek that not necessarily fall under those definitions. In any case the firm has to decide if an investment is innovative or not, but as R&D is by definition intentional, innovation that comes 'accidentally' or at least unplanned is not captured. There are for example spillovers which have proven to be highly relevant for many firms without any need of internal R&D effort (Cassiman & Veugelers (2006)).

Furthermore, collecting R&D data always relies on firms to report their efforts adequately. Even though the Frascati Manual helps in classifying entrepreneurial efforts in this area, there are still plenty of possible misclassifications. Several creative actions can contribute to a firm's knowledge stock without being driven by firm-level innovation (Lhuillery et al. (2016)). For patents there is a strong foundation for novelty. Even though not every patent will result in a marketable innovation, novelty is prerequisite for a patent to receive a grant, which is an argument for patents over R&D. Some firms might even report strategically, such that a firm can deliberately understate their innovative efforts for strategical purposes (Koh & Reeb (2015)), but disclosure is also an issue for patenting (Hall et al. (2014); Moser (2012)). However, it has been found that effects on performance are much stronger for patented inventions rather for the ones kept secret (Hall & Sena (2017); Hall et al. (2013); Hussinger (2006)).

The randomness of innovation furthermore makes it difficult to estimate stable effects of R&D on any innovation output variable, yielding high standard errors in most econometric estimations. On the other hand the heterogeneity of R&D is a fruitful field for economics and business scholars who seek to demystify the process of knowledge creation and distinguish good from bad innovation management. This will be tested later on in this thesis to identify firm characteristics that foster the transformation of R&D investments into actual intellectual property, namely patents. Those characteristics of interest here are governance features which I will discuss in detail later on. This brings us back to the Knowledge Production Function. I will also make an attempt to break open the P dimension in figure 2.2. Assuming a direct and instantaneous effect from investments to a firm's patent stock is somehow naive. The process of patenting itself implies a substantial amount of heterogeneity by firm and innovation. Firms who decide to patent an innovation hand it to the patent office as an application. The office then examines technical features and novelty and then decides if a patent is granted or rejected.

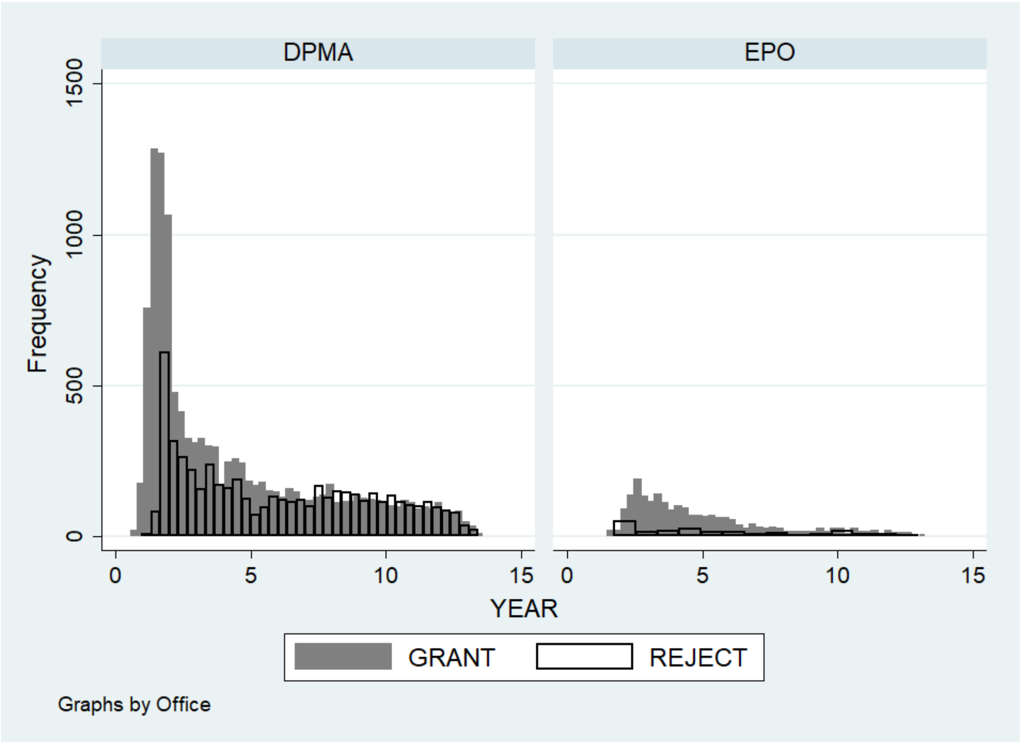
The decision process within the patent office deserves some attention. Figure 2.4 depicts a histogram for the distribution of elapsed time from application (filed in 2006 as a snapshot) to grant or rejection from German applicants at the German Patent Office (DPMA) and European Patent Office (EPO)[4]. For applications filed directly at the national office we can see that if a patent receives a grant, it does quicker that in the case the application is directly handed to the EPO. The reason lies straight at hand: A patent granted by the EPO is valid throughout the whole EU area, such that examination is usually more complex and lengthy. So if a firm hands an application directly to the EPO, it should be aware that decision time, fees but also legal protection (if granted) are higher. For example average fees for a European patent are three to four times those of a national patent. The firm can even decide to apply at the EPO according to the European Patent Convention (EPC) or even to the International Patent System administrated by the World Organizational Property Organization (WIPO), which is even more cumbersome and only pays for multinational firms with who are highly solvent and patient[5]. Such applications are usually called PCT applications, referring to the Patent Cooperation Treaty signed in 1970 and offering almost worldwide patent protection. These are excluded in figure 2.4 in order to depict the process on a lower administrative level. A comparison between national and PCT applications will be given later in the next section.

Another perception is that German applicants tend to consult their national office first. However, dropping international patents in econometric analyses might miss some valuable patents, especially if we include PCT patents, which are usually filed at the EPO. At the DPMA 68% of all grant decisions in 2006 are made within the first 5 years with the average decision time being 4.4

[4] All statistics in this section are drawn from the PATSTAT database and only include patents and not trademarks or utility models.

[5] At this point I will not go into further detail for national and international patent applications and decision procedures. For a summary of legal procedures on the national and European level see European Patent Office (2019a). I also refer to this publication for most legal explanations in this section.

Figure 2.4: Years until patent is granted or rejected at the German Patent Office (DPMA) and European Patent Office (EPO); applications from German applicants in 2006; PCT excluded; priorities only



Source: PATSTAT autumn 2019

years. Both values stay very stable throughout the years such that the snapshot for 2006 is representative. Average grant decision time for EPO applications is 4.9 years[6]. The EPO itself claims to decide usually within the first two to four years. This does not include possible opposition which takes another 3.5 years on average, such that our data fit EPO official statistics[7]. Not depicted in figure 2.4 are undecided applications and withdrawals. The former are nearly negligible, even though it is possible that applications are still not decided within the observed period of 13 years.

However, such cases are usually classified by the patent office as "pending and assumed to be withdrawn" because it appears that firms simply stop to pursue an application without officially withdrawing it. Applicants are often obliged to actively push an application as it moves through different administrative steps, most of them including fees. As shown in figure 2.4, the probability of being granted decreases substantially after the first couple of years and later on equates to the probability of being refused, at least for the DPMA. So many applications are simply dismissed by their applicants if decisions take too long. Such cases as well as official withdrawals on the other hand are very common, such that we cannot include them in the decision time discussion.

[6]These values do not change substantially even if we include PCT applications.
[7]Quality indicators on timeliness are provided by the Eurostat patent index (European Patent Office (2019b)).

An empirical analysis on the determinants of examination time is offered by Harhoff & Wagner (2009). They gather some interesting descriptive statistics on grants, withdrawals, rejections and pending applications, even though they do not restrict their analysis to German applicants which does prevent a direct comparison to the data presented in this section. They observe a slight but steady increase in examination time at the EPO from 1978 to 1998. Decisions upon grant or refusal are made after 5 years on average in 1998, what is just what we observe for 2006. So during the 2000's examination time is pretty stable. The authors also report a high rate of withdrawals of roughly 30%.

We can thus say that not taking into account the decision time at the patent office and more importantly the probability of failure can have serious consequences for economic investigations at the firm level. This is especially true for studies that try to estimate direct (instantaneous) effects of applications on financial indicators. I therefore distinguish between applications and grants and also analyze the intermediate process of applications yielding grants under certain entrepreneurial circumstances. Sure a firm has little impact on the decisions made by the patent office. Here I mainly refer to patent heterogeneity or quality and hypothesize that a patent of higher quality or novelty is more likely to acquire a grant and less likely to be refused. Firms with a higher percentage of their applications passing the skeptical examination of the office hold a higher knowledge stock. The temporal sequence of a grant causally resulting from an application allows me to econometrically investigate crucial factors influencing this process, meaning that applicants can influence the probability of their applications being granted by handing in high-quality patents.

Figure 2.4 also reveals a high amount of rejections, at least on the national level. Official statistics state that on average only slightly above 40% of all applications receive a grant (Deutsches Patent- und Markenamt (2016)). This statement can be confirmed if we look at all applications, not only granted and refused ones. For the EPO rejections seem very unlikely. However, applications filed at the EPO are – if not granted – usually withdrawn or simply pending and later deemed to be withdrawn. Rejection rates at the DPMA are higher than at the EPO, indicating that if an applicant can afford – in time and money – to wait for the EPO decision it usually pays. It is reasonable to assume that patents of higher quality or commercial importance are directly filed at the EPO such that grant rates are higher. The data also include only priority filings (see next section), such that each application included in figure 2.4 can be assumed as the first filing of a particular invention. Rejection statistics still have certain limitations and it is indeed worth to look at grants and applications.

In this thesis I will try to depict the full process of the Innovation Value Chain from the entrepreneurial decision to innovate towards final payoffs. My analyses are however short in alternative innovation output measures that are capable to form a firm's complete knowledge stock even though I apply different patent measures. One should thus see this work as a deep look into the origin and value of patents as only one aspect of innovation.

Furthermore even patents are heterogeneous. Pure counts cannot account for a patent's economic impact. By now the best bet to account for both quantity and quality are probably patent citations (A. Jaffe & de Rassenfosse (2017); Moser et al. (2018); Trajtenberg (1990)). For the US, the NBER citations database is available since the work of Hall et al. (2001) and has been used widely. We can even build patent and citations stocks (Hall et al. (2005)) in order to visualize the historical process of knowledge creation, even though there are some peculiarities to consider in comparison to count stocks, because there are now two kinds of patents: cited and citing ones. Whereas even count statistics have proven to be vulnerable to different counting techniques, this is even more severe for citations[8]. This is indeed what I will be doing if necessary and promising later on. Citations can also reveal interesting links besides patent value, e.g. geographic patterns and magnitude of innovation spillovers (A. B. Jaffe et al. (2000); A. B. Jaffe et al. (1993)). De Rassenfosse, Schoen, & Wastyn (2014) also show that relying on applications from a single patent office can cause biases. However, the accuracy of fit of a specific measure depends on the research question, such that I will use different measures depending on the actual analysis.

There are also other concepts to address patent heterogeneity. Some researchers stick to counting high quality patents (Basberg (1987)), even though such indicators require a subjective classification that is only partially appropriate for big data sets. Lanjouw & Schankerman (2004) further develop this approach to creating a quality index using a linear combination of multiple patent characteristics. However, individual weighting and the choice of characteristics are still at risk to be called arbitrary. Other indicators are patent renewal rates (Harhoff et al. (1999)), patent families (Verhoeven et al. (2016); Harhoff et al. (2003)), patent scope in terms of their technological impact, mostly referring to IPC[9] categories (Lerner (1994)) or a patent's contribution to firm value (Bessen (2008)). An extensive survey of the huge variety of patent quality measures is given by Squicciarini et al. (2013), who also includes direct applications and SQL queries for PATSTAT[10].

Even though citations have during the new Millennium gained much popularity compared to pure counts, there is still a debate on their value and the way they are extracted from official statistics. An extensive review on the heterogeneity of citation indices is given by Bakker et al. (2016). This again highlights the common heterogeneity in all innovation indicators (Moser et al. (2018); Lhuillery et al. (2016)) and the fact that even if we agree on patents as a suitable innovation indicator, there are various ways of measuring it with several hidden biases (De Rassenfosse, Schoen, & Wastyn (2014)). Citations are generally speaking defined as the number of patents which refer

[8]I will explain my choice of each patent measure in the respective chapter when they are applied

[9]Each application is assigned at least one International Patent Classification (IPC), in order to gather patents of similar technological features or purposes to groups. Such groups can help examiners at the patent office during examination of novelty or serve for statistical analyses on technological evolution or links between industries. They can also be matched to NACE2 industrial sectors. For further information see Organization (2015).

[10]For an introduction into PATSTAT with sample SQL queries see De Rassenfosse, Boedt, & Dernis (2014).

to a specific patent during a specific time period, indicating that patents cited more often are of higher value or novelty, even though the relationship between citations and patent value might be non-linear (Bakker (2017)).

Furthermore patents that have been cited frequently over time can be used as a measure for innovative output, a fact highly relevant to picture the complete Innovation Value Chain. Citations are thus very suitable to measure any effects on entrepreneurial targets, a purpose pure application and even grant counts might indeed fail to fulfill. However, this will be examined later on and comparisons of patent measures in empirical analyses will be offered. I will stick to the Innovation Value Chain by going step-by-step from applications over grants to citations and their stock. For these measures there is a clear temporal causality such that in going through these steps one more and more approaches the end of the process, which is of high relevance for the researcher and the manager.

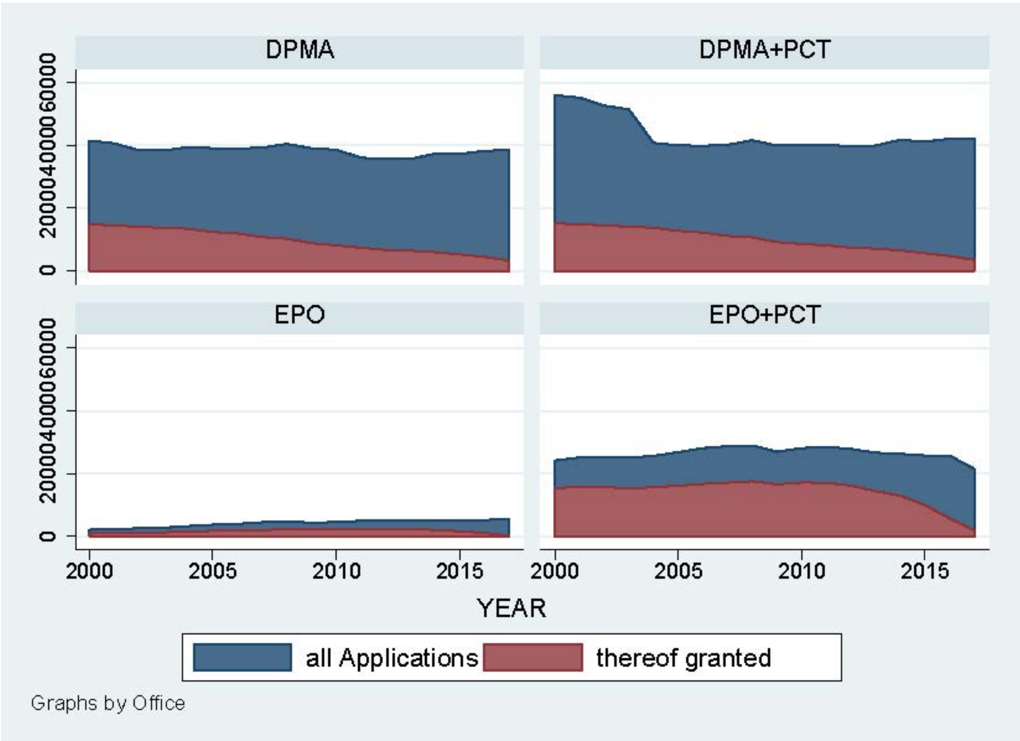
So to sum up, there are plenty of measures for innovation on the firm level of which every single one exhibits certain advantages and caveats. Even surveys who ask firm officials for all innovative and creative work are not immune to mismeasurement because they rely on subject assessments. It is thus important for any research in the field of Industrial Organization to be able to classify and value the innovation indicators available or empirically applied. All measures discussed here will probably be highly correlated, such that none of them is completely irrelevant. It is nevertheless possible that some results from empirical examinations might change with the choice of the measure. Even when we restrict our analysis to patents with discussing what can and cannot be found using this indicator to picture firm's innovation behavior, there are plenty of measures to choose upon. The choice is made in the upcoming chapters depending on what we attempt to analyze. Whereas patent applications are some kind of intermediate innovation measure – it is neither pure input nor output – grants, patent stocks and even more citations have gone quite far in the process of knowledge production and should be able to represent commercial usage more adequately. The temporal dimension is crucially important to choose the right variables and making use of different patent indicators also allows us to contribute to the Knowledge Production Function approach from figure 2.2 by identifying firm characteristics that increase efficiency.

I will now present some general descriptive patterns in the patenting behavior of German applicants. This will also help to justify the use of relevant patent indicators later on and provide interesting insights on the many applications of the PATSTAT database.

2.3 Patenting Behavior of German Firms

This section will present insights on how German applicants proceed if they have discovered an invention they consider worth patenting. It is important to understand the decision process behind applications on the firm level in order to come up with a model to predict it and to dig for common patterns. Furthermore I will provide a deeper understanding on the distinction between applications and grants. Both are of high relevance during the later chapters. Furthermore there is a number of studies using patent applications without distinguishing both types. As for other countries like the U.S., rejection rates are quite low, but I will show here that this is not the case for Germany. Also the choice of relevant patent offices and patent protection types is non-trivial as they are not chosen at random by the firm and the patent path the firm decides to take can have effects on fees, examination time and scope of intellectual property protection.

Figure 2.5: Applications at the DPMA and at the EPO, including already granted; German applicants



Source: PATSTAT autumn 2019

Figure 2.5 gives an overview on the evolution of applications and grants at the DPMA and the EPO handed in by German applicants, with (right) and without (left) international PCT applications. Granted applications refer to applications filed at the corresponding year and granted up to the point the data is collected, that is autumn 2019 for the descriptive statistics in this section.

There is however a lag from any decision up to the time it is observable in the data due to publishing processes, such that most patent statistics are barely representative for the last two years on average. We can see that German applicants still prefer their national office. This is reasonable because procedures are predictable, decisions are made more quickly and fees are substantially lower. If an innovation is assigned a national patent, a firm can still go further for a European or even worldwide application in a next step. Furthermore applications at both offices are quite stable, indicating no trend in excess patenting.

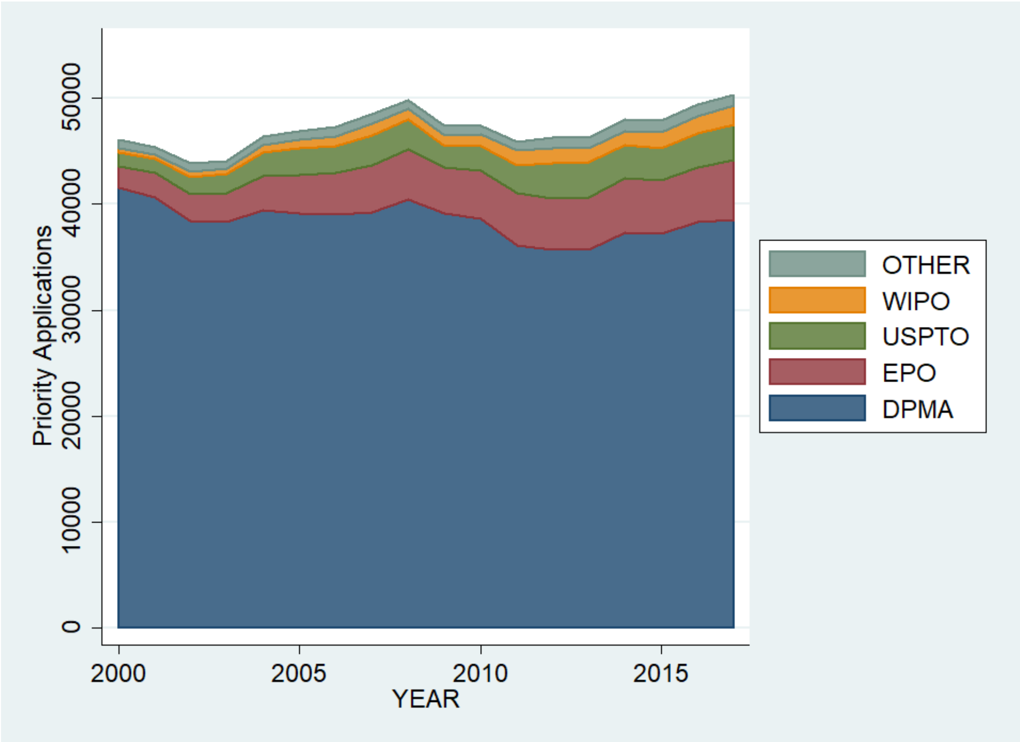
Differences between PCT and non-PCT applications are obvious. Only a very small amount of applications filed at the DPMA are PCT application[11]. Even though this path is possible, an examination at the EPO and other national offices is still necessary, making an initial filing at the EPO more attractive. Here the share of PCT applications is much higher. German applicants who approach the EPO usually seek wide international protection instead of just the European area. Harhoff & Wagner (2009) also report almost 50% of all EPO applications being PCT applications in 1998. This rate is even higher in figure 2.5 with no obvious trend. So we can conclude that German applicants seek international protection to a higher percentage than the average applicant who seeks to file a patent at the EPO.

When it comes to grants the statistics show very interesting patterns. For the DPMA we can confirm official grant rates of about 40% but also observe a downward trend. Considering figure 2.4 this should mainly be due to decision time which is short on average but can indeed be substantial. However, this trend is less explicit for the EPO with a sharp decline only in the end of the observed period. So the DPMA indeed seems to become more restrictive over time or applications become less patentable. Grant rates at the EPO are substantially higher than at the DPMA, potentially indicating higher quality of applications filed on the international level. Such patents probably come from international active firms who seek commercial utilization. These statistics fit the results by Harhoff & Wagner (2009), even though grant rates decreased from 71% to 55% during 1978-1998. Since then they seem very stable, such that developments in firm patenting behavior or office examination processes probably reached a plateau by the new Millennium.

Applications also seem stable over time, such that for applications there is no serious bias in PATSTAT. The reason is that PATSTAT – as operated by the EPO – only includes published applications. There is usually an 18 month legal lag between filing and publication and thus extracting very recent data from PATSTAT can be misleading, but not with a reasonable temporal distance. For grants, however, biases are very likely if one refers to the date of application. For my upcoming analysis in the effect of patents on entrepreneurial targets I rely on the date the patent was granted (not shown in figure 2.6), such that a systematic bias is ruled out. Another aspect worth considering is the fact that firms might hand the same invention to different offices. Every

[11]Due to changes in accounting practices after the PCT revision in 2004 applications before that date might appear higher in figure 2.5

Figure 2.6: Priority applications from German applicants by patent office (stacked counts)



Source: PATSTAT autumn 2019

time this happens, an applications is given a new unique identifier (Application ID), such that only counting different ID's could lead to duplicates in the data. This is more severe for firms operating in international markets as they seek international protection. PCT applications entering the national phase in national offices are also assigned new ID's, such that each application represents either a new invention or the same invention in a different market[12]. However, there are cases where including such duplicates is appropriate. De Rassenfosse, Schoen, & Wastyn (2014) show that restricting counts to one single office also can cause biases, such that I here once more point to the fact that there is no one-fits-all patent indicator, even after having decided for applications, grants or citations. If we look at interdependencies between patents and financial indicators of internationally active firms, simply counting each patent's first filings could undervalue certain innovations. Firms usually consult their 'domestic' patent office first and in a next step seek broader international protection. If the patent is not granted or proves negligible in terms of commercial value, the firm could drop further applications and save fees. Multiple international applications of the same invention can thus represent patent quality (Basberg (1987)). The same should hold for PCT applications as fees are substantially higher.

[12]The national phase of a PCT application is the examination inside a national patent office of a PCT application filed in another office (mostly the EPO). After a first test for novelty and applicability of a patent inside the EPO, national property protection is only given after examination by a national office.

To get an impression of applicant's usual patenting strategies figure 2.6 shows the number of priority filings of German applicants for the most relevant – concerning application counts – patent offices, including PCT applications. If only priority applications are considered, duplicates in terms of the same innovation being filed in different countries are ruled out. We can see a strong 'home bias' for most patents are first filed at the domestic office (DPMA). Next is the EPO, covering the European market. The United States Patent and Trademark Office (USPTA) also attracts high interest even for German applicants as it represents a huge market for commercial intellectual property exploitation, a pattern that is present for decades now (Pavitt & Soete (1980)). Then there is the World Intellectual Property Office (WIPO) which offers legal protection at an almost worldwide scale. However, it is only seldom considered for a first filing.

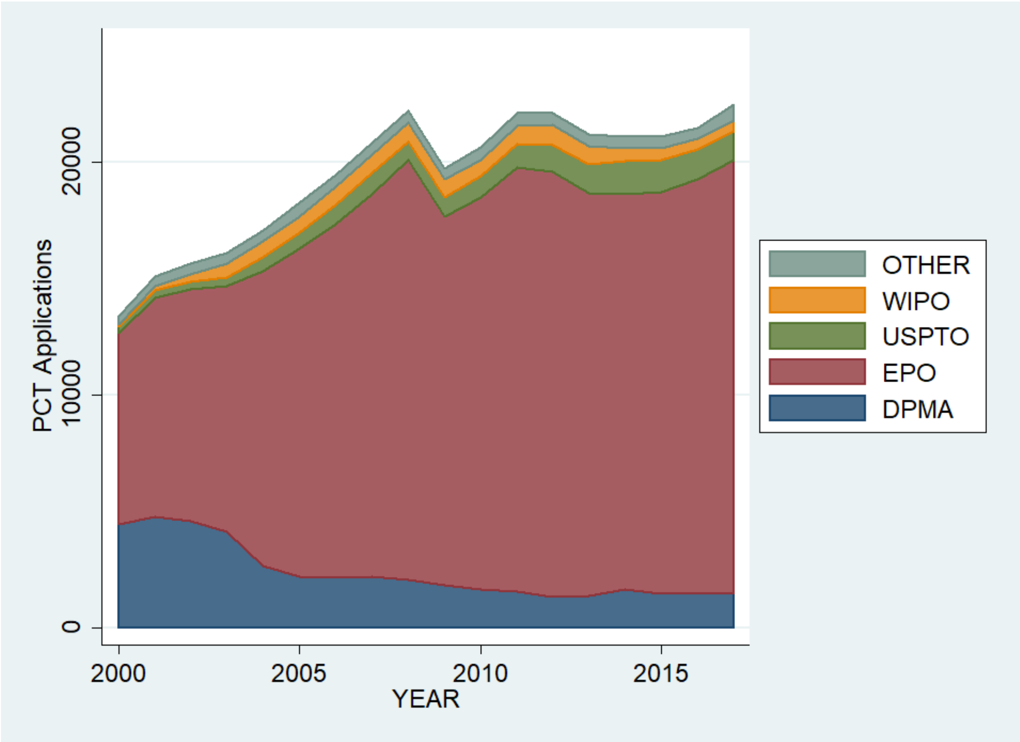
Comparing figures 2.6 and 2.7 we can say that, even though German applicants file many applications on the international level, e.g. at the EPO, most of them probably stem from a prior domestic application. Including or excluding applications that are not first filing depends on the research question and I will in my later analyses briefly discuss the choice of the adequate patent measure.

For international protection figure 2.7 shows only PCT applications by receiving office. Patents holding PCT protection are valid in all PCT member states, which are all industrialized and most developing markets[13]. We can also see a clear pattern for German applicants. The EPO is by far the most attractive address and is also gaining relevance over time[14]. Furthermore the USPTO is the most important non-domestic national patent office for German applicants, which again highlights the relative importance of the U.S. market compared to other national markets. The overall importance of PCT protection has increased significantly during the early 2000's with no obvious trend afterwards (except a sharp setback during the international financial crisis in 2009). Developments since 2015 look promising in terms of innovation-driven economic growth, but these years are not subject to my upcoming econometric analyses.

[13] By October 2019 there are 153 states that have signed the Patent Cooperation Treaty (PCT). Only few states still lack ratification. Among those, the most relevant in economic terms are Argentina, Venezuela, Bolivia, Uruguay, Paraguay, Pakistan, Afghanistan and Myanmar.

[14] As has been stated earlier, due to a revision of filing standards in 2004, there is a shift in filings from the DPMA towards the EPO at that point.

Figure 2.7: PCT applications from German applicants by patent office (stacked counts)



Source: PATSTAT autumn 2019

A combination of information about the origin of applicants at the DPMA and the relative importance of PCT applications is given as a snippet in table 2.1. This table is not extracted from PATSTAT but relies on official DPMA statistics. I provide this numbers from annual reports as a comparison between PATSTAT and DPMA publications in order to compare my data to official national statistics. We can see that the overall number of patents from German (domestic) applicants is significantly higher than in the figures above. Whereas PATSTAT yields roughly 40,000 applications during the observed period, the DPMA reports about 47,000. This stems from the fact that the DPMA usually is the first address for their domestic applicants (see also figure 2.6), such that the DPMA receives information much earlier than the EPO. So the difference most likely comes from unpublished applications in every year, as PATSTAT only includes published applications whereas the DPMA includes all in their annual reports to offer a more complete picture. Applications withdrawn before publication are thus not included in PATSTAT, what is the main reason for the DPMA reporting higher application counts.

Applications from foreign applicants – referring to their principal place of business – only make a small fraction of below 25% of all DPMA applications. German patent office and German applicants have strong bounds. This holds for both sides. The DPMA mostly files German patents and German applicants prefer the DPMA. This is indeed different for PCT applications which offer international protection as has been discussed above. The right half of table 2.1 shows PCT applications in national phase. This means patents which are first filed at an international authority – most likely the EPO – and then handed to the DPMA for national examination. Here we can see that most of these patents come from foreign applicants, which is not surprising. Putting together both patent types we again see that the DPMA – and this probably holds for most national patent offices – in about 75% of all cases deals with domestic applications.

Table 2.1: patent applications at the DPMA by patent type and nationality of applicant

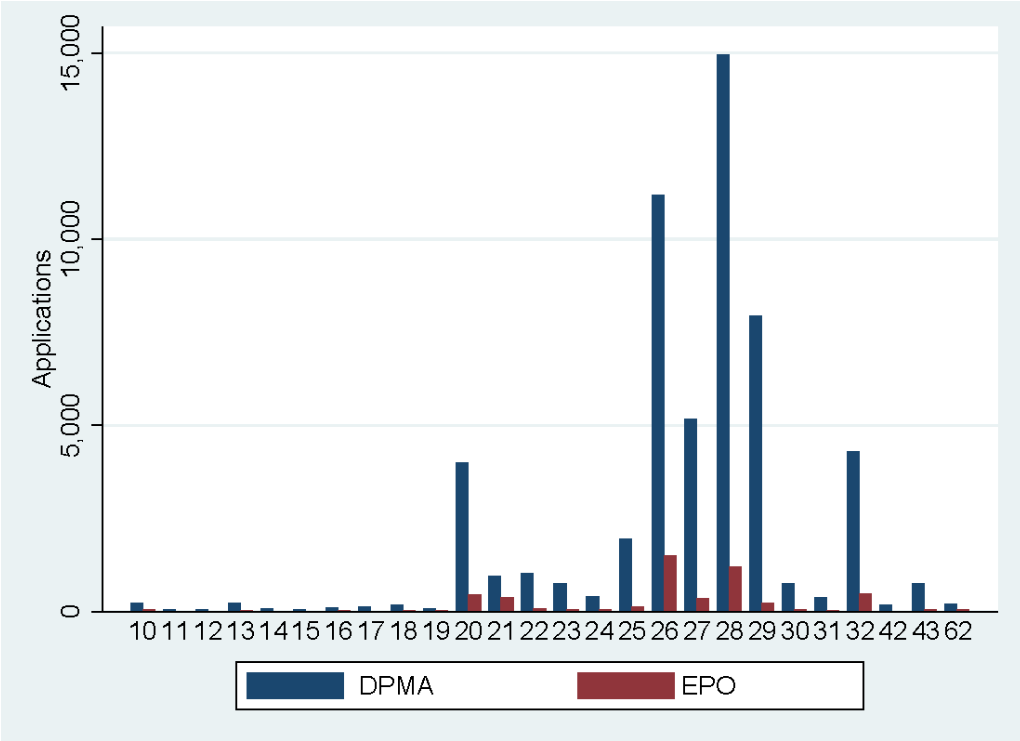
Year	National applications			PCT applications in the national phase		
	Domestic	**Foreign**	**Total**	**Domestic**	**Foreign**	**Total**
2014	47,303	12,617	59,920	851	5,191	6,042
2015	46,467	13,988	90,455	922	5,521	6,443
2016	47,318	14,263	61,581	1,175	5,150	6,325
2017	46,745	14,739	61,484	1,046	5,192	6,238
2018	45,602	15,266	90,868	1,007	6,020	7,027

Source: Deutsches Patent- und Markenamt (2018)

To also get an impression which firms patent, or to be precise which industries spawn the most patentable inventions, we can have a look at figure 2.8. Most patents in PATSTAT are assigned at least one NACE2 industry classification[15]. The x-axis refers to two-digit classifications listed in table 2.3 in the appendix. Those codes in PATSTAT only refer to manufacturing industries as well as a few from the construction and software sectors. This does not mean that only such industries patent in Germany, because the codes refer to patents rather than firms. E.g. also universities, hospitals or governmental organizations may file patents that belong to the manufacturing sector. However, this figure gives an interesting idea of the creative focus of German applicants. Top three sectors are in order: machinery and equipment (28); computer, electronic and optical products (26); motor-vehicles, trailers and semi-trailers (29). Besides those very technical sectors which as expected reveal the most patentable inventions, there are also many applications in the pharmaceutical and chemical industry. As a quick comparison to innovation inputs, figure

[15]Most patents only match one classification, but it appears that some are assigned to fit two sectors, such that aggregates counts in figure 2.8 sum to roughly 54,000 applications at the DPMA, whereas above statistics only report 40,000. Classifications stem from a-priori IPC categories. Some patents are not assigned such a category, such that it is possible for a patent not to be depicted in figure 2.8, even though most of them are due to the majority of patents still come from the manufacturing sector.

Figure 2.8: Applications in 2006 at DPMA and EPO by NACE2 industry; including PCT; priorities only



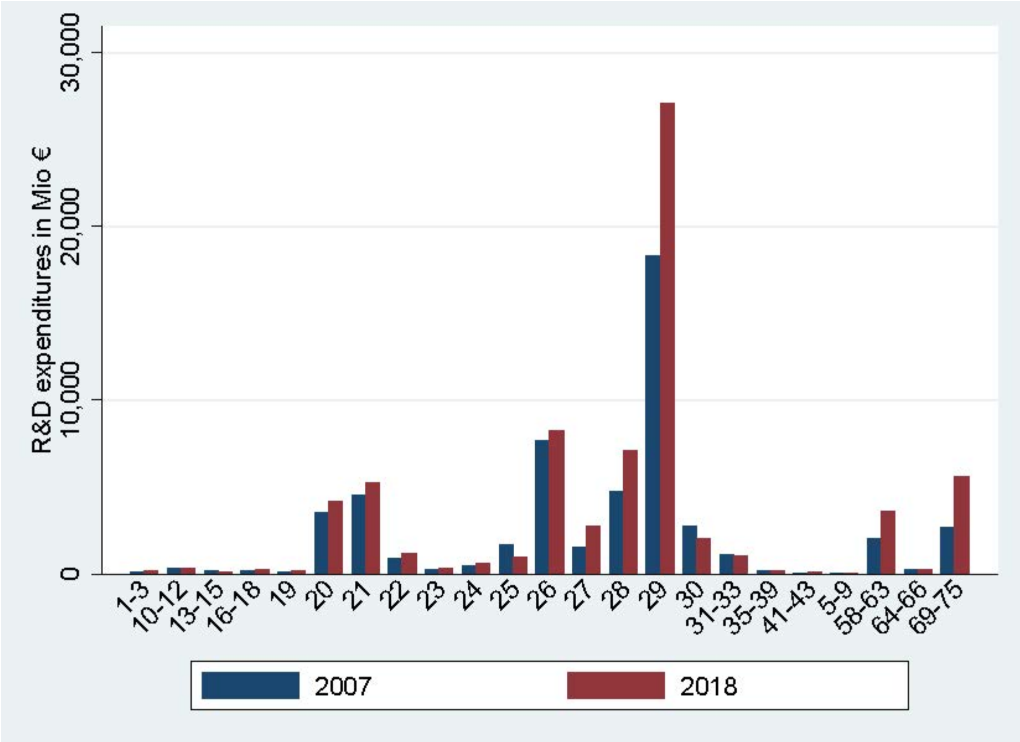
Source: PATSTAT autumn 2019

2.9 shows total R&D expenditures of German firms in 2007[16] and 2018, thereby also revealing some dynamics. We can see that R&D expenditures and patent applications are highly correlated over industry, but some industries differ substantially in their patent per R&D ratio. For instance, whereas machinery and equipment (28) displays the most patents, this industry heavily outnumbers motor-vehicles, trailers and semi-trailers (29) when it comes to R&D expenditures. Thus in some industries there are either many innovations kept secret, or patents are “more expensive” of or higher quality, leaving plenty of room for future research and challenging the popular opinion of constant returns to R&D on patents (Lewbel (1997); Griliches (1990)).

To sum up, information about patenting behavior of German applicants can be put into the following statements: German applicants usually patent in machinery, computers, motor-vehicles and chemicals and seek national protection first, such that they address their domestic patent office before they seek international protection. For the latter they then mostly file at the EPO, probably because it guarantees expertise for international procedures and strong bounds with other national

[16]2007 is the first year R&D statistics are taken from Stifterverband für die deutsche Wissenschaft (2018) and Stifterverband für die deutsche Wissenschaft (2009) on a NACE2 level. Data is gathered via annual surveys. Up to 2006 industry classifications in these surveys are different, such that I stick to the year 2007. Changes from 2006 to 2007 are small in both R&D and patent statistics, such that a descriptive comparison seems reasonable.

Figure 2.9: R&D expenditures of German firms in Mio. € by NACE2 industry



Source: Stifterverband für die deutsche Wissenschaft (2018); Stifterverband für die deutsche Wissenschaft (2009)

patent offices. Direct applications at national offices other than the DPMA are rare. However, if they occur, they strongly tend towards larger and commercially important markets like the U.S.

I will now turn towards the second main topic of this thesis besides innovation: Corporate Governance in form of ownership structure. Corporate Governance has proven to play a major role in firms' decision making processes, thus in choosing entrepreneurial targets as well as shaping strategies to achieve them. First I will give a detailed review on the theoretical literature on ownership structure and how it affects firms' decision making processes. Then I will focus on monitoring executives with no or only minor ownership in the firm they manage in order to form a basis for developing hypothesis on innovation management and firm performance. These hypotheses as well as a review on recent empirical findings on each specific topic will be presented in the later empirical chapters.

2.4 The Role of Ownership Structure in Corporate Governance

2.4.1 The Problem of Separating Ownership and Control

For an economist incentives of economic agents are of major importance. This is especially true in Industrial Organization where the main issues are corporate strategies and competition. In traditional economics the firm is simply seen as a profit maximizing unit in a given market within a given time horizon. If this was true, there was no real need for analyzing heterogeneous firm behavior or even economic policy other than macroeconomic issues like antitrust actions, shock mitigation or trade regulation. However, at least the radical changes in international corporate structures and in the ways how firms organize their business throughout the 20th century have shown us that firms can be as heterogeneous as the individuals that control them[17].

A seminal publication on the behavior of a modern organization is that of Berle & Means (1932). Their observations of the corporate structures of the western world reveal problems as well as chances of the steady division of ownership and control. Since growing firms established the idea of acquiring new financial resources by dispersing capital shares, corporate structures grew more and more complex and the owners diverged from actual control over 'their' firm, a phenomenon new to the usual term 'property'. If unregulated – by either the firm or policy makers – shareholders are at risk of being at the mercy of managers. Those managers are thus – in firms with highly dispersed capital – merely uncontrolled by the parties by whom they are employed. It is not only the fact that shareholders are in big firms not capable to control them, but also that they are less willing, because their actual power over corporate strategies is very low. As a result, executives may find themselves uncontrolled and having both incentives and power to either slack or redirect firm resources towards personal interest.

This problem is most relevant if shareholders have no voting rights within the decision making process of the firm, a circumstance of high importance during the early 20th century. Nowadays the acquisition of company shares usually comes with certain voting power, mostly over the choice of executives as well as other monitoring capabilities. However, capital dispersion and highly diversified portfolios of investors decrease both the percentage of firm profits they obtain and their capabilities to contribute to increasing such profits, even though given voting rights. This hypothesis has since then attracted many theories of how certain ownership structures or other corporate governance systems can restore the sense of firm property, foster the power of owners and spur, executives to contribute to firm performance.

One mechanism to keep the managers focused on maximizing firm value (and therefore share

[17] It is worth mentioning at this point that the theory on firm heterogeneity has benefited a lot from the resource based view on the firm, primarily developed by Barney (1991). However, this body of literature goes beyond the topic of this thesis and Corporate Governance and ownership structure can be seen as explaining a fraction of firm heterogeneity.

value) is monitoring. Berle & Means (1932) already point to both the necessity and the possibility of shareholders to exercise control over managers to retain and foster efficient business decisions. M. C. Jensen & Meckling (1976) refine their arguments by developing a formal theory of the firm and decision making processes of managers and external shareholders in order to profitably run a modern corporation in the sense of Alchian & Demsetz (1972). They support the view of the divergence of interests between both parties, commonly known as the principal-agent-theory (Eisenhardt (1989); Holmström (1979)) with the shareholder being the principal employing the manager to act as an agent on their behalf. Under this assumption an underperforming firms can be an equilibrium. They thus state that monitoring is necessary to push the manager to aim at maximizing the firm's market value. Thereby shareholders can assure to get the maximum residual claims, which is property rights on assets after liabilities have been met. Furthermore monitoring is costly and beyond pure contract theory, because it is nearly impossible to put all necessary actions and entrepreneurial targets into a formal agreement.

M. C. Jensen & Meckling (1976) make a first attempt on deriving an equilibrium of optimal inside and outside ownership as well as ownership dispersion given agency and monitoring costs. They state that optimal outside ownership – hence the degree of separation of ownership and control – is determined by the demand of outside financing and the marginal agency costs. Since these values can differ among firms and over time, there is no such thing as a stable optimal ownership structure. This is the main reason why scholars still struggle to find an answer to the question how shares should be distributed between insiders and outsiders; even outside ownership can be distributed diversely across small and large groups and different entities like individuals, bigger institutions or even public authorities. All of these players can thus have different utility functions and monitoring costs, making this issue complex for both theorists and empiricists.

From all relevant perspectives – policy, welfare and firm – the best bet would then probably be to reduce agency and monitoring costs as they prove to be a major source of inefficiencies. Even though the authors do not provide a proper theory of monitoring, they encourage its progression. Work like those of Fama (1980) and Alchian & Demsetz (1972) points at the firm itself to ensure its productivity. In big firms – where the separation of ownership and control is most common – internal mechanisms can represent a market on its own. Managers on every level are steadily competing for higher positions. Those who are able to redirect internal resources towards the most productive use as well as those who monitor and reveal any misconduct of their competitors are most likely to be rewarded with higher positions in the future. Furthermore the external labor market is constantly judging managers and rewarding or punishing them with career-consequences (Holmström (1999); Gibbons & Murphy (1992)).

Fama & Jensen (1983a) and Fama & Jensen (1983b) focus more explicitly on resetting the classical business model of combined ownership and control, thus less diversifying a firm's capital across external investors and its consequences. They also include incentive and principal-agency problems in the sense of residual risk bearing, which can be seen as negative residual claims if the firm does underperform. This can be of high relevance for the innovation topic throughout this thesis because innovation is risky (Holmström (1989)). They also discuss monitoring tools to overcome agency problems, both formal – like the board of directors – and informal – like the stock market – but state that there are indeed potential efficiency gains if ownership and control are aligned. This, however, will result in agents holding both, residual claims and residual risk. The effect on their decisions will thus depend on their personal degree of risk aversion. This is of high relevance for investments with heavily uncertain outcomes like innovation.

The overall magnitude of the problem is challenged by Demsetz (1983) who provides some descriptive evidence on the capital structure of US firms as well as compensation of managers. The worries verbalized by Berle & Means (1932) of a complete separation of ownership and control are thus partially unfounded or at least the problem weakened over time. Even the modern organization aims at aligning manager and firm interests by endowing the former with shares. Furthermore, performance- and stock-based compensation is a common contractual tool to avoid managers to not act in the firm's best interest but is not visible if only capital structure is analyzed. On the other hand Shleifer & Vishny (1997) highlight the importance of governance by owners and stress the scarcity of formal incentive contracts for managers. The general theory that managerial ownership helps in aligning interests of owners and managers has also received early support (Lewellen et al. (1985)). However, this kind of ownership might miss important and necessary achievements in shaping the capital structure of the modern firm, described by Berle & Means (1932), like accumulating external capital and knowledge. For example, Bloom et al. (2015) find that private equity as well as dispersedly owned firms exhibit substantially better management practices than any other kind of ownership, with private individuals and the government having the lowest management quality. This shows us that external investors can offer substantial – also non-monetary – benefits to the firm.

The general assumption of divergence of interests of managers and shareholders deserves some attention and is not unchallenged. It is reasonable to assume that firm performance and long-term survival do not dominate in managers' utility function. Bertrand & Mullainathan (2003) promote the Quiet Life Hypothesis, where managers are risk-averse in order to secure their position and not to be sanctioned by their principals. Especially on the dynamic takeover market managers tend to reduce efforts in the presence of anti-takeover legislation. Such law does not foster long-term investments and efficiency gains but rather leads to fortification of current structures and higher wages. Even though this can hold for both, separation and combination of ownership and control, the work of Stein (1988), Holmström & Costa (1986) and Narayanan (1985) states that external managers who are not bound to one firm for the most of their career tend to be risk-averse. They fear to be evaluated through short-term performance and stock price changes, a hypothesis backed by Hirshleifer (1993) and Hirshleifer & Thakor (1992), such that they avoid risky investments. This phenomenon is known as Managerial Myopia and can seriously hamper innovation.

On the other hand there is also reason to assume that managers – even if they do not own substantial company shares or are subject to other contractual channels that directly bind their income to firm performance – can indeed intrinsically act in the owners' interest. In this case there would be no agency problems. Stewardship theory assumes non-opportunistic managers (J. H. Davis et al. (1997); Donaldson & Davis (1991)). Managers can merely be driven by the fulfillment of their duties and the appreciation of their efforts by employees, colleagues and competitors rather than pure tangible compensation. Especially top-managers usually do not lack motivation and also do not have to struggle to make ends meet, such that life goals can change substantially towards non-financial utility as their career progresses. These merely psychological and cultural factors can differ by country (Krivogorsky & Grudnitski (2010)). For example Lee & O'Neill (2003) show that that whereas intrinsic motivation is high among Japanese managers, monetary aspects dominate in the U.S. The best case scenario would be a matching process between firms and managers such that the latter can fully identify with the objectives of the former. Theoretical work in this field is emerging (Bandiera et al. (2015)).

In case stewardship theory dominates, there are no real agency problems. Then there would be no need to motivate managers with stock ownership, performance-based compensation or costly monitoring and the full potential of the diversified modern organization can be exploited. For owner-led firms and among them especially family firms non-financial targets have also proven to drive the managers' decisions. As performance is also a multi-dimensional concept, owners who have a long-term bond with the firm can prefer low-risk strategies to secure firm survival and the firm's reputation at the cost of short-term profitability (Martin & Gomez-Mejia (2016); Chrisman & Patel (2012)). Thus management practices that do not target financial goals – which should increase firm value and favor the owners – do not necessarily be bad for the firm. So even when ownership and control are aligned, different owners can have different objectives, such that making ownership structure the sole driver of entrepreneurial orientation might fall short.

In case ownership and control stay (at least partially) aligned, a caveat that also counters the above explained pressure from inside (Alchian & Demsetz (1972)) and outside (Gibbons & Murphy (1992)) the firm is economic entrenchment (Morck et al. (2005); Shleifer & Vishny (1997)). Executives with substantial voting rights are hedged against control and the pressure of being replaced. Not only may the firm might endow managers with shares to keep interests aligned, the manager can independently purchase shares or influence the decision process of the firm that grants her voting rights. In doing so the managers can not only reallocate financial resources towards self-interest but also lower the probability of being replaced (Shleifer & Vishny (1989)). Following this argument, there would be a lack of motivation if ownership and control stay aligned. This controverts the initial prediction by Berle & Means (1932). Theory would thus expect a trade-off between the alignment of interests and the entrenchment effect, what makes the search for the 'correct' ownership structure basically an empirical one.

In a model of firms being at risk of takeover by competitors, Stulz (1988) derives an equilibrium of moderate voting power of managers that will be able to maximize firm value, such that the optimal ownership structure might be neither the full owner-led firm nor the firm with complete externally dispersed capital. In firms that are not owner-led, the issue becomes even more complex. Not only that we can have divergence of interests between managers and external shareholders but also between different kinds of shareholders, resulting in serious principal-principal conflicts (Young et al. 2015). Firms with dispersed capital structures are driven by a variety of interests of many different parties. Where minority shareholders usually have little incentives to become active in the firm, large external shareholders are willing and able to push their interest at the expense of others. Morck et al. (2005) and Morck et al. (2000) analyze a system of few big block holding families who have control over many firms via pyramid structures. Such complexity results in substantial agency problems and strong inefficiencies with even macroeconomic impact.

The choice of the 'correct' ownership structure for the firm still is a non-trivial task and might depend on firm- and industry-specific factors. If the dispersion of capital and control is a good thing might also change with a firm's entrepreneurial targets (Ghosh et al. (2007)). Demsetz & Villalonga (2001) argue that each firm chooses its own adequate structure of capital dispersion among external investors and internal stakeholders. This would imply for the scientific community and policy makers that analyzing this concept and giving advices is either not needed or counterproductive. It also complicates empirical analyses as ownership structure is not exogenously imposed to firms. On the other hand the general concepts of agency theory, asymmetric information, imperfect markets and self-interested internal and external agents tells us that it is likely for firms to exhibit a non-optimal ownership structure with particular negative consequences. Thus, insights on the pros and cons of the separation of ownership and control – even though they depend on firm and market characteristics – can help policy makers and especially entrepreneurs.

We can thus summarize that the classical firm with the manager also being the owner can be suboptimal in many but not all cases. The increase in capital structure complexity during the past century gives us a clear signal that there can be substantial efficiency gains in leaving behind the classical owner-led firm. However, as company shares begin to spread among external agents, the level of complexity increases, such that for the researcher the modern organization provides both, a fruitful field to study and multitude of relevant factors that have to be considered. What we can say with certainty is that, if control is in the hands of external managers who bear almost no the residual risk, there is need to keep interests of owners and managers aligned to prevent shirking and self-oriented behavior. The best case scenario would be stewardship or career concerns theory to dominate, such that managers act in the firm's best interest, no matter how they are compensated. If this is not the case, owners need to implement either contractual tools or continuous (costly) monitoring. I will now discuss various ways of monitoring.

2.4.2 Monitoring External Managers

Above I described the problems that arise when ownership and control is separated and how the distribution of ownership rights can affect a firm's strategic981 orientation. As separation is common in many (mostly bigger) firms, we can suspect that firms who chose such structures certainly see the benefits. However, besides the advantage of accumulation financial capital for the firm, spreading residual risk and utilizing external expertise by hiring professional managers, the above analysis revealed some caveats like managers who are both willing and capable to re-allocate internal resources towards their own interest (Shleifer & Vishny (1989)). So if the firm decides to benefit from the financial and knowledge-based resources that come with a dispersed ownership structure, it is certainly willing to monitor the decision makers that are then at risk to be merely driven by self- rather than firm-interest. One apparent consequence might just be shirking, because unmonitored managers can prefer a quiet life (Bertrand & Mullainathan (2003); Stein (1988)). Even though M. C. Jensen & Meckling (1976) already point to the fact that monitoring is both necessary and costly, the effectiveness of monitoring is still discussed (Lane et al. (1998); Amihud & Lev (1981)). So what are effective and common ways to monitor external managers?

There are indeed scenarios where no active monitoring is necessary. The first is intrinsic motivation and managers acting as stewards of their firm, as explained in the previous section. In this case there is no substantial divergence of interests between owners and managers, no matter how ownership is distributed. However, expecting perfect intrinsic motivation is naive. Other scenarios can involve firm-internal competition among executives (Alchian & Demsetz (1972)) or career concerns (Gibbons & Murphy (1992)). The latter would require the market for managers to function, such that managers are punished for underperforming with bad reputation and low future career opportunities. Stein (1988) draws attention to the takeover market which is also disciplining managers, even though this pressure pushes short-term oriented behavior. Recent evidence points towards a non-linear effect (Sapra et al. (2014)). All these channels certainly exist in most firms and markets, but are not expected to completely offset agency problems.

Monitoring is probably low in owner-led firms. With ownership usually comes a substantial amount of voting power, such that only a manager with few or even no ownership in the firm has to give credit to owners. Even though this requires owners to be willing and able to monitor the manager's effort, we can expect significant pressure through this channel. This argument is considered to be only of minor importance by Berle & Means (1932) but is highlighted by M. C. Jensen & Meckling (1976). Investors' interest in monitoring is probably increasing in the number of shares they own in a particular firm. If a firm's capital is atomistically dispersed among a very large number of shareholders, each one of them only holds a small part of a firm's residual claims, such that monitoring costs should exceed expected returns. Then we would expect that ownership concentration in the sense of the presence of large shareholders should increase the pressure on the manager to keep acting in the owners' interest (Hill & Snell (1988)).

Furthermore the power of small shareholders over managers is also small (Lee & O'Neill (2003); Aghion & Tirole (1997); Wruck (1989); M. C. Jensen & Warner (1988); Demsetz (1983)). Large and dominant shareholders are both more willing and more able to exert discipline over managers. They are also merely risk-averse because they have a large amount of their wealth sunk in one firm instead of seeking diversification (Hlasny & Cho (2017)). Even if direct control is limited, large shareholders might increase pressure by selling or buying shares (Czarnitzki & Kraft (2009); Shleifer & Vishny (1997); Hill & Snell (1988); Shleifer & Vishny (1986)). The firm itself then does not need to implement costly (formal) internal control mechanisms. Demsetz & Lehn (1985) argue that the amount of voting rights needed to put significant pressure on managers can be small, such that the real value of large dominant shareholders again is an empirical question.

Other authors focus on special types of investors. For example institutional investors should have both, incentives to monitor their investments as well as necessary structures and expertise that facilitate it (Demiralp et al. (2011); S. Gillan & Starks (2003); Clyde (1997); G. F. Davis & Thompson (1994)). Such entities like venture, pension or private equity funds have declared investing in different entities their daily business, such that they are expected to put more pressure on managers. This is basically what distinguishes them from large individual investors (Baysinger et al. (1991)). They also mostly have medium- to long-term interest in the firm such that they support managerial decisions for necessary investments and do not necessarily push short-term rents (Sapra et al. (2014); Aghion et al. (2013); Brossard et al. (2013); Hoskisson et al. (2002); David et al. (2001); Lacetera (2001)). This could counter managerial myopia and shirking, even though there is also evidence of the opposite for some institutions are not interested in costly monitoring, especially those with only little financial commitment (Burns et al. (2010)). Conflicting results on monitoring efforts and investment decisions most likely stem from the fact that institutional investors can be quite heterogeneous (Çelik & Isaksson (2014); Cornett et al. (2007); Zahra et al. (2000)).

A Governance tool of particular interest in this thesis is the German supervisory board (Aufsichtsrat). Stock-listed firms are obliged to implement a specific board that is particularly monitoring the board of directors (*German Corporate Governance Code* (2019)). This dual-board system has the potential to control management decision making but is only implemented in a few countries, mostly in Europe and in Asian banks, and each system has its individual features. For this reason research on this topic is not abundant (see for instance Farag & Mallin (2019); Farag et al. (2018); Huang (2010); Adams 2000). Measuring the effect of implementing a supervisory board is econometrically complicated, because it is legally imposed on any listed firm. Therefore my focus also lies on the effect of stock ownership in the hands of board members. The hypotheses will be developed in the specific chapters. We can expect similar behavioral effects for monitors and executives; however, magnitudes might differ and if incentives of monitors increase the effects are not well explored yet (Audretsch et al. (2013)). Monitors owning shares will have both, the legal responsibility to assure that managers act on behalf of the firm as well as higher incentives via financial involvement. Therefore this thesis extends the theory on managerial ownership by monitor ownership and also contributes to the literature by conducting empirical tests.

Another way to ensure that strategical decisions are made in the firm's best interest is selection of executives. Even though this cannot be classified as pure monitoring, it is a process of prematurely anticipating managerial behavior, reducing agency problems before they can occur. It is usually conducted by owners in order to avoid typical problems that come with the separation of ownership and control. As for example in the U.S. the board of directors has to involve inside and outside directors, whereas both might have different objectives (Aghion et al. (2013); Baysinger et al. (1991)). Independent directors can improve a firm's Corporate Governance structure, thereby increasing firm value (Bertoni et al. (2014)). Many firms thus do implement certain board structures, in order to secure monitoring effectiveness and independence of directors' decision making processes from internal pressure (Faleye (2007); Bebchuk & Cohen (2005); Hill & Snell (1988)).

A contractual approach to assure that managerial behavior is in line with firm and owner interests is performance- or stock-based compensation. Specific compensation contracts have high potential for and directly aim at lowering agency costs (Bebchuk & Fried (2003); Elston & Goldberg (2003); Murphy (1999); Holmström (1979)). The specific embodiment of compensation schemes is nevertheless debatable. Most importantly contracts have to depict the owners' concerns in order to eliminate divergence of interests. Such concerns might differ among shareholders (families, banks, funds, private individuals) and are often difficult to put into contracts. Actual compensation is also often only weakly correlated with performance, because managers can have significant power in shaping these contracts (Bebchuk et al. (2002); Kole (1997)). Finding the right incentive scheme can thus be as complicated as finding the right mix of common entrepreneurial targets for all owners. Stock-based compensation can be a suitable first attempt to align owner and manager interests, but owners can have objectives beyond pure share value. The same is true for managers and compensation, such that they also have to be motivated or via monitoring.

So far we can conclude that there most likely is no 'best choice' ownership structure, but a mix of certain Governance tools can ascertain a functioning top management that aims at the firm's best interest. Zahra et al. (2000) recommend three major factors that combine the most important aspects discussed so far: a certain degree of managerial stock ownership; the presence of large dominant shareholders; strong monitoring by external directors. Many studies only examine one aspect of Corporate Governance or ownership, what could explain the ambiguity of empirical results that will be discussed later in this paper depending on the particular focus of my analysis. Furthermore best practice might vary with market attributes and firm types such as start-ups (Audretsch & Lehmann (2014)), a firm type I cannot account for in ownership analysis due to data restrictions (see next chapter). The complexity of how to achieve Good Governance has recently been highlighted by Boivie et al. (2016), who offer an extensive review on empirical literature with no simple final conclusion on what can be called best practice for the firm.

I will now leave theoretical considerations behind and introduce the data base for the upcoming empirical analyses. Besides patent data that has been discussed in section 2.3, I use several other sources in order to test relevant hypotheses on firm-level innovation and Corporate Governance. Information comes from different sources and is of different structures, such that a discussion on the variables and matching methods is needed before we can proceed.

2.5 Datasets Preparation and Matching Methods

In order to reveal and analyze firm-level patterns we have to use firm-level data. The foundation for any analysis is provided by the Dafne database, gathered and assembled by Bureau van Dijk. This database includes financials of German firms and is conducted from official annual reports. I thus offer information on most important financial indicators as well as non-financials like the number of employees, industry or date of foundation. Dafne statistics cover all industries as well as geographical location in Germany. Coverage of some financial indicators is however sometimes not very satisfying. Standard indicators like employees, capital or profit are widely available among a large number of firms of all categories, but the more details we want to draw from this at first sight rich dataset the more observations and firms drop out of the analysis.

In some cases imputation is possible. Most imputations nowadays are applied making use of cross-sectional correlations, like Stata's *mi impute*-style commands. Missing information in certain variables are replaced by predictions stemming from implicit regression models with the gap-variable as regressand. The problem here is that if such methods are used intensively, correlation between variables increases steadily, which in turn increases collinearity between regressors in later models. This will result in increased standard errors and in turn will make it more difficult to find significant effects even though un-imputed data could have revealed some.

Another popular and easy way to impute missing data points is not the cross-sectional but the inter-temporal one. This method can be applied if lag and forward of a variable in the same firm are non-missing, such that the missing middle part is constructed as the arithmetic mean of lag and forward. This method is easily implemented and creates imputations that result in smooth developments over time for the variable at stake. Such smoothed lines are most reasonable to assume, even though no unexpected short-time shocks can occur using this method. Another caveat is potential endogeneity in dynamic panel models. If a variable is per definition a function of her own lag and forward, exogeneity cannot be claimed. The bias is in most cases negligible, but can become serious in models like Generalized Method of Moments (GMM), which will be applied later on[18]. Therefore I decide to combine both cross-sectional and inter-temporal methods. I con-

[18]This has been tested in GMM estimations applied in chapter 4 using both imputation methods, with and without forward. Using variables imputed with lags and forwards as internal instruments leads to steady rejections of

struct a panel regression model with time and firm fixed effects as well as the lag of each imputed variable as regressors using all available observations. This is done for all financial indicators as well as the number of employees. Omitting the forward reduces endogeneity problems in later dynamic panel models. The model in natural logarithms, which reduces outliers, then is simply

$$lny_{it} = \beta lny_{i,t-1} + \gamma_i + \delta_t + \varepsilon_{it}. \qquad (2.1)$$

For the imputations the logs are then reversed and gaps in variables are filled. I only impute if lag and forward of a variable are non-missing, such that not too many data points are imputed. The final data behaves well with no serious outliers or completely unreasonable trends, and the β coefficient is in all cases highly significant[19]. Yet this approach – as I use it conservatively – increases the usable data points not abundantly. The problem that the more variables are used in any analysis the more firms drop out prevails. In every analysis that uses Dafne – or most other products of Bureau van Dijk – there is a trade-off between generality in variables and the sample size. I therefore in all cases stick to most important variables with a little experimenting if the gain of explanatory power that comes with more variables warrants the loss in observations.

Table 2.2 provides a first look at this problem. It depicts the amount of non-missing observations during the period 2001-2015 by variable, whereas above-explained imputations are already included. Patent information does not restrict the dataset as PATSTAT includes the population of published patents which I merge with the Dafne dataset; the matching procedure will be explained later in this section. We can see that most information from balance sheets is equity, tangible assets and leverage, after which observation counts drop sharply.

The variables depicted in table 2.2 are the most relevant firm-level variables Dafne can provide a reasonable amount of information on and are: number of employees (EMP), fixed assets (ASSETS), sales or turnover (SALES), staff expenditures (STAFFEXP), equity (EQUITY), liabilities by shareholder equity (LEVERAGE), cash flow (CASHFLOW), profit before taxes (PROFIT) and material expenditures (MATEXP). In the second column we can see available observations by variable. Most information is available on equity, assets and leverage. Unfortunately a very important indicator for firm size is the number of employees, which is very restrictive here. Econometric analyses on the firm level demands reasonable size indicators. Variables like sales or assets could also represent size, but they are usually highly correlated with other variables, causing collinearity or even endogeneity. Labor is usually adjusted less frequently, representing more cross-sectional

validity of overidentifying restrictions, whereas the imputation method only with lags does not.

[19] Imputation is usually non-trivial and heavily depends on the dataset used, the methods applied and the research question. Therefore there is neither a one-fits-all approach nor any standard literature with general recommendations for any particular problem. The method I apply here works for our specific problems with relatively little caveats. For a general discussion on missing data and the art of imputation see e.g. Allison (2002) or U. Jensen & Rässler (2006) for an application on German establishment data. If data is not missing at random – what is probably the case here – imputations should in general be applied conservatively (Griliches (1986)). This is what I am doing here.

than inter-temporal variation. Thus the number of employees will be used in every upcoming analysis, causing a harsh sample-size reduction. The third column of table 2.2 shows the number of observations with at least EMP available plus the corresponding variable in the respective row, where we can see the decrease in observations even after using only two variables. The fourth column requires EMP and ASSETS to be filled out, plus the respective row. The other columns increase the required variables step by step, such that in the end (lower right element) only 114,069 observations have all nine variables filled, from a set of roughly 1.3 million German firms during the period 2001-2015, what is not much at all. Going through the columns we see that after losing a huge amount of observations when EMP is required, including further variables does restrict the sample only marginally. So there are only minor changes if we include two or nine variables, such that if we consider EMP necessary, further losses are negligible[20].

Table 2.2: Available observations by variable, 2001-2015

variable	obs	EMP	+ASSETS	+SALES	+STAFFEXP	+EQUITY	+LEVERAGE	+CASHFLOW	+PROFIT
EMP	701,853								
ASSETS	5,378,676	572,289							
SALES	1,646,251	250,613	237,453						
STAFFEXP	548,247	266,609	256,774	256,755					
EQUITY	6,445,942	619,752	501,708	501,677	501,641				
LEVERAGE	5,363,593	540,818	441,484	441,461	441,437	435,874			
CASHFLOW	813,444	266,353	258,620	258,590	258,552	221,845	209,844		
PROFIT	579,055	264,923	254,527	254,497	254,459	217,817	206,055	205,986	
MATEXT	214,148	148,547	144,233	144,229	144,220	121,118	114,431	114,257	114,069

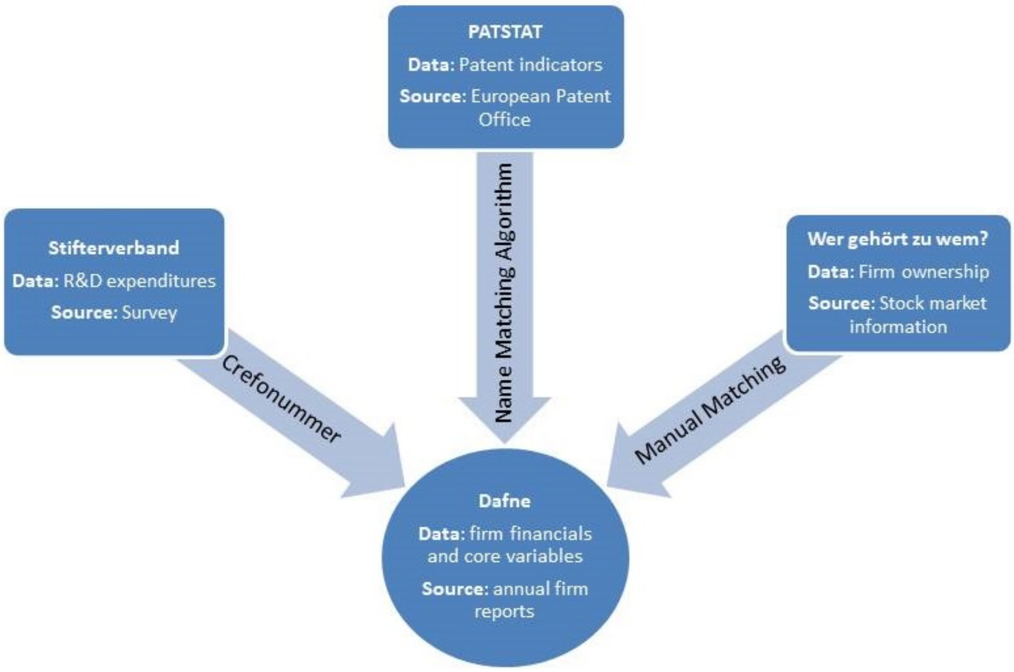
Source: Own calculations from Dafne, extracted 2015

Depending on the actual model that will be estimated throughout this thesis, the number of observations will indeed vary, also depending on other datasets used. Those are depicted in figure 2.10. The core dataset will be Dafne, but in order to get insights on innovation and corporate governance, the data in use can vary and only firm annual reports do not meet the requirement to address the issues at stake. Beside Dafne and Patstat, there is data from an R&D survey, conducted by the Stifterverband für die Deutsche Wissenschaft as well as ownership information from the *Wer gehört zu Wem?* dataset provided by Commerzbank. From the former dataset I will use only R&D expenditures, even though it contains manifold other questions on how firms innovate. To address the most important issues of this thesis, R&D expenditures will be enough at this point in order to not lose focus, which basically are patents and Corporate Governance in the sense of firm ownership structures. The data from the Stifterverband is merged pretty easily to the Dafne dataset, as both contain a unique firm identifier, the Crefonummer. This ID is assigned to each

[20] Those nine variables are only a snippet of variables available in Dafne or other Bureau van Dijk products, chosen as core indicators for research in industrial organization. More specific information is only sporadically available, such that it is not reasonable to include it. Ordering in column 1 of table 2.2 is chosen by relevance of the variables for my analyses. Addressing all possible combinations – which means not necessarily starting with EMP being filled in every case – would result in an N-dimensional matrix, which is impossible to implement here. So I chose the ordering by theoretical considerations of necessity for general microeconometric modeling.

firm by Creditreform and makes combining different datasets easy and accurate.

Figure 2.10: Datasets merged and matching methods



The *Wer gehört zu wem?* dataset has been gathered by Commerzbank and has three major drawbacks: First is simply ends in 2010. Because providing this data was done for commercial purposes by Commerzbank and collecting the data is very cumbersome, the provider decided to end the project. For this reason every analysis including this dataset is restricted to end in 2010. Second is only includes stock listed companies and a few smaller companies who provide ownership data on a voluntary basis, what again restricts the sample size in empirical analysis. Third it does not include the Crefonummer as a company ID, such that we have to stick to other matching methods. However, for the two reasons mentioned before, there are only about 700 companies in the set, such that we here rely on manual matching with Dafne data. This makes matching a little time-consuming but yields very precise results, as manual matching is in most cases superior to most machine-aided rules or algorithms.

The most complicated matching procedure is the one applied to match Dafne and PATSTAT, which I will explain now in detail. As always in matching, there is no best practice because the method of choice depends on the data available. However, each matching procedure should consist of three consecutive steps: Parsing, matching and filtering (Raffo & Lhuillery (2009)), even though the concrete configuration of each step still varies with the data. PATSTAT also includes different levels of name aggregation. Most importantly, there is in many cases a difference between an inventor (the person who hands the application to the office or is most responsible for developing the patent) and an applicant (most likely the firm employing the inventor). In case the inventor is not filing the application on behalf of his employer, inventor and applicant are the same. I use the highest available aggregation level for applicant names (the attribute PSN_NAME) in order to guarantee that we end up with the company owning the invention[21].

For the first step company names in Dafne and PATSTAT are harmonized by

- harmonizing special letters (e.g. ä, ö, ü, ß),
- removing special characters resulting from imprecise data gathering (e.g. redundant spaces and commas),
- removing legal forms (e.g. Aktiengesellschaft, Holding, Gesellschaft mit beschränkter Haftung),
- removing general information (e.g. Company, Deutschland),
- removing city names (e.g. Volkswagen Wolfsburg, Siemens Berlin)

in order to obtain maximum similar company names independent of long but irrelevant company information which could distort similarity scores. Parsing is highly recommended as company names are often written very heterogeneously and – as we realized for the DPMA which passes German applications to the EPO – are often misspelled and might even end up with different ID's.

For the second step all company information which were both included in PATSTAT and Dafne are gathered in order to not only rely on a company's name, which were the city of a company's headquarter and its zip code which were checked and harmonized as well but needed much less effort. Then similarity scores for company names (the "matching stage") and their corresponding cities are calculated; the latter ware necessary for the "filtering stage". There are several established measures commonly used in applied research which all have their own benefits and drawbacks. I decide to make use of two different scores, the Jaccard-distance measure for company names as provided in Stata's matchit command and the relative Levenshtein-distance (which is Levenshtein distance divided by the number of letters in the name with the most letters); furthermore the relative Levenshtein-distance for city names. After calculating both, Jaccard- and relative Levenshtein-distance (which are both bound between 0 and 1) for company names, they show correlation of 0.94 for final matches indicating that the choice of the measure between these two does not matter much but can for some firms increase precision.

In the "filtering stage" one has to decide for an optimal relation between recall and precision, taking into account all available information. Following Frietsch et al. (2014) who also seek to match PATSTAT and Bureau van Dijk firm data, I first define recall rate as the percentage of

[21] For Dafne I also use consolidate data if available, such that I end up with company and not just plant data. Using the same aggregation level when merging different datasets is important.

matches achieved by the algorithm:

$$REC = \frac{t_p}{t_p + f_n}, \tag{2.2}$$

with t_p as true positives and f_p as false positives and f_n as false negatives. To assess the quality of the matching results, one has to obtain a subset of "true" fits of companies to check if a fit determined by the method is correct. This will yield the precision parameter, which is defined as

$$PRE = \frac{t_p}{t_p + f_p}, \tag{2.3}$$

Thus the precision measure will yield the percentage of correct fits across all fits. Therefore a subset of firms is matched by hand using all available information from annual reports, companies' websites, business registers etc. The results is a set of 4,323 perfectly matched companies providing the benchmark for valuing the matching procedure, which is a very large amount and way beyond the 1,000 companies checked by Frietsch et al. (2014).

Next I apply a trial and error practice in order to find the maximum relation, called F-score, which is

$$F = 2 \cdot \frac{PRE \cdot REC}{PRE + REC}. \tag{2.4}$$

Thus a high F-score will yield a "good fit". All three values are bound between 0 and 1 with the F-score yielding a compromise between recall and precision.

Furthermore I move ahead of the usual approach of trying a couple of possible thresholds and comparing the results. I program an algorithm trying out any possible combination of company names similarity score, city names similarity score and zip code match. Each run of the algorithm creates a list of possible matches which is then verified with the list of perfect matches. Thus for each run this procedure calculates recall rate, precision and the F-score. This ends up with a comparison of several million possible F-scores. This technique can somehow be summarized as

$$max[F(REC, PRE)], \tag{2.5}$$

where *REC* and *PRE* depend not only on company names but also on city names and zip codes. This is way more precise than comparing – say – eleven different F-scores between a similarity score threshold between 0.85 and 0.95 as done by Frietsch et al. (2014).

This approach results in a final F-score of 0.94 compared to 0.79 in Frietsch et al. (2014). So the matching approach is of very high quality because of using two different similarity scores, using information about cities and zip codes, programming an algorithm to maximize the F-score and having a high number of perfect matches to check the algorithm.

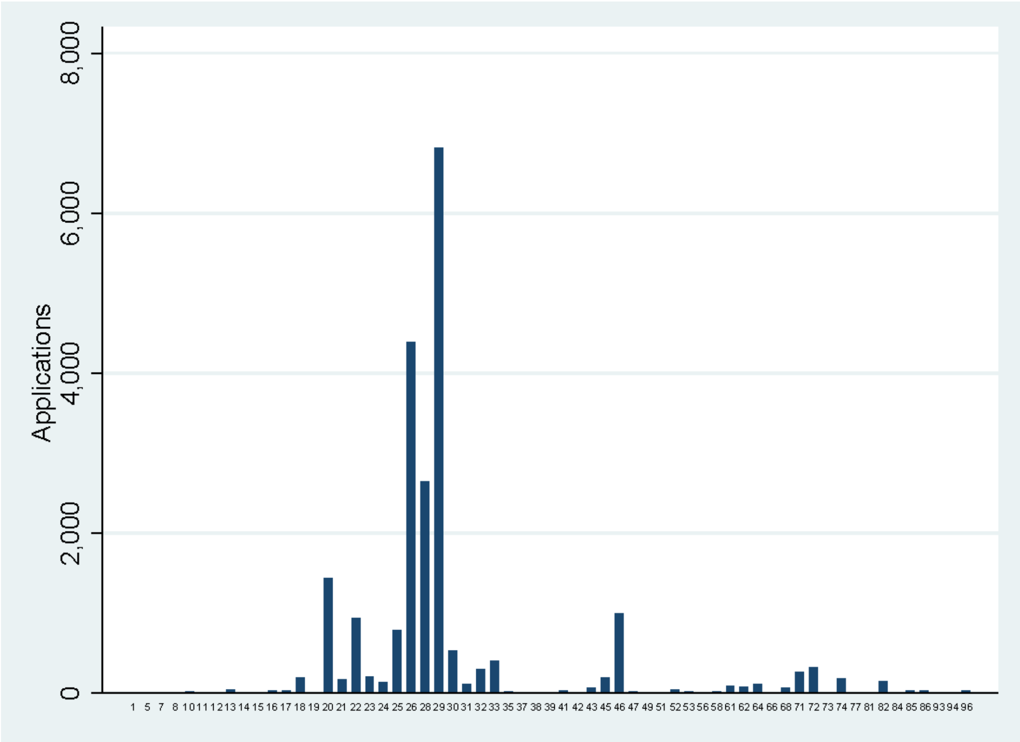
In order to further evaluate the accuracy of matching patent statistics and firm financials figure 2.11 shows applications at the DPMA by industry in 2006. We can now compare this histogram to figure 2.8 from above. What distinguishes both graphs is that NACE2 classifications come from PATSTAT in figure 2.8 and from Dafne in figure 2.11. As mentioned earlier, NACE2 codes in PATSTAT refer to patents, whereas codes in Dafne refer to firms. So both application counts should be highly correlated, even though perfect conformity is not to be expected. For instance, codes from PATSTAT are almost all from the manufactory sector , whereas it is also possible that firms from other sector file patents that are mainly of technical use and thereby are matched manufacturing sectors. Pure counts are highly correlated with minor differences. Still most applications are filed by companies in sectors like machinery, software and motor-vehicles.

However, if we restrict our sample to observations that report information on the number of employees and fixed assets – what is done in figure 2.11 to give a more representative picture of the actual usable sample – we lose some information like manufacture of electrical equipment (27). Furthermore there are notable shifts in most innovative industries like from manufacture of machinery and equipment (28) towards manufacture of motor vehicles, trailers and semi-trailers (29). This does not mean that the sample is not representative or that the matching is defective. It simply means that patents mainly stem from those industries, what is realistic for Germany. We can also see many non-manufacturing sectors being innovative, for instance wholesale trade, except of motor vehicles and motorcycles (46), Architectural and engineering activities (71), scientific research and development (72) or other technical activities. So simply cutting all non-manufacturing industries can be oversimplifying.

To specify information on company applications, table 2.4 in the appendix shows the top 50 German applicants in 2006 in my dataset, also restricting on firms that report the number of employees. Comparability to official statistics from annual DPMA reports is limited, even though they also report firms with the most applications. Reproducing official statistics is not easy and sometimes not desirable for the reason of heterogeneous measuring techniques explained in section **??**. Furthermore the definition of a firm is also heterogeneous because aggregation of multinational firms and their plants and subsidiaries is not always straightforward. Even though counts can differ, the most innovative companies are very similar to those in official statistics (DPMA 2006). Table 2.4 also includes worldwide applications, which are not restricted to priorities, such that internationally active firms can file the same invention in different countries. Firms with large worldwide application counts can thus be assumed to be active applicants in various international markets.

Because each of the upcoming chapters uses at least slightly different variables, the final samples used can differ (recall the discussion on table 2.2). Therefore I will keep further descriptive statistics to the specific chapters. At this point I was able to develop a reasonable data pool to draw observations for the later empirical models and justify matching accuracy. In addition to

Figure 2.11: applications in 2006 at DPMA by firm NACE2 industry after matching; including PCT; only firms in final sample that have EMP and ASSETS non-missing



the fact that adding more variables from Dafne to the analysis can decrease the sample size, the most restrictive database is by far *Wer gehört zu wem?*, because it ends in 2010 and focuses on large companies (mostly stock listed ones). The latter is at least not subject to a sample selection problem because ownership in small companies is less of an issue and only bigger companies make use of the option to distribute their shares. I will thus do both, analyze the interdependencies of innovation and ownership structure for this smaller group of firms and later drop the ownership dimension to substantially increase the sample size without the loss of an interesting research hypothesis on the value of innovation.

2.6 Appendix

Table 2.3: NACE industry classifications

A – AGRICULTURE, FORESTRY AND FISHING	
01	Crop and animal production, hunting and related service activities
02	Forestry and logging
03	Fishing and aquaculture
B – MINING AND QUARRYING	
05	Mining of coal and lignite
06	Extraction of crude petroleum
07	Mining of metal ores
08	Other mining and quarrying
09	Mining support service activities
C – MANUFACTURING	
10	Manufacture of food products
11	Manufacture of beverages
12	Manufacture of tobacco products
13	Manufacture of textiles
14	Manufacture of wearing apparel
15	Manufacture of leather and related products
16	Manufacture of wood and products of wood and cork; except furniture; manufacture of articles of straw and plaiting materials
17	Manufacture of paper and paper products
18	Printing of reproduction of recorded media
19	Manufacture of coke and refined petroleum products
20	Manufacture of chemicals and chemical products
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
22	Manufacture of rubber and plastic products
23	Manufacture of other non-metallic mineral products
24	Manufacture of basic metals
25	Manufacture of fabricated metal products, except machinery and equipment
26	Manufacture of computer, electronic and optical products
27	Manufacture of electrical equipment
28	Manufacture of machinery and equipment n.e.c.
29	Manufacture of motor vehicles, trailers and semi-trailers
30	Manufacture of other transport equipment
31	Manufacture of furniture
32	Other manufacturing
33	Repair and installation of machinery and equipment
D – ELECTRICITY, GAS, STEAM AND AIR CONDITIONING SUPPLY	
35	Electricity, gas, steam and air conditioning supply
E – WATER SUPPLY; SEWERAGE, WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	
36	Water collection, treatment and supply
37	Sewerage
38	Waste collection, treatment and disposal activities; materials recovery
39	Remediation activities and other waste management services
F – CONSTRUCTION	
41	Construction of buildings
42	Civil engineering
43	Specialized construction activities
G – WHOLESALE AND RETAIL TRADE;REPAIR OF MOTOR VEHICLES AND MOTORCYCLES	
45	Wholesale and retail trade and repair of motor vehicles and motorcycles
46	Wholesale trade, except of motor vehicles and motorcycles
47	Retail trade, except of motor vehicles and motorcycles
H TRANSPORTATION AND STORAGE	
49	Land transport and transport via pipelines
50	Water transport
51	Air transport
52	Warehousing and support activities for transportation
53	Postal and courier activities
I – ACCOMMODATION AND FOOD SERVICE ACTIVITIES	
55	Accommodation
56	Food and beverage service activities

Table 2.3 contd.

J – INFORMATION AND COMMUNICATION	
58	Publishing activities
59	Motion picture, video and television program production, sound recording and music publishing activities
60	Programming and broadcasting activities
61	Telecommunications
62	Computer programming, consultancy and related activities
63	Information service activities
K – FINANCIAL AND INSURANCE ACTIVITIES	
64	Financial service activities, except insurance and pension funding
65	Insurance, reinsurance and pension funding, except compulsory social security
66	Activities auxiliary to financial services and insurance activities
L – REAL ESTATE ACTIVITIES	
68	Real estate activities
M – PROFESSIONAL, SCIENTIFIC AND TECHNICAL ACTIVITIES	
69	Legal and accounting activities
70	Activities of head offices; management consultancy activities
71	Architectural and engineering activities; technical testing and analysis
72	Scientific research and development
73	Advertising and market research
74	Other professional, scientific and technical activities
75	Veterinary activities
N – ADMINISTRATIVE AND SUPPORT SERVICE ACTIVITIES	
77	Rental and leasing activities
78	Employment activities
79	Travel agency, tour operator and other reservation service and related activities
80	Security and investigation activities
81	Services to buildings and landscape activities
82	Office administrative, office support and other business support activities
O – PUBLIC ADMINISTRATION AND DEFENCE; COMPULSORY SOCIAL SECURITY	
84	Public administration and defense; compulsory social security
P – EDUCATION	
85	Education
Q – HUMAN HEALTH AND SOCIAL WORK ACTIVITIES	
86	Human health activities
87	Residential care activities
88	Social work activities without accommodation
R – ARTS, ENTERTAINMENT AND RECREATION	
90	Creative, arts and entertainment activities
91	Libraries, archives, museums and other cultural activities
92	Gambling and betting activities
93	Sports activities and amusement and recreation activities
S – OTHER SERVICE ACTIVITIES	
94	Activities of membership organizations
95	Repair of computers and personal and household goods
96	Other personal service activities
T – ACTIVITIES OF HOUSEHOLDS AS EMPLOYERS; UNDIFFERENTIATED GOODS- AND SERVICES-PRODUCING ACTIVITIES OF HOUSEHOLDS FOR OWN USE	
97	Activities of households as employers of domestic personnel
98	Undifferentiated goods-and services-producing activities of private households for own use
U – ACTIVITIES OF EXTRA TERRITORIAL ORGANISATIONS AND BODIES	
99	Activities of extraterritorial organizations and bodies

Table 2.4: Top 50 applicants according to sample from Dafne; EMP reported

Company Name	**Applications DPMA**	**Applications all**
Robert Bosch Gesellschaft mit beschränkter Haftung	3026	7483
Siemens Aktiengesellschaft	2705	7514
Daimler AG	1035	1508
Bayerische Motoren Werke Aktiengesellschaft	689	1214
BSH Hausgeräte GmbH	647	2007
VOLKSWAGEN AKTIENGESELLSCHAFT	601	885
Infineon Technologies AG	593	1340
AUDI Aktiengesellschaft	515	658
Continental Aktiengesellschaft	401	1187
Henkel AG & Co. KGaA	381	1279
BASF SE	293	4698
Airbus Operations GmbH	273	1033
Koenig & Bauer AG	251	415
Linde Aktiengesellschaft	203	539
Behr AG	195	391
Heidelberger Druckmaschinen AG	193	373
Webasto SE	175	455
Mann + Hummel GmbH	170	437
Carl Zeiss AG	158	548
Wacker Chemie AG	154	532
Giesecke & Devrient Gesellschaft mit beschränkter Haftung	153	499
Giesecke & Devrient Holding GmbH	153	499
REHAU AG + Co.	145	305
Hella KGaA Hueck & Co.	142	196
MAHLE GmbH	140	370
TRW Automotive GmbH	140	203
SCHOTT AG	122	325
Wilhelm Karmann GmbH	121	169
Carl Zeiss Meditec AG	121	328
Beiersdorf Aktiengesellschaft	118	285
MTU Aero Engines AG	116	375
KHS GmbH	113	510
Bayer CropScience Deutschland GmbH	112	1275
Johnson Controls GmbH	98	223
ABB AG	93	197
EPCOS AG	89	253
SICK AG	89	194
Eberspächer Unna GmbH & Co. KG	85	158
Deutsche Telekom AG	85	226
Rohde & Schwarz Vertriebs-GmbH	83	312
Eberspächer Gruppe GmbH & Co. KG	83	152
tesa SE	81	271
Amazonen-Werke H.Dreyer GmbH &Co.KG	76	136
Huf Hülsbeck & Fürst GmbH & Co. KG	74	187
Faurecia Automotive GmbH	73	90
Teekanne Holding GmbH	73	213
KRONES Aktiengesellschaft	72	220
Oerlikon Textile GmbH & Co. KG	72	216
Krauss-Maffei Wegmann GmbH & Co. KG	70	229
Valeo Schalter und Sensoren GmbH	66	140

3 Corporate Governance and Innovation Success

Corporate Governance and Innovation Success

Tim Grünebaum and Kornelius Kraft

(unpublished)

3.1 Introduction

Innovation is of major importance for competitiveness of firms and overall growth of economies. Even though innovation has proven to be beneficial on the firm level (Hall et al. (2013); Griliches (1986)), executives might tend to avoid promising but risky projects as they fear career consequences. Different Corporate Governance regimes shape the process of investing into innovative assets and transforming them into innovative output (Chiang et al. (2013)). Governance of innovation in turn can be affected by ownership structure of the firm (Aghion et al. (2013); Beyer et al. (2012); Ortega-Argilés et al. (2005); Hoskisson et al. (2002); Hill & Snell (1988)). This work refers basically to classical arguments made by Berle & Means (1932), M. C. Jensen & Meckling (1976), Fama & Jensen (1983a) and Fama & Jensen (1983b), stating that ownership structure heavily shapes agency and incentive schemes.

While owner-led firms imply maximal access to residual claims for the investor if the innovation project is successful, risk is also maximal. In contrast, the modern stock company can distribute risk over many shareholders (who in turn reduce risk by holding shares from many companies), but constructing an optimally designed incentive contract for executives is a complicated task (Manso (2011); Kole (1997)). With widely dispersed capital ownership, control of top managers becomes more difficult due to asymmetric information (Aghion & Tirole (1997); M. C. Jensen & Warner (1988); Demsetz (1983)). As a consequence managers might pursue non-profit maximizing projects, which serve their own interests and avoid risky innovation projects (Bertrand & Mullainathan (2003)).

The effect of Corporate Governance on innovation has been investigated with controversial results (Iturriaga & López-Millán (2017); Choi et al. (2012); David et al. (2001)). The investigation usually focuses on comparisons of input (R&D) or output (frequently patents) between different firm types. Our paper also starts with a comparison, but more important is the analysis of the success of the activities, a topic with yet only limited empirical evidence (Duran et al. (2015); Chiang et al. (2013)). Direct capital ownership might shape the innovative performance of executives and make them more conservative, resulting in less investment or a higher output per input rate as they focus on less risky projects or are more interested in the projects to succeed. Furthermore we see control as a crucial dimension. Owners are mainly uncontrolled as they do not have to give account to other investors. External managers might be disciplined if capital is concentrated in the hands of large influential shareholders.

Our approach is the analysis of R&D as the input of the innovation project and patents as output. In contrast to earlier studies we distinguish between applications, grants and citations and analyze the role of ownership structure in the transition process, thereby estimating if the chances for success of an application is determined by this kind of governance mechanism. Furthermore we also expand the literature of ownership structure by taking into account the German *Aufsichtsrat* (supervisory board) as a specific monitoring device. Germany is well suited for an examination of the success of innovation activities, as its economic performance is largely based on innovativeness. Moreover, the German patent system allows the evaluation of the value of the innovation activities by the patent office as an external and neutral institution. We analyze applications, grants and citations. In some countries the large majority of applications are also granted. This is not the case in Germany. The process of granting patents in Germany is challenging and only about 40% of all applications actually lead to granted patents, which allows us to examine the success of innovation projects.

The empirical investigation is based on a sample of German firms, combined from several sources. The data includes information on firm characteristics, R&D, patents as well as on ownership structure. Results show that owners intervening in innovation management generate less innovation output from investments, whereas external managers monitored by owners show higher innovation efficiency.

3.2 Theoretical Background on Extent and Success of Innovation Activities

Investments into innovation have specific characteristics which distinguish them from investments into other capital goods. The process from R&D to development of process or product innovations takes a long time, frequently involves high costs right in the beginning a long time before success chances can seriously be evaluated, is bureaucratically complex and risky (Holmström (1989))[1]. Expenditures for R&D are sunk, encompass largely salaries of the researchers and produce no tangible assets. Knowledge as an output of innovation is often non-exclusive to the firm, resulting in underinvestment (Arrow (1972)). Financing of R&D is thus problematic and predominantly internal resources are used (Hall & Lerner (2010)).

With respect to our topic we discuss how owner-led (or owner-controlled) firms differ from the management-led ones (M. C. Jensen & Meckling (1976)). The classical theory of the firm is based on the assumption of risk-neutral, long-run value maximizing entrepreneurs. Scarce resources like R&D expenditures are used efficiently and principal-agent and asymmetric information problems are by definition absent. We take this model as our point of reference, although below we present counterarguments to this position.

This paper focuses on incentive conflicts between managers and shareholders and how the ownership structure of the firm can counter such conflicts and facilitate an efficient innovation process.

[1] Wedig (1990) derived from the Capital Asset Pricing Model (CAPM) that R&D is around 3.5 times riskier than other assets. Ghosh et al. (2007) also find R&D investments to increase future firm risk. On the other hand Meroño Cerdán et al. (2018) see risk and innovation as independent constructs. Hussinger & Pacher (2019) show that, whereas R&D increases uncertainty, high quality patents mitigate this effect, highlighting the importance of a distinction between certain innovative measures.

This process includes the decision to invest in R&D as well the transmission process from input into output in the context of the Knowledge Production Function (Pakes & Griliches (1984)). We distinguish three kinds of firms according to their ownership structure: owner-led firms, management-led firms with dispersed capital and management-led firms with concentrated ownership. Each firm automatically falls under one of these categories.

Furthermore we consider capital ownership of monitors. The German two-tier system differentiates the board of directors, consisting of CEO and other executives, and the supervisory board, consisting mostly of external experts obliged to monitor the board of directors as a part-time job. Research on this topic is very limited, especially when it comes to monitor ownership, such that we are able to enter a promising field and can test if ownership affects monitoring intensity and effectiveness throughout the innovation process.

3.2.1 Owner-led Firms

Owner-led firms are – generally speaking – firms where executives hold company shares. There is no straightforward definition on the specific amount of shares held. Therefore we discuss the case of managerial ownership in general, which has been a research subject in several recent theoretical and empirical studies, even though no unambiguous opinion has arisen yet. Clearly any party owning shares is expected to be more focused to contribute to a firm's financial returns because of the direct involvement of her/his own wealth (Shleifer (1998)) and to abstain from pursuing own interests like empire building or maximizing non-monetary benefits from the job. The merging of ownership and control can overcome problems of high agency costs and diverging interests as unveiled by Berle & Means (1932) and formalized by M. C. Jensen & Meckling (1976), Fama & Jensen (1983a) and Fama & Jensen (1983b).

More explicitly Hoskisson et al. (2002) call managerial ownership a "governance tool". If this is true, shareholders other than the executives need not to actively monitor the top management because the sensitivity of an owner-manager's income to the market valuation of her shares works disciplining. With respect to our topic, the owner-led firm is then expected to maximize long-run profits and ensure its survival. This does not necessarily mean that the owner-led firm maximizes innovation activities. It could indeed pursue the projects with the highest prospect of maximizing firm value, a goal innovation is not always able to achieve (Hall (1993)). The long-term orientation of owners – especially speculators who invest via stock markets – has been challenged long ago (Porter (1992)).

Furthermore owner-managers can have either different incentives to push the success of innovative projects (Cosh et al. (2007)) or different management skills (Bloom et al. (2015)). Risk-aversion set aside, owners and managers plausibly have different knowledge stocks about the firm and about the market they operate in. Which of these is more favorable for innovation management is yet an empirical question. Owners should be more concerned about the firm's performance and market valuation and thus the results and rewards of research projects whereas external managers bring external knowledge and experience.

Hussinger & Pacher (2019) show that, whereas R&D expenditures increase information ambiguity and thus uncertainty about a firm's market value, highly cited patents as a visible high quality output are of pretty certain value. We would thus expect risk-averse individuals to act conservatively when it comes to investment decisions, but to be strongly motivated to transform investments into assets like patents. In this context our paper contributes to both, the literature on risk aversion of certain types of executives – we aim at finding which party this is – as well as on their motivation and skill to make innovation projects succeed. Three points can be raised that oppose the hypothesis of owners fostering innovation. First, the above mentioned "classical" hypothesis of risk-neutral owners might not be appropriate. Most likely the owners concentrate the largest part of their wealth in the firm (Hill & Snell (1988)). They therefore have every reason to be risk-averse and risk aversion is expected to rise with the extent of capital ownership. However, if an investment has occurred, owners should be interested in the project to succeed as more tangible assets like patents are rewarded by the market (Hussinger & Pacher (2019); Hirshleifer et al. (2013); Hall et al. (2005)).

Second, the literature discusses the "entrenchment effect". While a small or a very large capital share drives the management to efficient decisions, this might not be the case if an "intermediate" level of capital is owned (Morck et al. (2005); Shleifer & Vishny (1997)). If the top management holds a significant share of the firms' capital, firing them after an unsuccessful innovation project is difficult if not impossible, hedging the executives against failures of innovation projects. Then the executives might pursue activities, which are not in the interests of the other shareholders. Innovativeness might then be below the level realized in the cases of a smaller or higher capital share held by top management.

Third, determination of the CEO might not always be the result of an efficient selection process. Bloom & Van Reenen (2007) demonstrate that in family owned firms frequently the selection of the CEO is not based on maximal entrepreneurial talent, but simply the oldest son becomes at some point in time the top manager. Bloom & Van Reenen (2007) show that such firms have a quite poor performance, although family firms in general have a positive correlation with good management practices. Nevertheless, they also mention that this way of CEO selection is in Germany not very common.

3.2.2 Management-led Firms with Concentrated Capital

Executive compensation is (at least in Germany) to a large degree fixed and strongly correlated with firm size. Nevertheless, nowadays variable incentives are of significant relevance and according to Dyballa & Kraft (2020), for a sample of 405 German stock companies over the periods 2006-2011, the variable part comprises 38% of total compensation. However, of these 38% only 6 percentage points are long-run and the largest part of incentive pay is still short-run oriented. As innovation usually pays – if at all – years after investments have been made, managers will focus on boosting rapid payoffs and not long-run projects like innovation.

Furthermore innovation is risky and as managers put their job at risk if investments do not show immediate returns and shareholders are unsatisfied. Short-run monetary incentives and risk both point to the conclusion that managers without capital ownership are not motivated to pursue innovation projects. If monitoring is not possible and the contracts are not long-run incentive-oriented, the literature summarizes possible behavior of managers by preferences for quiet life (Bertrand and Mullainthan 2003), managerial myopia (Stein (1988); Holmström & Costa (1986)) or career concerns (Aghion et al. (2013); Holmström (1999); Gibbons & Murphy (1992)). Clearly, laziness' is not a valuable input for such complicated processes like innovation projects. Career concerns are more complicated. If an innovation project fails for exogenous reasons, in the case of information asymmetries the shareholders might make the manager responsible and fire him or her, implying large negative career effects. Manso (2011) points to the importance of tolerance of early failure and of long-rung incentive plans to spur innovation.

Large shareholders probably are better able to monitor managers than the typical small shareholders due to strong voting power, channeled interests and high motivation due to financial commitment (Zahra et al. (2000); Aghion & Tirole (1997); Shleifer & Vishny (1997); Hill & Snell (1988); Demsetz (1983)). Due to active monitoring they should have more information whether the failure of an innovation project is caused by management mistakes or exogenous factors. Large shareholders might induce innovation oriented behavior of managers with the implicit promise, not to dismiss them in the case of exogenously determined failure. Again risk might be a counterargument: Minetti et al. (2015) as well as Bolton & Von Thadden (1998) point to the plausible assumption that, due to un-diversified wealth, large shareholders are risk-averse and less inclined than the small shareholders to innovate. Also principal-principal conflicts might diminish if capital is less diversified among different shareholders (Young et al. (2008)). The effect of ownership concentration on innovation thus calls for an empirical test due to opposing potential channels.

3.2.3 Management-led Firms with Dispersed Capital

By inversion of the arguments in favor of the efficiency of the existence of large shareholders we expect that dispersed ownership is not helpful with respect to innovativeness. While with dispersed capital shares risk for each individual shareholder is minimized, control of the top managers is difficult (Lee & O'Neill (2003); Aghion & Tirole (1997); Wruck (1989)). Asymmetric information will in most cases be a problem, as numerous (small) shareholders have very limited knowledge about the effort of the managers and also about the impact of the executives' effort in comparison to exogenous factors on firm success. Incentives are short-run and the executives face the risk of dismissal if an innovation project fails. In Germany large shareholders are mostly long-term interested and hold their shares over many years, whereas small shareholders tend to quickly buy and sell shares as can be seen in the USA (Porter (1992), Lacetera (2001)). Consequently the former investors are more patient" with managers, providing an innovation-friendly environment.

Still weakly controlled managers may behave differently than owners. Given the career concerns hypothesis there is always the job market (Holmström (1999); Aghion et al. (2013); Gibbons & Murphy (1992)) as well as firm-internal competition for higher positions (Fama (1980); Alchian & Demsetz (1972)) constantly judging them, supplying a certain level of informal control. Theorists arguing against the need for direct monitoring assume that ambitious managers will not get away with shirking, overinvesting and misallocating scarce resources as the job market will punish such behavior. Contrary to owners who run their own company, managers always try to build up reputation and this might also be by successful innovations. Clearly, this argument relies on a functioning labor market for managers, what can be challenged considering the information problems associated with identification of the true determinants of firm success. We expect weakly monitored managers to behave more opportunistic and also more heterogeneously as their actions are merely determined by their personal interests.

3.2.4 Monitor Ownership

The German supervisory board appoints, discharges, controls, supervises and advises the board of directors (*German Corporate Governance Code* (2019)). The members can thus be seen as sole monitors and experts to secure a firm's long-term perspectives in every aspect. Whereas countries with no such institution require other actors like the capital market, unions or governmental financial supervisions to undertake monitoring actions, tasks are precisely allocated in the German system. If any system outperforms the other cannot be said with certainty and probably varies by industry and entrepreneurial target. We thus test if the presence of owners among these monitors shapes the innovation process.

As stated above, even though innovation is risky, it might be necessary for a firm's long-term survival. Monitors, who are in most cases compensated at fixed rates, should therefore be less driven by short-term interests. This could push executives to undergo innovation projects that usually increase uncertainty in the short run but pay off in the long run. So the sheer presence of professional monitors can discipline managers to innovate. However, this is not testable here because all listed firms in Germany have a supervisory board. In turn we test if monitors' incentives increase if they own shares and if this affects the innovation process. In general, owning shares makes monitors more sensitive to changes in the firm's market value, an argument reaching back to Holmström (1989) and Alchian & Demsetz (1972). For being a member of the supervisory board is a part-time job and having multiple board position is normal in Germany (Oehmichen (2011)), capital ownership should shift monitors attention towards that specific firm. Even though R&D expenditures increase uncertainty, innovation still increases market value (Hussinger & Pacher (2019); Griliches & Mairesse (1991); Griliches (1986); Griliches & Mairesse (1981)). However, Patents are of more certain value (Hall et al. (2013); Hall et al. (2005); Hall (2000)). In this case monitors owning shares should merely be interested in innovation projects to succeed instead of simply encouraging R&D investments. Furthermore, because monitors owning shares should be more concerned about the firm, they usually gather more information on how managers actually perform, rather to just take a quick look at company financials, for monitoring is costly (Tirole (2006); M. C. Jensen & Meckling (1976)). This could give managers the necessary support to undergo innovation strategies that only pay in the long run and increase tolerance of early failure. More cautious monitoring could also increase evaluation of innovation management quality throughout the process of knowledge creation. We expect entrenchment problems for monitors to be less relevant as well, because monitoring is a part-time job with plenty of room for more activism, such that commitment should increase with the amount of shares held.

We expect monitors in general to be less risk-averse than managers because their job is less at stake in case of short-term underperformance. In this case ownership can make them more risk-averse due to sensitivity to market valuation, resulting in lower investments but higher monitoring of undergoing projects. On the other hand a more long-term strategy pursued by monitors might encourage managers to undergo rather risky projects instead of those with higher probability of success (in our case of resulting in a granted patent). One could also think of monitors who interfere in projects that should be managed by executives or experts on lower administrative levels and thereby harm the process. In a nutshell, for both – managers and monitors – there a plenty potential ways how capital ownership might shape their behavior, such that empirical investigation is utterly needed.

3.2.5 Institutional Ownership

Another argument testable in this context is the role of institutional investors. The patience-argument of well-informed large shareholders from above fully applies, but might be even stronger in case of professional investors with expertise (Brossard et al. (2013); Burns et al. (2010); S. Gillan & Starks (2003); Zahra et al. (2000); Clyde (1997); G. F. Davis & Thompson (1994)). Such investors – contrary to large shareholders like individuals and families – are most likely interested in diversifying their portfolio. They are furthermore capable to do so as their financial resources are usually high. However, as such investors are often able to administer huge amounts of financial resources, they can become major players within firms. As Aghion et al. (2013) argue (and also find empirically), institutional owners both invest more into the innovation process and also generate more successful new ideas.

Particular objectives of institutional investors might differ. There is reason to believe that they are merely myopic (G. S. Hansen & Hill (1991); Hill et al. (1988)) as they seek quick returns. This could make them less interested in risky long-term projects. On the other hand studies like Hall et al. (2005), Hall (2000) and Blundell et al. (1999) have shown that innovation can pay quickly for the firm via higher market valuation. This in turn should encourage even myopic investors to innovate. Assuming rational investors, they should not dismiss innovation as such many studies have shown that innovation pays (Hall (2011)). Institutional investors might also be more pressure-resistant in case they have no business-relation with the firm they invest in (Kochhar & David (1996); Brickley et al. (1988)), such that they have more influence on the decision making process (S. L. Gillan & Starks (2000)), usually resulting in more innovation. This is usually associated with effective monitoring as investors do not directly shape corporate strategies but encourage managers to undergo certain investments (Shleifer & Vishny (1986)). In our setup we are able to test both hypotheses of such investors influencing investment decisions as well as acting as active monitors to make projects succeed.

3.3 Review of Empirical Literature

Empirical evidence on the relation between Corporate Governance and innovation in general is ambiguous as a predominant opinion is indeterminable so far (Asensio-López et al. (2019); Belloc (2012)). Few studies find a robust positive effect of managerial ownership on R&D expenditures, which is a clear input measure (Driver & Guedes (2012); Becker-Blease (2011)). Barker III & Mueller (2002) report a positive effect that vanishes after inspecting specific subsamples. Czarnitzki & Kraft (2004) for Germany find a negative effect that in turn depends on leverage. Ortega-Argilés et al. (2005) report a negative effect of the relative number of owners in management position on R&D intensity in Spain. The same holds for ownership concentration.

In some cases researchers observe a trade-off between reduction of agency costs and entrenchment if the manager's property rights become dominant to hedge her from outside control. This inverted-U effect has also been found in some studies. Beyer et al. (2012) report this result for Belgium, Ghosh et al. (2007) and S. Cho (1992) for the USA. Ghosh et al. (2007) also distinguish insider ownership from CEO ownership and find that only the latter has an effect. Contrary to this hypothesis, Mezghanni (2010) uses a similar approach for France and finds a U-shaped effect.

So even though some authors report positive effects of managerial ownership on R&D spending, ambiguous results seem to dominate (Hlasny & Cho (2017); Iturriaga & López-Millán (2017); Choi et al. (2012); David et al. (2001); Lacetera (2001); Hill & Snell (1988)). This might be due to different governance systems affecting manager's incentives (Lee (2005); Lee & O'Neill (2003); Miozzo & Dewick (2002)) or heterogeneous contracts across firms as discussed above. E.g. Lerner & Wulf (2007) find that long-run incentives for R&D managers lead to highly cited patents, while short-run incentives have no impact. Also Nguyen (2018) supports the Managerial Myopia hypothesis by showing that firms can foster innovation by implementing long-term based compensation schemes on their managers.

Iturriaga & López-Millán (2017) test if innovation input (R&D intensity) depends on different characteristics of a company's shareholders. Banks, Corporations and institutional investors seem to have an impact of a company's R&D investments, individual investors do not. Thus we can at least to some extent rule out the hypothesis that individual shareholding is the sole force of interest. We have to consider individuals in management or at least monitoring positions which we will do in our later analysis. Similarly, Aghion et al. (2013) and Brossard et al. (2013) show that institutional ownership leads to more innovation, most likely via less risk aversion and the known benefits of innovation on market valuation (Kochhar & David (1996)). Furthermore institutional owners reduce the probability that CEOs are fired in case of short-run underperformance due to high financial commitments for innovation projects, inducing the top managers to pursue such activities. In the view of Aghion et al. (2013) career concerns are more important for managerial behavior than preferences for a quiet life.

Empirical results on ownership concentration are still inconclusive. Whereas some authors find that such structures can foster innovation by alignment of interests, monitoring and tolerance of early failure (Lacetera (2001); Francis & Smith (1995)), others report the opposite even for similar geographical markets (Succurro & Costanzo (2019); Minetti et al. (2015); Ortega-Argilés et al. (2005)). The pressure applied by large shareholders has shown to significantly increase pressure on managers (Czarnitzki & Kraft (2009); Shleifer & Vishny (1997)). However, the effect on innovation is still on debate. Lee & O'Neill (2003) find effects to vary by country, where monitoring is most effective in countries like the U.S. as interests of owners and managers are more likely to differ. Thus ownership concentration can pool and thereby strengthen owner interests, increasing monitoring efficiency.

The case of family ownership as a long-term commitment to a firm has recently attracted some attention. Whereas family firms seem to invest less in R&D and are more risk-averse, they generate more innovative output (Matzler et al. (2015); Muñoz Bullón & Sanchez-Bueno (2011); Munari et al. (2010); H.-L. Chen & Hsu (2009); Naldi et al. (2007)). However, as the term family firm is under dispute (Harms (2014)), authors argue that even family firms are heterogeneous in their investment decisions and call for a more sophisticated look into family firms (Urbinati et al. (2017); Pötzl (2014); Block (2012); Chrisman & Patel (2012); Zahra (2005)). A meta-analysis on innovation in family firms by Duran et al. (2015) also considers both, input and output. Due to the manifold measure of both dimensions they are forced to gather many of such parameters into those two categories. We believe that e.g. patents (applications and grants) and innovative sales are very different and therefore focus on the former.

For monitor ownership there is very few empirical evidence (Balsmeier et al. (2014); Audretsch et al. (2013)), especially concerning its effect on innovation. For example Adams & Ferreira (2008) find that monitoring efforts of outside directors correlate positively with pay-offs they can generate from firm performance. We thus ask if monitor ownership shapes innovation strategies and increases Corporate Governance quality. Opposing effects like triggered risk-aversion or monitors interfering in innovation projects that should better be left to the experts are also easily conceivable.

Empirical studies on the determinants of innovation success – thus the proper handling of resources to generate a high output-per-input relation – are also not abundant. Wong (2013) shows that projects are more likely to succeed if managers get involved in those projects. Based on evidence by Zahra et al. (2000) that managers do so if they own shares, there is reason to believe that managerial ownership fosters innovation output. Corporate Governance quality in general has found to benefit innovation success in terms of patent quality and patent productivity (Chiang et al. (2013); Chin et al. (2009)). The relevant issue in this context is thus which theoretical channel described above dominates and thus which kind of ownership structure increases Corporate Governance quality.

A drawback of recent empirical literature is the often ambivalent use of R&D expenditures and patents as a measure of innovation effort. A clear distinction is needed in order to test the relevant hypotheses and not to mix up conclusions. Even though this issue is common knowledge in innovation economics, scholars still seem to mix incentives and efficiency. For the case of patent applications – which will be our second step of innovation production – some studies reported a negative impact of owner-led firms (Decker & Günther (2017); Chin et al. (2009); Ortega-Argilés et al. (2005)) whereas other found no effect (Hlasny & Cho (2017); Choi et al. (2012)). This could be interpreted as low incentives to innovate which might be misleading if we do not account for R&D investment, thus the first step of the Innovation Value Chain. We will do this in the next chapter and by doing so distinguish between incentives and efficiency in developing new ideas on the firm level. Moreover we also account for patent grants to deliver a more detailed picture of the innovation process. We distinguish between the pure number of ideas and their quality and thereby evaluate the role of the ownership structure in the transmission process.

3.4 Research Strategy

Our goal is to compare a sample of German firms with respect to R&D expenditures and patents. One special feature of our approach is the capability to model the clear temporal pattern of the innovation process, which is closely related to the Knowledge Production Function promoted by Pakes & Griliches (1984) as well as the structural approach introduced by Crépon et al. (1998)[2]. Our general model setup looks as follows:

$$R\&D_{it} = \beta_1 \cdot OWN_{it} + \gamma_1 \cdot X_{it} + \varepsilon_{1it} \tag{3.1}$$

$$APPLN_{it} = \delta_1 \cdot R\&D_{it} + \beta_2 \cdot OWN_{it} + \gamma_2 \cdot X_{it} + \varepsilon_{2it} \tag{3.2}$$

$$GRANTS_{it} = \delta_2 \cdot APPLN_{it} + \beta_3 \cdot OWN_{it} + \gamma_3 \cdot X_{it} + \varepsilon_{3it} \tag{3.3}$$

$$CITES_{it} = \delta_3 \cdot GRANTS_{it} + \beta_4 \cdot OWN_{it} + \gamma_4 \cdot X_{it} + \varepsilon_{4it} \tag{3.4}$$

The four dependent variables represent R&D investments as a first-step input, patent applications and patent grants as consecutive steps from the decision to innovate towards a marketable invention whose novelty has been approved by the patent office. R&D investments help in developing applications, which in turn result in grants, which can be seen as successful innovations[3]. Citations in turn can measure things like patent quality or overall impact on the market's technology level. Besides that we test the relevant hypothesis using a vector of ownership variables OWN and control variable vector X. The final specifications will be given in the results section as we test different equations with some variable transformation. The equations are estimated separately, such that they do form a theoretical construct but not an empirical structural system of equations.

We contribute to the existing debate of managerial ownership by carefully distinguishing between innovation input and output and thereby evaluating innovation efficiency. In many studies patents have in general been characterized as output. This might be true for countries like the USA where most applications are granted, but not for Germany where a firm has to carefully consider what invention to hand to the patent office. Evaluation periods can take several years and still patent offices reject a large share of applications. Simple application counts might not stand for a high innovative firm in general.

3.5 Data

To implement our analysis we combine several datasets from the period 2001-2010 in order to gather as much information as possible about firms' innovative activities. As a general basis we use Dafne, provided by Bureau van Dijk (BvD). This dataset – as it has been used in other studies – provides information about a company's financials based on annual reports. For the period of

[2]In contrast to the popular survey-based CDM model we estimate the equations separately and not as a system as the panel structure of our model allows for the time-dimension. Thus the parameters and error terms in each of the three equations are different.

[3]See section 2.2 for a discussion on the relationship between patenting, invention and innovation.

interest Dafne contains information about 1.3 million German companies. Unfortunately there is a huge amount of missings and we have to find a compromise between number of observations and number of variables included. Information on R&D expenditures is taken from an annual survey conducted by the *Stifterverband für die Deutsche Wissenschaft e.V.* on behalf of the German *Federal Ministry of Education and Research* (BMBF). The data is also reported to the European Commission (Stifterverband für die deutsche Wissenschaft (2015)). This survey can be taken as a complete inventory count of the population of German companies engaged in R&D. For this reason we set R&D investment to zero if a company does not appear in the list of companies surveyed. The survey data can easily be merged with the BvD dataset via a unique company-ID (*Crefonummer*) provided by Creditreform.

Ownership data for German companies is scarce. Even though companies usually report the distribution of their shares if not completely diffusely held (say below 1% held by a single investor), a central and reliable up-to-date source is missing. Dafne offers some information, but overall the ownership data is not sufficient for an empirical analysis. For this reason we stick to a different source in this paper which is less recent but more reliable. We take ownership data from the *"Wer gehört zu Wem?"* database provided by Commerzbank. Unfortunately Commerzbank dismissed the project in 2011. Matching with the other sources was done by hand which was time-consuming but resulted in very precise results.

Finally we take patent applications and grants from PATSTAT, provided by the European Patent Office (EPO). In this case matching was complicated and demanded a more structural approach. In matching practices there is a typical trade-off between precision and recall, meaning if we only match companies where we are 100% sure about their identity we end up with very few matches and thus a small (and maybe because of selectivity effects biased) sample. On the other hand crude matching criteria decrease the quality of the sample. We use a similar approach as Frietsch et al. (2014) who also match PATSTAT with BvD data. Alike Raffo & Lhuillery (2009) we apply a matching approach consisting of the following three stages: "parsing stage", "matching stage" and "filtering stage". Overall we improve this process by programming an algorithm yielding very precise results compared to other matching methods (see section 2.5 for Details).

3.5.1 Dependent Variables

We take four different dependent variables in order to offer a more complete picture of the innovation activities. They represent the most important steps within the Innovation Value Chain as they build on each other and follow a clear temporal pattern. We basically refer to the model established by Crépon et al. (1998) but enhance it by two additional steps and the time dimension. The first variable is R&D intensity (R&D investments divided by total sales) which will give a measure of a firm's incentives to invest in risky long-term projects. The willingness of managers to invest in R&D should serve as an indicator for their risk-aversion and long-term orientation.

In a next step we analyze the number of patents applied by a firm in a certain year as an innovation outcome. Patent applications can be seen as a stage between innovation input and output because not all applications will be granted and there is still a severe amount of uncertainty the firm has to face after applying for a patent. On average almost 60% of all applied patents in Germany are rejected after years of examination (Deutsches Patent- und Markenamt (2016)). Hence, a patent application in Germany cannot yet be seen as a successful innovation. On the other hand this critical examination system by government authorities enables us to identify a patent's quality. We therefore hypothesize that a granted patent is of higher novelty and quality than a rejected application. Of course there may be other reasons beside pure quality of an innovation that causes a patent to be rejected, such as legal issues (Harhoff & Wagner (2009)). However, a firm will be aware of such a risk and will probably put more effort in a patent's chance to be granted if it is important to the firm and its management authorities.

Table 3.1: Descriptive statistics

variable	**mean**	**sd**	**min**	**max**
APPLNPRIO	6.706625	48.65153	0	797
APPLNDPMA	7.199607	50.02308	0	840
APPLNALL	16.69512	99.71159	0	2090
GRANTSPRIO	2.915778	31.28693	0	1029
GRANTSDPMA	2.717574	25.24544	0	924
GRANTSALL	8.967434	76.55705	0	2421
CITESPRIO	2.387423	31.28388	0	955
CITESDPMA	1.245649	10.63449	0	289
CITESALL	5.050533	66.88882	0	2388
RDINT	.0089737	.0240239	0	.183231
EMP	4407.816	12900.64	3	115573
LEV	2.464538	2.871517	.0540541	33.40771
WAGES	57485.93	23797.37	14909.58	302330.5
CAPINT	98.43448	142.2845	1.194963	999.1002
SHAREMAN	.0552047	.1815319	0	1
SHARESUP	.0421954	.1476774	0	1
HERF	.4938552	.3529725	1.00e-05	1
INST	.0979552	.2146596	0	1
N	3383			

We therefore also analyze patent grants as a third target variable. This will be the first step to be characterized as a successful innovation which can now be introduced to the market. More grants will determine a firm's innovation output and any element within the firm or the market boosting the number of patent grants can be seen as a positive force for a firm's innovativeness. Moreover, firms with more grants per application can be characterized as more efficient and more cautious as they secure an invention's marketability which will in turn pay for the firm in a direct or indirect way (e.g. by securing its market position against competitors). As a last step we include patent citations. Highly cited patents have been proven as very valuable for the firm and have been used widely in empirical investigations (Hussinger & Pacher (2019); Moser et al. (2018); A. Jaffe & de Rassenfosse (2017); Hall et al. (2005)). To be cited, patents have to be granted, such that citations are the next logical step in the creation of value generating knowledge. A patent receiving a significant amount of citations proves to have an impact on the market, inspires and supports new innovations. Such a patent thus represents innovation success and is also expected to generate economic value for a firm, a hypothesis which is about to be tested in the next chapter of this thesis.

As others have pointed out, there is also a notable amount of heterogeneity in the selection of patent measures (Bakker et al. (2016); Lhuillery et al. (2016); De Rassenfosse, Schoen, & Wastyn (2014)). As a kind of robustness test we thus use three different patent measures for each of the three stages examined here: applications, grants and citations. The first is priority counts (declared as ending with "PRIO"). As discussed in sections 2.2 and 2.3, priority patents are expected to carry the highest quality or novelty among any counts. Firms should value these the highest because they are not based on former innovations filed at other markets or offices. Overall, priority patents prove to have the highest "quality" because the percentage of applications resulting in a grant as well as citations per grant are highest among all patent measures. Next are patents filed at the German patent office (declared as ending with "DPMA") to represent the domestic market only. German firms usually file their patents here first an then might take it to foreign markets. The DPMA's evaluation process is also quite demanding compared to other patent offices such that patents that are filed here should have a high chance to make it through the examination process in other countries. This can also be seen below in table 3.1 as applications are higher than priority counts but grants are lower. The final measure is worldwide patents (declared as ending with "ALL"), where most applications, grants and citations stem from as they aren't restricted to certain characteristics. So they include duplicates from the same invention filed in different countries and should therefore represent a firm's international orientation or seek for worldwide conformity and thus less risky innovations. Uniform results for our patent equations for all three patent measures should support the results. On the other hand heterogeneous results should not dismiss the models in general because they might also represent different corporate strategies. Different effects of ownership variables on each of them can rather give interesting insights on which ownership structure favors which innovation strategy and should be interpret with care.

3.5.2 Explanatory Variables

Our focus lies on different measures of ownership structure. There is e.g. no consensus about the issue of managerial ownership and different measures are applied, e.g. dummy variables (Beyer et al. (2012), Czarnitzki & Kraft (2004)), CEO-ownership (Cosh et al. (2007)), or the number of owners in management position (Ortega-Argilés et al. (2005)).We measure managerial ownership as the percentage of company shares held by the board of directors, similar to David et al. (2001), Zahra et al. (2000) and Hill & Snell (1988). We name this variable SHAREMAN. Furthermore – and as a major improvement to past studies – we are able to construct a similar variable for the supervisory board (denoted SHARESUP).

The German Corporate Governance system is constructed as a two-tier system and distinguishes between managing and supervising institutions which are board of directors and supervisory board. The former is responsible for operative decision-making and has to call the Annual General Meeting and implements its resolutions. The supervisory board represents shareholders and employees and has to ensure that their interests are reflected by the executive board's decisions. This board has to give report to the supervisory board. The supervisory board monitors and advises the board of directors and is therefore a clear monitoring tool. We test if shares held by this board shape its actions and have an impact on the firm's innovation strategy and performance. A major task of the supervisory board is the selection, appointment, contract-renewal and dismissal of executives. A subcommittee of the supervisory board, the personnel committee, determines total compensation as well as structure of the compensation packages in term of variable, fixed, short-and long-run components[4].

To extend our picture of different ownership types we also have access to information on shares held by institutional owners (INST) as well as ownership concentration, which is measured by constructing a Herfindahl-Hirschman index of a firm's shares in each year (HERF). This index also ranges from 0 to 1 where high values indicate a concentrated ownership structure and is constructed as

$$HERF_{it} = \sum_{k=1}^{N} x_{itk}^2 \tag{3.5}$$

with x_{itk} being the share of shareholder k in firm i and year t.

As control variables we use the natural logarithm of the number of employees to account for firm size (LNEMP), total assets divided by total sales as a proxy for capital intensity (CAPINT), Leverage defined as liabilities divided by shareholder equity (LEV), and the natural logarithm of average labor expenditures (LNWAGES) – thus average yearly wages – as a proxy for human capital. All models also include year and industry dummies. The latter only contains the main categories from the NACE2 classification identified by alphabetical numbers as too many dummies with only a few observations per group may distort the estimators.

In the patent equations we use patent applications at the time the application is received by the patent office and patent grants at the time the patent is granted. As a last level and measure of technological impact or relevance, we count forward citations for a 5-year period, thus the sum

[4] Details on legal issues are given in the *German Corporate Governance Code* (2019) and for a discussion on monitor incentives in Germany see von Khurja (2015).

from *t* until *t+4*. Nicholas (2008) shows that citations occur over a long period, such that only one year of citation counts would not be appropriate. This approach allows us to account for a clear temporal and causal structure. We also contribute to the discussion on the heterogeneity of patent measures (Lhuillery et al. (2016); van Zeebroeck (2011)) by offering different variables for applications, grants and citations [5]. First we count only worldwide priority patents on all three levels (APPLN, GRANTS and CITES) to avoid double counts for a specific invention. This only counts one specific invention as one patent and should represent quite radical new ideas. Second we restrict the data to patents applied in Germany as the domestic market at the *Deutsches Patent- und Markenamt*, where around 80% of all patents by German applicants are filed, such that correlation with priority patents is high but not perfect. Third we apply no restrictions, counting worldwide patents. On the one hand this leads to double counts if an invention is filed at different offices. On the other hand this procedure allows for a quality weighting if a firms decides to introduce an invention to different markets. Compared to the other measures, a large amount of worldwide applications and grants should represent worldwide conformity of innovations. Whereas priorities represent radical novelties, a spreading of ideas to foreign markets should stand for less risky ones and an international strategy. This variety of measures should either support our results in case of conformity or offer valuable insights on the importance of innovation governance on different administrative levels.

Table 3.1 depicts descriptive statistics for all variables in levels. A quick look at the relevant ownership variables reveals a heterogeneous capital structure in German stock-listed companies. Shares held by top managers and monitors are quite small but with high variation, such that our analysis can give interesting insights in what structure favors innovation strategies. Compared to other countries (see e.g. M. C. Jensen & Warner (1988)), managerial ownership is low. The same is true for institutional ownership. For a straightforward definition has not gained acceptance yet, we stick to the definition of classical investors like various funds and insurance companies (Çelik & Isaksson (2014)). However, our sample also includes firms with very high rates, such that we are able to compare all kinds of capital structures. This also holds for the control variables, which show that the sample includes a strong variety of firms.

3.6 Model Setup

The first step of the innovation process is the R&D input. Accordingly our variable of interest in eq. 3.1 is the log of 1 plus R&D expenditures divided by sales, thus R&D intensity (LNRDINT). As many firms do not invest in R&D we have many observations with zeros and therefore use Tobit regression. As standard control variable we use the log of the number of employees to represent firm size. In order to proxy the firm's human capital, we add average wages, calculated as total personnel expenses divided by the number of employees. Highly qualified workers are expected

[5] For a detailed discussion see sections 2.2 and 2.3.

to increase a firm's willingness and ability to innovate. Capital intensity could either represent the technology and the opportunity to benefit from process innovation or possible competition in resource allocation between conventional and risky investments. Financial data has been deflated by a yearly consumer price index. Ownership variables are specified as defined above. Tobit produces inconsistent coefficients (not only standard errors) if heteroskedasticity is present. Wald tests show that this is here indeed the case and therefore we apply heteroskedastic Tobit (Greene (2003)). This model is based on a replacement of the standard variance component σ by a functional form $\sigma_i = \sigma \cdot exp(Z'\alpha)$ which is obtained by inserting the log number of employees, capital intensity and industry dummies into Z' which seem to be responsible for heteroskedasticity after some pre-testing.

Another crucial issue in every attempt to analyze causal channels in any correlations between ownership structure and other firm-level variables is endogeneity (Gugler & Weigand (2003); Himmelberg et al. (1999)). Some investors – either internal or external – can be sensitive to changes in financial indicators such that they buy or sell shares if e.g. the firm is over- or underperforming. Similar reactions might occur to changes in innovation strategies with even more heterogeneous behavior of owners and investors as valuation basically depends on their level of risk aversion and their investment horizon. Furthermore shares can be given to managers as part of their compensation (Kole (1996)). So we also offer endogeneity-robust estimations. In the absence of strictly exogenous instrumental variables we apply an approach suggested by Lewbel (2012), which allows robust estimations of parameters if errors are heteroskedastic. Lewbel (2012) promotes a two-stage procedure of estimating the model without any endogeneity correction an then construct a vector of instruments $(X - \hat{X})\hat{e}$ for the second stage regression where X represents the exogenous variables and $\hat{e}$ the residuals from the first stage model. The original approach is designed for continuous dependent variables, but Lewbel (2018) and Baum & Lewbel (2019) discuss the case of non-continuous variables. Even though they encourage further work in developing specific estimators for such a case, they find no direct argument against using the original estimator. We treat all four ownership variables as endogenous[6].

As the second step in eq. 3.2 patent applications are explained. The dependent variable is a typical count data and the usually applied methods are the Poisson or Negative Binomial count data models. It has been shown (Gourieroux et al. (1984)) that in the Poisson model the coefficients are consistent even under overdispersion (provided the conditional mean function is correctly specified). Robust standard errors are consistent even if the distributional assumption is incorrect. For the Negative Binomial Estimator the coefficients are consistent under a correct mean specification, but with the distributional assumption being crucial. As discussed in detail by Long &

[6] In some cases the Hansen J-test rejects the null of appropriate second-stage instruments, such that we had to also treat more variables as endogenous. There was no clear pattern in this phenomenon, such that variables like LNRDINT or LNWAGES could not be claimed strictly exogenous in a few equations. Such cases were rare and we report results with adequate test statistics. Qualitative statements were in all cases robust to slight changes.

Freese (2014), Cameron & Trivedi (2013) and Wooldridge (2010) the variance function might be inconsistent if the dependent variable is not negative binomial. This problem does not arise for the Poisson model as a distributional assumption on the mean or variance structure is not needed. Thus, even if the dependent variable is not count, the parameters are consistently estimated and simply accounting for a robust variance estimator (as we will use clusters) will be sufficient to obtain consistent standard errors even in case of overdispersion. The Poisson Estimator is fully efficient if we do not want to make any distributional assumptions and our interest is in the mean. Thus this estimator – despite rarely applied in practice – is better than its reputation. A similar argument has been made by Hall & Ziedonis (2001) in an application on patent data. They argue that a rejection of the null hypothesis of equidispersion calls for robust standard errors. We also apply a test proposed by Cameron et al. (2009) and conclude that we in fact have to deal with overdispersion, requiring robust standard errors. The same procedure is chosen for patent grants and citations as they are all count.

As a model-improvement we apply the quasi-fixed effects panel model proposed by Blundell et al. (1999) where we proxy fixed effects by the log of pre-sample information on the dependent patent variable, which is LNPSAPPLN for applications as PATSTAT offers complete coverage of an applicant's patent history. We decide to only include this variable in the application equations because grant and citation models already include their pre-required counterpart patent variable on the right side of the equation and two explanatory patent variables cause severe collinearity problems. Past technology acquisition strongly affect firms' future innovation capabilities (Ahuja & Katila (2001)). Including explanatory patent variables also helps to mitigate problems that stem from left censoring as many firms in our sample to not innovate at all. Usually zero-inflated models could be used here, but they do not allow necessary endogeneity considerations, an issue we value higher than censoring.

First estimation attempts show that taking the mean a firm's complete pre-sample patent history is suboptimal because of underlying time trends. Therefore we only account for the pre-sample years 1995-2000, which should (and in fact do) work well as a proxy for unobserved heterogeneity in innovation capabilities for applications. For grants and citations we include applications and grants respectively on the right side of the equations as shown in equations 3.3 and 3.4. To make the model setup comparable to the equation 3.2 and to properly account for time lags between the different patent steps, these variables are calculated as a 5-year mean lag. They thus represent the mean of the subsequent 5 years before year t. We suppose that this is adequate for both grants and citations. For grants, 5 years is the average period required for a patent application to receive a grant decision (see section 2.3); for citations this period leaves some time for a grant to be cited by other innovations.

As for the R&D equation we aim at applying Lewbel endogeneity-robust estimation techniques also for patents. However, this estimator is designed (and implemented in Stata) for linear models and not for Poisson regression. The estimation procedure we apply is thus as follows: We estimate the linear model first, then store the generated instruments and include them in an IV Poisson model for which we report the results. Besides the second-step Poisson estimation, this procedures is equivalent to the original Lewbel-approach and should not generate severe problems as long as the instruments are valid, which is tested using a Hansen J-test for both the linear and the Poisson model. We thus account for several important characteristics of the data in this context, namely censoring, count data and endogeneity.

3.7 Results

Table 3.2 shows the results on R&D intensity, thus the first stage of our Innovation Value Chain.[7]. We decide to report both the heteroskedastic Tobit as well as the linear Lewbel estimator, because - unlike for the patent equations - we do not have pre-sample information on the right sight of the equation to account for left censoring in the Lewbel model. Despite expectations from earlier studies like Baysinger et al. (1991) or Beyer et al. (2012), it turns out that in our sample ownership structure has no clear impact on R&D expenditures. Only in the Tobit model shares held by managers show a significant negative effect on R&D intensity. However, when applying the Lewbel estimator the effect vanishes. On the other side capital concentration becomes slightly negatively significant, such that the hypothesis of external monitoring lowering risk aversion can be rejected.

The fact that results change by estimator points in the direction discussed above that ownership - at least for these two variables - might be endogenous in terms of shareholders reacting to a firm's R&D strategy. It is thus likely that investments are merely determined by other firm attributes, like human capital, size and capital intensity. Even institutional ownership which is a core argument of Aghion et al. (2013) does not shape the pure investment decision in our sample. We therefore now focus on the patent equations which allow us a detailed look into how investments are used and how successful the firm can convert ideas into actual innovation. David et al. (2001) state that ownership alone probably cannot explain most investment decisions and that activism of particular investors is more important, a variable hard to measure. Furthermore, personal attributes of managers have turned out to play a major role (Barker III & Mueller (2002)).

Tables 3.3 shows results for the patent applications regression, applying IV Poisson techniques using internal instruments from a linear Lewbel model. All of the results on poisson equations here show marginal effects at the mean. We believe that the process of transition from ideas to patentable inventions is best pictured by the first filing of a patent. Control variables show rea-

[7]Relevant test statistics are displayed at the bottom of the table. Wald Chi-squared tests support the overall choice of the variables. For the Lewbel-regression the Kleibergen-Paap LM test rejects the null of the matrix of reduced form coefficients on the excluded instruments having not full rank in all cases, indicating relevant instruments. The Cragg-Donald Wald F-statistic indicates that instruments are not weak and cause negligible biases if any, referring to relevant critical values taken from Stock & Yogo (2005). Furthermore the Hansen J-test does not reject the null of valid overidentifying restrictions, again supporting the use of the instruments.

sonable coefficients. Beside a positive size-effect, the coefficients for human capital are positive but only significant in the first column, which represents innovations of high novelty. Capital intensity hampers innovation, alike in the R&D equation, indicating possible competition between investments into innovative and conventional assets. Furthermore pre-sample applications also support the hypothesis of highly autoregressive innovation processes what also makes the model more suitable to the panel-structure of the data by imitating fixed effects (Ahuja & Katila (2001); Hall et al. (1986)). The coefficients for R&D intensity are positive though insignificant, what merely stems from the fact that pre-sample applications seem to capture all innovation effects. A test of measuring pre-sample applications in levels instead of in logs supports that conjecture by increasing significance for the other variables, but probably producing mismeasurement biases by severely lowering its own t-statistic.

Concerning the ownership variables we see that managerial ownership rather harms the process of transforming investments into more tangible value like patent applications (unlike Balsmeier et al. (2014); Ortega-Argilés et al. (2005); Czarnitzki & Kraft (2004)). We cannot directly interpret this in the sense of entrenchment, because it is rather the conversion of inputs into outputs where ownership attenuates managers' ability to improve the process. The same is true for institutional ownership, rejecting the hypothesis of institutions acting as monitors for the efficient use of their investments (Aghion et al. (2013)). The results imply that internal management and professional investors prove inferior to external expertise from hired managers who are not exposed to pressure from strong institutions.

On the other hand, for domestic patents in column (2), concentrated capital in the hands of fewer private owners indeed increase conversion of financial investments into tangible innovative assets via a unified voice. However, this effect is not stable throughout application measures such that capital concentration cannot be recommended in general but only for domestic patents. The results thus speak in favor of the career concerns hypothesis (Gibbons & Murphy (1992)) as well as firm-internal competition sufficiently disciplining managers (Alchian & Demsetz (1972)) but not quiet life (Bertrand & Mullainathan (2003)) or managerial myopia (Stein (1988)). The firm should rather try to increase overall human capital (in our models represented by LNWAGES which proves positively significant for highly innovative priority applications) and employ medium-level innovation experts.

In the patent grant models presented in table 3.4 coefficients for R&D intensity are positively significant in the first two columns, indicating an increasing probability of applications resulting in grants when investments are higher, whereas the number of applications is still the best predictor. Managerial ownership has no effect here, such that patent quality or novelty is not affected by inside managers. On the other hand there is a strong effect of monitor ownership. It thus seems that owners in the supervisory board indeed do monitor the innovation process after investments have been made. This holds ony for priority and domestic patents which are more risky and valuable than worldwide grants. We deduce that such authorities push novelty of innovations and also increase the chances of success, a pattern every firm should welcome. The same is true for capital concentration in case of priority patents. Institutional ownership on the other hand hampers the conversion of radical inventions into tangible innovative assets.

In the last step results on patent citations are presented in table 3.5. Control variables basically behave as in the models before with reasonable coefficients. Results on ownership are more diverse, with managerial ownership having a positive effect only on international citations, indicating a wider scope and rather international conformity than radical innovations. A strong and consistent effect can be found for monitor ownership, which positively affects all citation measures. This is another hint that owners should rather be active in the supervisory board than in the board of directors. Firms should thus make use of external managers with strong expertise and control them through an active and enthusiastic supervisory board. Also firms should consider handing shares to monitors in order to make them more concerned about how resources are used and projects are managed. Concentrated or institutional ownership as both measures of external monitoring pressure rather harm patent citations, indicating lower patent quality or impact on the overall technological level in the industry. From all ownership dimensions we examine, the only robust positive effect on a firm's overall innovation process thus stems from monitor ownership. Firms should therefore be encouraged to combine the knowledge from hired professional managers with close monitoring from owners in the supervisory board.

Table 3.2: Estimation results natural log of R&D intensity

	(1) het. Tobit	(2) Lewbel IV
LNEMP	0.0076**	-0.0035
	(1.97)	(-1.23)
LNWAGES	0.0053	0.0197**
	(0.83)	(2.03)
CAPINT	0.0000**	-0.0000***
	(2.17)	(-2.80)
LEVERAGE	0.0015**	-0.0009*
	(2.36)	(-1.86)
SHAREMAN	-0.0973**	-0.0185
	(-2.29)	(-1.38)
SHARESUP	-0.0282	-0.0114
	(-0.83)	(-1.00)
HERF	0.0040	-0.0418*
	(0.72)	(-1.74)
INST	0.0001	0.0064
	(0.02)	(0.26)
heterosk. equation		
LNEMP	-0.3763***	-
	(-7.15)	
CAPINT	-0.0019***	-
	(-3.84)	
Observations	3383	3383
Non-Zero Obs	1038	1038
firms	661	661
Log Pseudolikelihood	383.79605	-
Wald Chi^2 statistic	44.26	-
R-squared	-	0.0413
F-statistic	-	2.77
Kleibergen-Paap LM statistic	-	121.00
Cragg-Donald Wald F statistic	-	2.476
Hansen J-statistic	-	0.9995

Notes: standard errors are clustered at the firm level; all specifications also include a constant, year and industry dummies; heteroskedasticity equation includes a constant and industry dummies. Wald Chi^2 statistic statistic tests the null of no joint significance. R^2 refers to the use of GMM moment matrix. Kleibergen-Paap statistic tests the null of not full rank of the reduced-form coefficient matrix, thus irrelevant instruments. In turn the Cragg-Donald Wald statistic tests if instruments are weak; critical values vary and can be taken from Stock & Yogo (2005); here possible biases are negligible. Hansen J-statistic tests the null of exogenous instruments. $^{*}p < 0.10,^{**}p < 0.05,^{***}p < 0.01$.

Table 3.3: Estimation results patent applications

	(1) Priorities	(2) DPMA	(3) worldwide
LNEMP	0.3646***	0.2637***	0.3848***
	(5.41)	(3.71)	(2.97)
LNWAGES	0.6677***	0.3773	0.6886
	(3.21)	(1.48)	(1.46)
CAPINT	-0.0040***	-0.0032***	-0.0045***
	(-4.10)	(-3.65)	(-2.84)
LNRDINT	0.4417	0.3525	0.2467
	(1.23)	(0.97)	(0.47)
LNPSAPPLN	0.9524***	1.0086***	0.7716***
	(18.68)	(14.51)	(6.29)
SHAREMAN	-0.9093*	-0.7485**	-0.4503
	(-1.96)	(-2.13)	(-1.10)
SHARESUP	0.3719	0.2595	-0.2297
	(1.02)	(0.73)	(-0.60)
HERF	0.1358	0.3399**	0.1406
	(0.59)	(2.05)	(0.44)
INST	-0.8564**	-1.1888***	-0.7749
	(-2.20)	(-3.48)	(-1.54)
Observations	3383	3383	3383
Firms	661	661	661
p-value Hansen J-test	0.9889	0.8995	0.9994
IV tests from linear Lewbel IV model			
Kleibergen-Paap LM statistic	84.248	84.248	83.514
Cragg-Donald Wald F statistic	2.754	2.754	2.691
p-value Hansen J-test	0.7448	0.6180	0.4996

Notes: standard errors are clustered at the firm level; all specifications also include a constant, year and industry dummies; zero-inflated equation includes a constant and industry dummies. Wald Chi^2 statistic statistic tests the null of no joint significance. R^2 refers to the use of GMM moment matrix. Kleibergen-Paap statistic tests the null of not full rank of the reduced-form coefficient matrix, thus irrelevant instruments. In turn the Cragg-Donald Wald statistic tests if instruments are weak; critical values vary and can be taken from Stock & Yogo (2005); here possible biases are negligible. Hansen J-statistic tests the null of exogenous instruments. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 3.4: Estimation results patent grants

	(1) Priorities	(2) DPMA	(3) worldwide
LNEMP	-0.0242	0.2113***	-0.0415
	(-0.89)	(3.19)	(-1.20)
LNWAGES	-0.0238	0.1696	-0.1440*
	(-0.18)	(0.69)	(-1.71)
CAPINT	-0.0055***	-0.0066***	-0.0026***
	(-12.77)	(-7.25)	(-7.37)
LNRDINT	1.0032***	0.8448***	0.1239
	(3.25)	(2.84)	(0.68)
LNAPPLN	1.2630***	1.1220***	1.1698***
	(50.01)	(22.07)	(39.30)
SHAREMAN	0.0978	-0.3643	-0.1044
	(0.26)	(-0.73)	(-0.57)
SHARESUP	0.6338**	0.9353***	0.0336
	(2.49)	(3.19)	(0.11)
HERF	0.3050***	-0.0287	-0.0309
	(3.96)	(-0.15)	(-0.46)
INST	-0.4238**	-0.6847	-0.0161
	(-1.98)	(-1.06)	(-0.13)
Observations	3383	3383	3383
Firms	661	661	661
p-value Hansen J-test	0.9991	0.9909	0.7717
IV tests from linear Lewbel IV model			
Kleibergen-Paap LM statistic	84.787	82.086	82.275
Cragg-Donald Wald F statistic	2.810	2.670	2.721
p-value Hansen J-test	0.4780	0.8877	0.7226

Notes: standard errors are clustered at the firm level; all specifications also include a constant, year and industry dummies; zero-inflated equation includes a constant and industry dummies. Wald Chi^2 statistic statistic tests the null of no joint significance. R^2 refers to the use of GMM moment matrix. Kleibergen-Paap statistic tests the null of not full rank of the reduced-form coefficient matrix, thus irrelevant instruments. In turn the Cragg-Donald Wald statistic tests if instruments are weak; critical values vary and can be taken from Stock & Yogo (2005); here possible biases are negligible. Hansen J-statistic tests the null of exogenous instruments. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 3.5: Estimation results patent citations

	(1) Priorities	(2) DPMA	(3) worldwide
LNEMP	0.7191***	0.2672***	0.6239***
	(12.89)	(5.20)	(8.61)
LNWAGES	2.6001***	0.4541	1.8845***
	(15.06)	(1.64)	(8.10)
CAPINT	-0.0050***	-0.0014*	-0.0081***
	(-8.65)	(-1.67)	(-8.90)
LNRDINT	1.0279**	0.4057	0.8542***
	(2.42)	(0.45)	(3.10)
LNGRANTS	0.8790***	1.3087***	0.9440***
	(27.12)	(23.68)	(17.97)
SHAREMAN	0.9552	-0.7344	1.8414***
	(1.01)	(-0.32)	(3.43)
SHARESUP	2.4750***	1.2305**	1.9218***
	(5.21)	(2.23)	(3.63)
HERF	-0.5279***	-0.6836***	-0.3362
	(-3.75)	(-3.06)	(-1.60)
INST	0.1654	-4.6278***	-0.6497**
	(0.51)	(-3.91)	(-2.51)
Observations	3383	3383	3383
Firms	661	661	661
p-value Hansen J-test	0.3479	0.9555	0.7215
IV tests from linear Lewbel IV model			
Kleibergen-Paap LM statistic	83.116	81.229	82.612
Cragg-Donald Wald F statistic	2.770	2.782	2.698
p-value Hansen J-test	0.9527	0.8636	0.5298

Notes: standard errors are clustered at the firm level; all specifications also include a constant, year and industry dummies; zero-inflated equation includes a constant and industry dummies. Wald Chi^2 statistic statistic tests the null of no joint significance. R^2 refers to the use of GMM moment matrix. Kleibergen-Paap statistic tests the null of not full rank of the reduced-form coefficient matrix, thus irrelevant instruments. In turn the Cragg-Donald Wald statistic tests if instruments are weak; critical values vary and can be taken from Stock & Yogo (2005); here possible biases are negligible. Hansen J-statistic tests the null of exogenous instruments. $^{*}p < 0.10,^{**} p < 0.05,^{***} p < 0.01$.

3.8 Conclusion

We study the impact of Corporate Governance on innovation activities. Corporate Governance is interpreted and measured by different dimensions of capital ownership as an incentive mechanism. We find that managerial ownership leads to less applications with a later small positive effect on international citations, indicating either inefficiency or risk aversion by focusing on international conformity rather than radical innovations. There results do not recommend such corporate policy as superior to hired external managers with no financial commitment in the firm, such that it should rather stick to external experts with strong monitoring. This monitoring is most effective if owners are present in the supervisory board because they increase both the chances for a patent to be granted and the effect they have on the overall technological level of the market, measured in citations. This result is backed by multiple patent measures and proves strongest for priority patents, which represent radical innovations.

Other monitoring vehicles like capital concentration and institutional ownership also rather harm a firm's innovation strategies. Ownership concentration – if not in the hands of managers – seems to improve monitoring over managers only for certain measures. Whereas it benefits domestic applications and priority grants but nothing else, it further results in less citations, thus lower quality and overall technological impact. Institutional investors in our sample do not satisfy the expectations raised by other studies to show superior innovation performance but rather prove harmful throughout the consecutive steps of knowledge production. Overall, due to the fact that some effects vary by patent measure, firms should carefully consider to align their ownership structure and their innovation strategy in order to achieve their goals.

We conclude that the problem of external managers acting selfish rather than pushing risky but long-term orientated investments in the sense of Berle & Means (1932) is less severe. The separation of ownership and control can have certain benefits like making use of experts from a wide labor market and prevent entrenchment. Our results recommend a direct monitoring by owners via the supervisory board. Firms could also attract the attention of monitors by endowing them with shares, thereby directly rewarding them for their commitment. Our study considers major components of Corporate Governance and shows its importance for innovativeness in terms of efficiency differences with respect to the outcome of R&D investments. Expertise from external managers as a major advantage of the modern firm combined with effective monitoring benefits technological progress. We back the results by evaluating different stages of the Innovation Value Chain, considering different patent measures and applying reasonable techniques like endogeneity-robust count estimators.

4 Corporate Governance, Innovation and Firm Performance – A Dynamic Panel Approach

Corporate Governance, Innovation and Firm Performance – A Dynamic Panel Approach

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(unpublished)

4.1 Introduction

Management quality has proven to be a major driver of firm performance (Bender et al. (2018)). This quality strongly depends on the effort managers put into their enterprise which is shaped by incentives and the benefits they can generate from their effort (Lazear & Oyer (2013)). These benefits are expected to be highest if managers are also owners, a governance structure that also comes with low agency costs (Fama & Jensen (1983a); Fama & Jensen (1983b); M. C. Jensen & Meckling (1976)). We empirically investigate this classical topic for Germany and then turn to monitor ownership as an often overlooked but promising way to trigger substantial efficiency gains with fewer caveats than in the managerial case.

Whereas earlier findings on the effect of managerial ownership on firm performance are very diverse due to opposing effects and endogeneity (Demsetz & Villalonga (2001)), monitor ownership has drawn much less attention but is expected to induce different incentive shifts with notable consequences (Audretsch et al. (2013); Schulten (2013)). By endowing them with company shares, utility functions of managers and monitors align with those of owners but can induce entrenchment (Morck et al. (2005); Shleifer & Vishny (1997); Holmström (1989)), two channels with opposing effects on incentives. We expect predominant positive effects of monitor ownership because even a moderate amount of shares can induce high financial benefits relatively to low direct compensation. We are able to confirm this conjecture for performance and profitability whereas managerial ownership proves insignificant and ownership concentration as another governance tool decreases profitability as has also been shown by Aghion et al. (2013) and Bloom et al. (2015).

We furthermore contribute to the debate of performance effects of innovative assets (Mohnen & Hall (2013)) and the real value of patents (Boldrin & Levine (2013)). We test different patent measures and find citations to have the highest predictive power for firm performance alike earlier studies (A. Jaffe & de Rassenfosse (2017)).There are however no notable effects on profitability such that we can conclude that patents have a value for the firm but only on specific entrepreneurial targets, a fact managers and economists should be aware of. Our results suggest that direct effects of managerial ownership on firm performance are not universal. Instead researchers and firms should not disregard the possibility to foster monitoring effectiveness by endowing monitors with company shares. These conclusions are backed by our empirical procedure of recently improved Generalized Method of Moments (GMM) techniques (Kiviet (2020); Kripfganz (2019)).

This paper is structured as follows: Section 4.2 provides an overview on theoretical channels and empirical findings on ownership and innovation affecting firm performance. Section 4.3 describes our estimation strategy in making performance effects quantifiable via a structural production function approach and discuss different measure. Our dataset as well as first descriptive insights are presented in section 4.4. Section 4.5 carefully explains our path towards a reasonable empirical specification, includes final results and robustness tests and section 4.6 concludes.

4.2 Development of Hypotheses

4.2.1 Managerial Ownership and Firm Performance

Besides manifold empirical investigations, results on the effects of managerial ownership on firm performance are still inconclusive. So first we give a quick summary on results and more importantly theoretical considerations in order to then motivate our hypothesis for different incentive schemes in case of monitor ownership.

In an early study Morck et al. (1988) already find an inverted-U shaped effect on company valuation represented by Tobin's Q. These results are partially supported by a theoretical model by Stulz (1988), who states that firm value increases with managerial voting rights, a factor highly correlated with ownership. At the same time Hill & Snell (1988) were not able to report a similar effect. More recently and using different methods and sample, other studies were either able to report positive (Lilienfeld-Toal & Ruenzi (2014); Drakos & Bekiris (2010a); Boyer & Ortiz-Molina (2008); Erickson et al. (2005); Jones & Mygind (2002)), negative (Bertoni et al. (2014); Giovannini (2010); Mandací & Gumus (2010)), U-shaped (C.-J. Chen & Yu (2012)) or even higher polynomial effects (Cheng et al. (2012); Cui & Mak (2002)), only to name a few. This already highlights the heterogeneity of the ownership-performance link and the complexity and sensitivity of its identification (Dalton et al. (2003); Barnhart & Rosenstein (1998)). Furthermore definition of firm performance and profitability is non-trivial and may drive the results (Tangen (2005)).

There are still two major theoretical channels. The first is alignment of interests of managers and shareholders. Both parties are seen as utility maximizers, whereas their utility functions differ. Managers draw utility from classical monetary values like compensation, but also from other measures like reputation or job security. Not all of them are correlated with the shareholder's interests, which are mainly profits or market valuation. Combining managing and voting power helps in aligning interests and thereby lowering agency costs (M. C. Jensen & Meckling (1976)) and information asymmetries (Boyer & Ortiz-Molina (2008)).

This argument is nevertheless debatable. First, interests of shareholders might also differ substantially (Demsetz (1983)). The major argument in favor of negative performance effects of managerial ownership is entrenchment of the manager. It states that the usual risk for an externally hired manager of being replaced decreases with his voting power (Morck et al. (2005); Bebchuk & Cohen (2005); Shleifer & Vishny (1997); Morck et al. (1988)). In such firms 'lazy' managers would be less sanctioned in cases of underperformance because their position is less at stake. Furthermore higher voting rights also increase their power over reallocating firm assets towards personal interests (Lippi & Schivardi (2014)). In contrast, even if managers own shares and face less pressure from owners, indirect consequences of reduced effort would be reputation losses, usually called career concerns (Aghion et al. (2013); Holmström (1999); Gibbons & Murphy

(1992)). Furthermore even in family firms where we would expect a very rigid top-management, Kotlar et al. (2014) find family members struggling for their position.

Both aspects, alignment of interests and entrenchment, might indeed balance out. Demsetz & Villalonga (2001) find no overall effects of managerial ownership and concentrated ownership on a company's market valuation after accounting for potential endogeneity. This might be a hint that ownership structure is rather determined by performance than vice versa. This conjecture, included in the theoretical model by Aghion & Tirole (1997) and empirically supported by Wang & Shailer (2015), Drakos & Bekiris (2010b), C. R. Chen et al. (2006), Erickson et al. (2005), Gugler & Weigand (2003) Himmelberg et al. (1999), Barnhart & Rosenstein (1998), M.-H. Cho (1998) and Kole (1996), strengthens the argument of controlling for endogeneity in any ownership-performance relationship. We therefore use IV-based techniques.

From a juridical perspective, managerial ownership is legal and common in Germany, even though a reasonable degree of independence should be maintained which is not explicitly regulated. Incentive effects are still highly debatable, calling for further empirical investigation (Schulten (2013)).

4.2.2 Improving Firm Performance through Effective Control Mechanisms

We now turn towards monitoring as another promising way to reduce agency costs. Whereas the unbundling of management and control should trigger severe and obvious conflicts of interest, monitoring might be a strong governance tool to bring in line interests of shareholders and (externally hired) managers and furthermore counter entrenchment. Reviews on the interdependencies of corporate governance and ownership are provided e.g. by Connelly et al. (2010) and Denis & McConnell (2003). Koeberle-Schmid et al. (2009) find that monitoring is associated with higher firm performance whereas Garg (2013) states that excessive board monitoring of CEO activities can yet harm the firm. Theoretical work by Tirole (2006) and Aghion & Tirole (1997) predicts that principals have higher incentives to monitor (or even take control over) the most important decisions whereas they delegate the lesser important ones to agents. So increasing monitoring quality can have momentous effects. Adams (2000) even states that monitoring intensity might be a (non-linear) function of managerial ownership, indicating an endogenous system of managing and monitoring. On the other hand, there is also reason to expect no effect, such that an empirical test is needed. For instance the seminal study by Amihud & Lev (1981), which strongly promotes the benefits of monitoring, is seriously challenged by Lane et al. (1998).

We test if owners are also better monitors by considering the German two-tier system of legal separation of management (Vorstand) and supervisory board (Aufsichtsrat) which allows us to clearly disentangle effects. The former party has been discussed in the previous section. Now we develop hypotheses for monitor ownership from theoretical considerations and (scarce) previous findings. Furthermore we shortly discuss ownership concentration and institutional ownership as measures of external monitoring. As only few countries have a specific board only for monitoring, strong external shareholders might take on this task, calling for a comparison between these two concepts.

4.2.2.1 Monitor Ownership

"How can one improve the incentives for the monitor? By making him financially responsible for the consequences of his judgments" (Holmström (1989)). This simple statement – going back to arguments verbalized by Alchian & Demsetz (1972) – has still attracted very little attention from scholars compared to managerial ownership but can offer notable benefits. The above explained trade-off between reduced agency costs and entrenchment for managers that comes with alignment of ownership and control can be different in the case where owners are not directly involved in the management process but are controlling (external) agents. Basically we hypothesize that monitor ownership will have a more explicit positive effect on performance via increased monitoring effort and offer four major arguments.

The first very obvious point is compensation. The *German Corporate Governance Code* (2019) (paragraph G. 18) recommends compensation for members of the supervisory board to be merely fixed, leaving plenty of room for further incentive boosts. Where managing a company is a full-time job, being a member of the supervisory board is usually a side job. Pay-offs from increasing market valuation of their shares will be equal for monitors and managers. However, relative effects on their utility differ. Since managers already generate returns from increased firm performance due to common variable compensation and bonuses, such gains are – if any exist – much smaller for monitors (von Khurja (2015)). Thus, increasing monitor shareholding also increases their relative concern about this particular firm's financial development, encouraging them to strengthen their monitoring activities. Full-time managers already put all their effort into the firm such that relatively small returns from increased share value or dividends should tend to play only a minor role. This incentive effect for managerial ownership exists but has proven to be complex (Kole (1997)). We thus enhance the view of Shleifer (1998) by stating that incentive effects should be higher for monitors than for managers. Furthermore monitoring is costly and will only pay if benefits like residual claims or share value growth are sufficiently high (Tirole (2006)). Adams & Ferreira (2008) find that monitoring efforts of outside directors can increase already with relatively modest financial rewards.

Second, a person might be part of many different supervisory boards at the same time, in which case they have to split their effort between these positions. In an extensive study on Germany during the 2000's, Oehmichen (2011) finds robust support for this hypothesis, showing negative effects of multiple board positions on return on assets and return on invested capital. On average each supervisory board member had 2.07 extra positions in other firms, showing that most German stock-listed companies are exposed to such characteristics. For our analysis this means that endowing supervisory board members with company shares should shift their incentives towards the company they partially own. The firm can thus amplify its importance within the monitor's utility function to a higher extent than it could for the manager, who already is fully concerned with the firm's interest.

The third incentive mechanism that might differ between managers and monitors is job risk. Managers have higher power over a firm's strategic orientation and are held more responsible. Consequently, if there is need to replace any decision maker, the first mechanic usually is the monitor to replace the manager. The former is thus less concerned about short-term firm performance than the latter. Managers not only might lose their job but also gain negative reputation for future positions, usually called career concerns (Aghion et al. (2013); Holmström (1999)). This is expected to weaken the entrenchment effect and should be of less importance for the monitor because of lower job risk and mellow consequences in case of dismissal. On the other hand Ertimur et al. (2012) find significant negative reputation effects for bad monitoring, calling for further empirical investigation of the relative magnitude of the channels.

Fourth and finally, entrenchment effects could differ. Members of the German supervisory board need to preserve a certain degree of independence, but without a strict threshold (Metten (2010)). Even though stock ownership of monitors is not explicitly prohibited, ownership structures causing strong conflict of interest are to be ruled out (von Khurja (2015)). As the supervisory board is by law obliged to the firm's interest, stock ownership should via the alignment of interest argument not cause serious problems. Entrenchment might be an issue and has been considered by German and European law but should occur less frequently than in the managerial case due to legally claimed independence of the supervisory board.

Putting these arguments together we hypothesize that holding shares should shape monitors' behavior to a greater extent than it should do for managers. The latter case has been widely discussed in the literature (see the previous chapter). For monitors there are still considerable research gaps, both theoretically and empirically. One of the few existing empirical studies on this topic is that of Audretsch et al. (2013) who focus on members of the firm-owning family having monitoring rather than managing positions. The authors argue that families managing their own firm display per se weak or no monitoring because they do not have to give account to external shareholders. The authors find positive performance effects in family-monitored firms similar to Hülsbeck et al. (2012). We will test if this holds as a general rule also for non-family firms. Comparable studies include those of Erickson et al. (2005) for Canada who reports that insiders are better monitors and Cheng et al. (2012) for Hong Kong who find more complex non-monotonic effects. Recently van Aaken et al. (2020) find that monitoring efforts of the German supervisory board decrease with overall family ownership, indicating that owners tend to undertake such tasks. We hypothesize that having owners in the supervisory board can amplify those efforts.

4.2.2.2 Ownership Concentration

A governance tool in the tradition of M. C. Jensen & Meckling (1976), refining the argument of Berle & Means (1932) is aligning shareholder interest. With unbundling ownership and control comes not only divergence in interests of those two parties but also in interests of different owners. Demsetz (1983) replies to this statement by pondering positive effects of ownership concentration like reduced agency costs and negative ones like lower management ability of dominant owners. The latter is supported by Aghion et al. (2013) and Bloom et al. (2015).

From a monitoring point of view, concentrating company shares in the hands of only a few very powerful parties can cause convergence of interest (Burns et al. (2010)), whereas dispersion can decrease monitoring effort due to lower monetary returns per party (Aghion & Tirole (1997)). Even if those parties do not actively have control over strategical decisions they can increase pressure on (external) managers and are thereby an effective control mechanism (Czarnitzki & Kraft (2009); Shleifer & Vishny (1997); Shleifer & Vishny (1986)). Hence concentrated ownership might be a substitute for legal regulation to achieve management control. A clear advantage over managerial stockholding is the likely absence of entrenchment effects.

Ownership concentration has often proven to increase firm performance (Singal & Singal (2011); Mandací & Gumus (2010); Kapopoulos & Lazaretou (2007); Wruck (1989); Hill & Snell (1988)). There is however also evidence of the opposite, originating most likely in lack of consensus between different types of shareholders (Hamadi (2010); Erickson et al. (2005); Shleifer & Vishny (1997)). Effects also seem to differ by industry and country (Margaritis & Psillaki (2010); Heugens et al. (2009); Denis & McConnell (2003)) and have also found to be non-linear with no straightforward conclusion on an 'efficient' level (Balsmeier & Czarnitzki (2017)).

Demsetz & Villalonga (2001) argue that ownership structure in general might be determined endogenously, such that the firms and markets we analyze tend to reflect an ex ante selection mechanism and no effect we observe is causal. The heterogeneity of the concentration-performance relation has still not vanished as theoretical concepts and empirical methods are still being refined (Wang & Shailer (2015)). We therefore apply methods that could make causal effects observable.

4.2.2.3 Institutional Ownership

The dataset also allows us to identify an investor's identity. We make use of it to also test a prominent hypothesis of institutional investors exhibiting special governance features. Whereas every investor is interested in an increase in share value, particular interests like investment horizons might differ (Hill et al. (1988)). However, the specific pattern is on debate. Whereas institutional investors might – as they manage severe amounts of capital in different firms – have low interest to actually monitor a specific firm, there is also reason to assume the opposite due to higher financial commitments and high pressure from their 'customers' (Connelly et al. (2010); Brickley et al. (1988)). Furthermore they most likely have high expertise in investing and can do both, ex ante choosing the most profitable investment target and then gathering relevant information to provide effective monitoring (McCahery et al. (2016); K. H. Chung & Zhang (2011); Aggarwal et al. (2011); Parrino et al. (2003); R. Chung et al. (2002)). In doing so they can discipline managers to not draw financial resources from the firm in the sense assumed by Berle & Means (1932).

Evidence on the direct effect of institutional ownership on firm performance is mixed (Cornett et al. (2007); Sundaramurthy et al. (2005)). Yet the topic steadily attracts interest of researchers for institutional investors play a major role in almost all developed countries (Dyck et al. (2019)). Studies like Michel et al. (2020) Nashier & Gupta (2016) and V. Z. Chen et al. (2008) report an overall positive effect of institutional ownership on firm performance, indicating effective monitoring, whereas Tsouknidis (2019) reports the opposite. The often contradicting empirical findings point in the direction of a more complex relationship and the literature on this topic is emerging. Many factors have proven to be relevant, such as concentration of institutional capital in a firm, the level of firm-specific risk and the ability of the investor to influence the manager (Hutchinson et al. (2015)), investment horizon (Neubaum & Zahra (2006)), investment objective and their monitoring ability (Muniandy et al. (2016)) and of course investor type (Ruiz-Mallorquí & Santana-Martin (2011); Johnson & Greening (1999)). K. H. Chung & Zhang (2011) also state and find that institutional investors merely gravitate towards firms with effective Corporate Governance structures. Thus, if endogeneity is not taken into account, any (positive) correlation we find might be driven by selection and reverse causality (Charfeddine & Elmarzougui (2010); Duggal & Millar (1999)), what again motivates our empirical approach. As institutional ownership is just one dimension of corporate structure capable of shaping a firm's governance system, we will not go into further detail to split institutional investors into different categories. If there was a general (less diversified) effect on any of our performance measures, our estimation procedure should be able to identify it.

4.2.3 Innovation and Performance

We now expand the ownership topic by innovation. Here we use patent data in order to contribute to the discussion on the actual value of patents for the firm (Boldrin & Levine (2013)). The Oslo Manual classifies patents as intellectual property related activities where data is easily available but at the expense of an incomplete coverage of a firm's innovative behavior (OECD/Eurostat (2018)). Hall et al. (2013) shed light on the empirical fact that despite innovation is important for many firms, relatively few of them actually do use patents for intellectual property protection[1]. They nevertheless find positive effects on firm turnover, promoting the patent system as a beneficial tool for firms and proving patent data to be valuable for the researcher (see also Griliches (1990) and Basberg (1987)).

[1] In our sample around 52% of the firms apply at least for one patent during the whole observation period of 2001-2010. However, we only include listed firms in our analysis to rule out a bias for the ownership variables. In such firms innovation is usually more common than in smaller firms.

Firms are nevertheless not obliged to patent their innovations. A typical drawback is the disclosure of detailed information about the innovation, which offers competitors the possibility to 'invent around', even despite legal protection. Other caveats are strategic utilization, inappropriateness in service or management innovations and industry- or size-driven biases (Kemp et al. (2003)). Hussinger (2006) argues in favor of patent protection by finding that patents improve innovative sales whereas innovations kept secret do not, a result also backed by Hall & Sena (2017). Dang & Motohashi (2015) also find patent stocks to be a good indicator of firm innovativeness.

Several studies have found a robust positive effect of patents on performance indicators (Hall & Sena (2017); Boeing et al. (2016); Maresch et al. (2016); Hall (1999)). Whereas Löfsten (2014) for Sweden finds significant positive effect on sales, there is none on profitability. On the other hand Roper & Hewitt-Dundas (2015) compare a firm's quite static patent stock to dynamic knowledge flows and find that only the latter contribute to innovative output. Artz et al. (2010) see patents only as intermediate innovative assets without a direct impact on performance, a statement that fits evidence for the UK (P. A. Geroski (1995); P. Geroski et al. (1993)). Comparable studies for Germany include Ernst (2001) as well as Czarnitzki & Kraft (2010) who argue that – despite a substantial time lag – patents can positively affect firm financials.

A measure showing rather strong correlation with performance indicators is patent citations (A. Jaffe & de Rassenfosse (2017)). Following Trajtenberg (1990), scholars have found robust evidence for citations pushing market value (see e.g. Hirshleifer et al. (2013); Hall et al. (2005)). Recently Hussinger & Pacher (2019) show that, whereas R&D investment increases uncertainty about a firm's market value, highly cited patents can counter this effect. Citations can thus be used for measuring patent quality and furthermore investigating spillovers between competitors as well as the absorptive capacity of firms (Mancusi (2008)). Thereby patents can have two opposing effects on innovation competition: Preventing competitors from making use of the same (or very similar) technology and spreading new ideas via spillovers, the main reason why firms might hesitate to apply for patents (Mention (2012))[2]. We will thus compare grants to citations in order to find the measure with the highest predictive power when it comes to performance and in a next step investigate Corporate Governance schemes via different ownership structures.

The literature on the innovation-performance or innovation-productivity relationship in general without an explicit focus on patents is way more extensive, so we will just give a quick and non-exhaustive reply on that topic in order to classify our approach. Sound literature reviews are offered by Mohnen & Hall (2013), Hall (2011), Cohen (2010) and Kemp et al. (2003).

Early empirical work on the role of R&D for US firm growth already show both, the power of innovation in explaining significant percentages of productivity growth, and the complexity in es-

[2]For a detailed discussion on different patent indicators and their utilization see section 2.2.

timating direct causal effects (Griliches & Mairesse (1991); Griliches (1986); Griliches (1986); Griliches & Mairesse (1981)). Despite low data quality compared to recent available sources, the conclusions basically remain. Innovation (in this case R&D) has proven to have strong predictive power for productivity, employment growth and market share (Calvino & Virgillito (2018); Peters (2008); Ettlie (1998)). However, even if data availability and methods for statistical identification of causal effects have developed substantially during the last decades, results still depend on aspects like industry, country and measures applied (Coad et al. (2019); Baum et al. (2017); Bowen et al. (2010)). Results have become more diverse when researchers began to turn towards countries outside the OECD (Crespi et al. (2016); Crespi & Zuniga (2012)).

Besides quantitative measures like patent counts and R&D investments, surveys have been used widely in economics of innovation (Mairesse & Mohnen (2010)). They let us distinguish two major types of innovation: new products and new processes[3]. Product innovations allow the firm to enter a (partially) new market. Process innovation basically serves as a cost reduction for existing products, providing a comparative advantage in a given market. The most common source for multidimensional firm-level innovation data is the Community Innovation Survey (CIS). Since the seminal work of Crépon et al. (1998) a battery of studies has been using this survey in a structural equation environment to portray and analyze the knowledge generating process within the firm, reaching from investment decision towards innovative sales. This model has yet been improved (Baum et al. (2017); Peters, Roberts, & Vuong (2017),Peters, Roberts, Vuong, & Fryges (2017)) to better understand dynamic end simultaneous innovation processes. Survey-based information has since then proven to have significant predictive power for firm performance (Hall et al. (2009); Griffith et al. (2006)).

We will now leave theoretical considerations and recent evidence behind and develop our model. We apply a well-known structural approach that will lead us to an econometric specification that will be able to estimate causal effects of ownership structure and innovation.

4.3 Estimation Strategy

We will as our main model estimate a Cobb-Douglas style production function with the natural log of sales as the dependent variable. This is only one way to identify determinants of firm performance but offers a sound theoretical foundation also specifically for innovation (Harhoff (1998)). We will also account for unobserved heterogeneity in order to make full use of our panel structure. The basic model to be estimated is then

$$Q = F(K,L,M) = \eta \cdot K^{\alpha} \cdot L^{\beta} \cdot M^{\lambda} \tag{4.1}$$

[3] Indeed there are other innovative assets like service and management innovations. However, their definition is cumbersome and their value for the firm has in most cases proven to be smaller than products and processes (Atalay et al. (2013)).

where capital (K), labor (L) and material (M) are the typical input factors with respective elasticities generating Q as output. We have already added firm specific productivity η. The inclusion of material is already an improvement to what we call the 'classical' production function. Estimation then requires taking natural logarithms and adding a vector of j control variables X_{it} with parameter vector ϕ as well as indices i for firms and t for the year of observation, resulting in the econometric model

$$LNSALES_{it} = \alpha \cdot lnK_{it} + \beta \cdot lnL_{it} + \lambda \cdot lnM_{it} + \phi \cdot X_{it} + v_{it} \tag{4.2}$$

with v_{it} being an econometric error term and Q replaced by the natural log of empirically observed company sales LNSALES. X also includes the variables of interest as explained above, which are innovation and ownership information. v_{it} then includes unobserved firm productivity and an *iid* error term, thus $v_{it} = \eta_{it} + \varepsilon_{it}$.

Empirical identification of the relevant coefficients is non-trivial. Griliches & Mairesse (1995) provide a critical review of the literature from the original theoretical concept of the Cobb-Douglas function towards applications on micro data and address several problems like simultaneity and misspecification. However, econometric techniques have constantly been improved such that we are capable to disentangling effects of pure input factors, unobserved firm productivity and other key factors (Aguirregabiria & Slade (2017)).

Estimating model 4.2 with simple panel methods like the fixed effects estimator will cause biases and requires productivity to be time-invariant. The reason for the former is closely related to the problem in autoregressive panel models described by Nickell (1981) and stems from firm-internal input adjustments. As fixed effects usually represent firm-specific productivity they are known to the firm, shaping the choice of input factors and triggering endogeneity (Alonso-Borrego (2010); Aguirregabiria (2009)). We thus seek for a method accounting for firm-specific heterogeneity as well as endogeneity.

Besides the classical production function we also contribute to the debate of heterogeneity of performance measures (Tangen (2005)) and test if incentive mechanisms triggered by ownership reallocation differ by entrepreneurial target. In this case we test if ownership structure has notable effects on profitability measures return on assets (ROA) and return on equity (ROE). These measures are also of high interest for shareholders because they usually shape market value of shares, dividends or other payouts with direct influence on shareholders' utility. We therefore expect significant incentive boosts for decision makers if they are endowed with company shares. Considering our arguments from section 4.2.2 such boosts should be even higher for monitors because benefits from increased profitability easily outweigh their traditional compensation.

The technique we will apply here is the Generalized Method of Moments (GMM), developed for panel data by Arellano & Bond (1991) and enhanced by Arellano & Bover (1995), Ahn & Schmidt (1995) and Blundell & Bond (1998), introducing new sets of potential moment conditions. This method uses instrumental variable estimators without explicitly requiring external instruments but lags and differences of endogenous variables. Detailed explanations of the method are offered by Baltagi (2013) and Behr (2003) among others. Blundell & Bond (2000) also offer a direct application of their System-GMM or Sys-GMM estimator to production functions, showing substantial efficiency gains. Other studies have since then used GMM techniques on different issues and using it for productivity estimation has often proven reasonable (Hirsch & Mueller (2012); Conti (2005)). Other approaches to deal with endogeneity problem in dynamic panel data models not applied in this paper ae offered by Olley & Pakes (1992), Levinsohn & Petrin (2003) and Wooldridge (2009) who use other internal information to eliminate firm specific heterogeneity.

In our application we make use of a recently developed statistical package for Stata: *xtdpdgmm* (Kripfganz (2019))[4]. The up to then latest package that has been used widely is *xtabond2* (Roodman (2009)), offering Sys-GMM introduced by Blundell & Bond (1998). Besides strongly improved user-friendliness in specifying the model and the instrumental variables, *xtdpdgmm* offers a new set of non-linear moment conditions discussed by Ahn & Schmidt (1995). These moment conditions, resulting in an increased number of potentially valid instruments, improve efficiency relatively to the original Arellano & Bond (1991) estimator but are redundant when Sys-GMM (Blundell & Bond (1998)) is used. However, the instruments introduced by the former sometimes display poor efficiency and those from the latter are not always valid.

Making use of all information at hand, the available moment conditions are as follows: Introduced by Arellano & Bond (1991):

$$E[\mathbf{X}_{i,t-s}\,\Delta v_{it}] = E[\mathbf{X}_{i,t-s}\,\Delta(\eta_i + \varepsilon_{it})] = E[\mathbf{X}_{i,t-s}\,\Delta\varepsilon_{it}] = 0 \qquad , \qquad s = 2,3,...,T \tag{4.3}$$

Introduced by Ahn & Schmidt (1995):

$$E[v_{it}\Delta\varepsilon_{it}] = E[(\eta_i + \varepsilon_{it})\Delta\varepsilon_{it}] = 0 \qquad , \qquad s = 1,2,...,T-1 \tag{4.4}$$

Introduced by Blundell & Bond (1998):

$$E[\Delta\mathbf{X}_{i,t-1}\;v_{it}] = E[\Delta\mathbf{X}_{i,t-1}\;(\eta_i + \varepsilon_{it})] = 0 \qquad , \qquad s = 2,3,...,T \tag{4.5}$$

[4]Future studies on this topic might also make use of full information maximum likelihood (FIML), a method recently developed by Allison et al. (2017) who also offer *xtdpdml* as a Stata package that also allows for the very precise weak instrument test by Olea & Pflueger (2013). For our case this method did not work out because of convergence problems due to the unbalanced nature of our panel. Even though FIML methods might improve efficiency with less restrictive assumptions, unbalanced-panel issues are very severe here as they also greatly increase computational complexity.

For strictly exogenous variables we can even add the moment conditions

$$E[\mathbf{X}_{it}\ \ddot{\Delta}\varepsilon_{it}] = 0 \qquad , \qquad s = 1,2,...,T \tag{4.6}$$

where $\ddot{\Delta}\varepsilon_{it} = \sqrt{\frac{T}{T-1}}(\varepsilon_{it} - \bar{\varepsilon}_i)$, which basically result in a fixed effects estimator with the square root term serving as a scaling factor for unbalanced panels. In a GMM setting we are able to use different moment conditions for each set of variables depending on their properties, even predetermined variables can be treated accordingly. When applying the GMM concept choosing the 'correct' model is not straightforward. GMM is sometimes sensitive to small changes in model specifications, such that testing different models and being cautious during the model setup process is highly recommended. Most recently Kiviet (2020) developed a guideline for dynamic panel models and discusses problems and pitfalls, which are also discussed by Kripfganz (2019).

The final model has to pass the test for overidentifying restrictions (L. P. Hansen (1982)) to rule out endogeneity of the chosen instruments. Furthermore serial correlation of the error term ε_{it} has to be absent for 4.3 to 4.5 hold. This can be tested with a simple test already developed by Arellano & Bond (1991). We also monitor unnecessary (too many) instruments (Roodman (2009)) and compare model fit based on Bayes information criterion (BIC). Kiviet (2020) recommends starting a sequential selection process with a relatively broad model with many variables only using 4.3 and dropping unnecessary variables step by step, applying a general-to-specific approach. After having found a valid model setup, one can reach for efficiency improvements by adding more moment conditions. We will explain our model selection procedure as well as the final model in the results section 4.5.

4.4 Data and Descriptive Statistics

We use firm-level data for Germany for the period 2001-2010. The temporal restriction is necessary because ownership data is only available during this period. We extract it from the *Wer gehört zu Wem* database initially gathered by Commerzbank. Unfortunately this data service ended in 2011 as collecting and structuring the data became too costly. However, having access to this kind of data allows us to test the exact hypotheses from above. We match data with firm financials from Dafne provided by Bureau van Dijk and patent data from the PATSTAT database by the European Patent Office (EPO). We restrict our dataset to listed companies for whom a supervisory board is mandatory. Furthermore all our firms operate industries that are usually innovative, so we drop industries like services, real estate, energy supply, health care, education, arts or public administration. Deriving innovation strategies for such companies would be misleading. We then end up with an unbalanced panel of 604 companies and 3027 observations.

To estimate a Cobb-Douglas production function our dependent variable is LNSALES, which is the natural log of company sales, as the empirically observable counterpart of output Q. LN-

MATERIAL, LNASSETS and LNEMP represent the natural log of material spendings, assets and employees respectively. These are the 'classical' input factors from equation 4.1 which are transformed into output. Further control variables include LNWAGES, which is the natural log of average wages per firm-year, representing human capital, LEV for leverage, defined as liabilities by shareholder equity and log of firm age LNAGE. All monetary variables are measure in thousand euros and have been deflated using a yearly CPI. Table 4.1 depicts descriptive statistics for the variables in levels before taking logarithms.

Table 4.1: Descriptive statistics

variable	**mean**	**sd**	**min**	**max**
SALES	1750135	7230123	1095.312	1.09e+08
ROA	4.409319	5.672254	-23.25467	25.57439
ROE	8.308249	14.47976	-52.93527	78.34821
MATERIAL	785840.6	3739653	1.962162	7.02e+07
ASSETS	1129076	7159772	151.0303	1.26e+08
EMP	6381.204	29819.98	3	502763
WAGES	53842.13	14184.96	20971.77	111969.8
LEV	2.657246	2.847501	.0549451	27.90202
AGE	66.77502	55.06125	1	632
SHARESUP	.0371912	.1387009	0	1
SHAREMAN	.0440082	.1654356	0	1
HERF	.5628736	.3639961	1.00e-05	1
INST	.0820039	.1995023	0	1
GRANTS	9.481335	119.1767	0	3775
CITSTOCK	31.65718	321.3292	0	8893.117
N	3027			

All further variables are those of major interest. Our main hypothesis on the ownership-performance relation can be tested using SHAREMAN and SHARESUP who represent the percentage of shares held by members of the board of directors and the supervisory board respectively. We can see that the values are quite low, indicating that for instance cases of dominant owners in top positions are not common. However, if we are able to find significant performance effects we could prove the state-of-the-art in German firms as inefficient and making use of managerial and monitor shareholding is desirable. INST measures the number of shares held by institutional investors, which are mostly investment and pension funds as well as insurance companies, which could be classified as 'classical' institutional investors (Çelik & Isaksson (2014)). HERF is a Herfindahl-Hirschman type measure of ownership concentration with HERF=1 as total concentration and HERF converging towards zero as total dispersion.

GRANTS is the number of patents granted to firm i in year t. In order to observe an effect on firm performance we decide to use grants over applications for three reasons: First it usually takes years for the patent office (in Europe and Germany) to decide upon a patent. Trying to estimate a performance effect in the year of application is thus not to be expected. Second in Germany almost 60% of all applications are rejected (Deutsches Patent- und Markenamt (2016)), a rate that can be confirmed by our data, such that applications do not necessarily represent innovative output. Third we can treat grants as exogenous (or at least predetermined) for the reason that a firm cannot adjust them instantly. Even though GMM accounts for this problem, avoiding endogeneity is always the best choice.

We will test robustness of the innovation effect by re-estimating the model using a firm's citations stock (CITSTOCK) instead of GRANTS according to Hall et al. (2005) but with slight changes to their equation (8)[5]. They argue that citations have much higher predictive power when it comes to firm financial indices. The citations stock is constructed by counting the forward citations of each patent from the year it was granted up to five years in the future. Then adding them up with a common depreciation rate of $\delta = 0.15$ yields

$$CITSTOCK_{it} = (1-\delta)CITSTOCK_{i,t-1} + \sum_{v=1}^{5} C(t,t+v). \tag{4.7}$$

For example C(2005,2007) counts the forward citations a patent granted in 2005 received from patents applied in 2007. We set $v_{max} = 5$ contrary to Hall et al. (2005) who count all citations up to their last available year. Their approach should cause biases because older patents are systematically valued higher due to more years they could receive forward citations. In a longitudinal study on knowledge stock evolution starting in the 1910's Nicholas (2008) finds that patents are cited over decades, supporting both our conjecture of a forward bias and the value of citations over pure counts. Furthermore we use citation data up to 2015, guaranteeing full citation coverage up to patents from 2010, our last sample year[6]. Another minor change is that we start at $T_0 = 1980$ and further use a simple linear autoregressive model with fixed effects to predict the initial value $CITSTOCK_{i0}$. As long as the firm's citations in each year are at least 15% of their citations the year before the citations stock is monotonically increasing. This is mostly the case here but the bias vanishes asymptotically due to the depreciation rate and firms that were founded after 1980

[5] Concerning the choice on adequate patent measures in section 2.2, we decide to count all grants and not only priorities. This inevitably results in double counts for certain inventions. However, when it comes to measuring effects of patents on firm financials, we believe that leaving out patents that refer to national priorities heavily underestimates their impact on international markets and thereby their value for the firm. Multinational firms using different patent systems generate sales from these markets such that an invention patented in different countries generates more value than an invention restricted to a single market. Our choice of GRANTS thus also accounts for quality or more precisely scope. Furthermore, estimations using patents applications yielded no significant effects, indicating that performance-effects are driven by innovation processes that can be called 'finished'.

[6] An econometric approach to avoid a bias is to include time fixed effects in any regression including citations (Trajtenberg (1990)). This should be able to exclude all artificial temporal variation in citations. However, this technique implies equal biases over all firms and patents, a problem avoided by simply restricting the time horizon of forward citations.

do not suffer from any bias as their patent history is completely observed.

Any descriptive patterns for the ownership variables are hard to detect. SHAREMAN and SHARESUP are nonzero only for 13% and 12% of all firms respectively. This means that – despite the fact that family firms are common in Germany (Pötzl (2014)) – firms that have shareholders in active managing or monitoring positions are still a minority. Finding significant effects for such firms could shape our view on ownership as a governance mechanism.

Concerning the discussion on the profitability of innovation, figure 4.1 displays the natural log of total sales for innovators and non-innovators as a first insight, whereas the former are defined as having applied for at least one patent during the observation period. Both variables are close to a uniform distribution and the empirical distribution for innovators is slightly shifted to the right, indicating higher output for innovators. Furthermore a simple t-test rejects the null of equal means with a p-value of almost zero. We would thus expect innovators to be more profitable. However, other inputs are excluded such that a careful empirical examination is necessary to draw a conclusion.

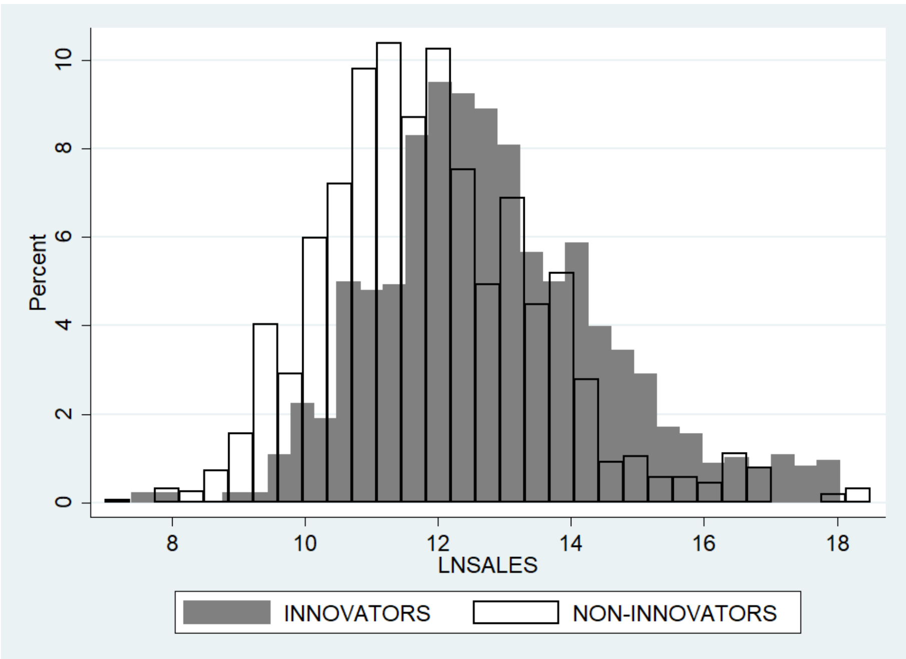


Figure 4.1: empirical distribution of LNSALES by innovators

4.5 Model Selection and Results

As discussed in section 4.3, model selection in GMM estimation is non-trivial. Therefore practitioners in this context should do both, be precise in choosing the preferred specification and then test it for robustness by applying slight changes. We thus stick to the sequential selection process introduced by Kiviet (2020). Cobb-Douglas production functions have a strong theoretical foundation, such that we do not start with a too broad model like we should do if the true model is mainly unknown. We begin our search for a reasonable specification by estimating equation (2) with all variables discussed in the previous section and a set of time dummies as recommended by Roodman (2009) and Kripfganz (2019) in a simple Arellano & Bond (1991) Difference-GMM to avoid technical biases. All specifications apply finite-sample adjustments for standard errors as suggested by Windmeijer (2005). We then go through the recommended steps by repeatedly testing the moment conditions as well as autoregression in the error term and adjusting the instruments accordingly. In doing so we achieve efficiency gains and end up with a reasonable specification for our hypotheses.

The results can be seen in table 4.2 where we show our final specifications for the production function as well as profitability equations for return on assets (ROA) and return on equity (ROE). Column (1) shows results from a Sys-GMM model promoted by Blundell & Bond (1998) using only the first suitable lags as instruments. These are second-order lags for the level and third-order lags for the difference equations. Lower lags cannot be used because the model exhibits an AR(1) error term as can be seen in the lower columns. So we cannot use the Ahn & Schmidt (1995) moment conditions which are redundant anyway if Sys-GMM is used. Column (2) shows the same model but with a firm's citations stock instead of grants. Columns (3) and (4) show our models on ROA and ROE respectively. The Hansen-test for overidentifying restrictions does not reject the null in all cases, indicating proper instruments.

The choice upon reasonable instruments is not trivial. There is no test statistic such that we have to stick to proximate rules of thumb and robustness tests. Roodman (2009b) suggests that the number of instruments should not exceed the N dimension, what is fulfilled in all our specifications. More recently Kiviet (2020) recommends a range depending on N and T. Too many (unnecessary) instruments go with the cost of a typical weak instrument problem and overestimation of the Hansen test statistic, which is actually what we observe during the process of model selection when adding more lags as instrument. So we decide to stick to a relative moderate count. The estimated coefficients for the classical input factors are all highly significant and a linear hypothesis test on constant returns to scale – which means the coefficients for material, assets and labor add up to one – is not rejected at a 1% level of significance. Furthermore human capital represented by average wages increases firm performance similar to other empirical studies like Crespi et al. (2016). The coefficient for leverage is positive in all models but insignificant. So firms may boost sales in the short term at the cost of leverage but this does not hold as a general rule.

The point estimate of SHARESUP is in all models (even during the extensive model selection process) positive, indicating that monitor ownership is beneficial for firm performance and firms with such ownership structure outperform their competitors. We can thus confirm our hypothesis that endowing members of the supervisory board with shares triggers substantial incentive boosts. Other explanations include those discussed in section 4.2.2.1 of such firms increasing their importance relative to competitors if monitors have multiple board positions, low job risk and weak entrenchment. Results on managerial ownership SHAREMAN are unstable throughout the process of model development but are consistent concerning a qualitative statement. Even signs vary and there is no statistical significance at all, indicating that in our data there is no observable effect on firm performance.

Considering the manifold arguments on possible endogeneity issues and managers being endowed with shares mainly as reward for past success we can state here that the effect – if any exists – is negligible. Looking at managerial ownership alone might also disregard other management factors like the identity and skills of executives (Bandiera et al. (2020)). To put it in a management recommendation also with regards to past studies, it might indeed be the case that managers with shares are more severe of their contribution to their firm and agency problems can be reduced. However, this is far from becoming a general rule applicable to a large group of firms or even the whole population. Findings on family firms where ownership and control are merely aligned also address firm heterogeneity (Carney et al. (2015); Hack (2009)) and even heterogeneous Corporate Governance systems (Klein (2009)), such that straightforward and simple conclusions are not to be expected for managerial ownership.

Capital concentration represented by HERF overall proves harmful for profitability measures ROA and ROE. This fits findings by Aghion et al. (2013) and Bloom et al. (2015) who argue that management quality increases with capital dispersion by utilizing diverse sources of human capital. This shows that in our sample capital concentration is not beneficial for the firm because it does not represent an effective monitoring mechanism and cannot be seen as a substitute to legal monitoring authorities like the supervisory board. Also considering our results and the diverse previous findings on managerial ownership, we promote monitor ownership as a promising way to foster governance effectiveness.

Table 4.2: Effects of ownership regimes on different performance measures

	(1) LNSALES	(2) LNSALES	(3) ROA	(4) ROE
LNMATERIAL	0.3101***	0.3130***		
	(8.24)	(8.41)		
LNASSETS	0.1906***	0.1891***		
	(5.77)	(5.76)		
LNEMP	0.5096***	0.5104***	-0.0072	-0.6496
	(8.99)	(9.03)	(-0.02)	(-0.67)
LNWAGES	0.6656***	0.6625***		
	(5.08)	(5.01)		
LEV	0.0140	0.0130		
	(1.57)	(1.49)		
LNAGE	-0.0381	-0.0347	-1.0567	0.8506
	(-1.19)	(-1.12)	(-1.62)	(0.52)
GRANTS	0.0009**			
	(2.45)			
CITSTOCK		0.0002***	-0.0011	-0.0057
		(3.34)	(-0.39)	(-0.93)
SHARESUP	0.3242**	0.3240**	4.9472**	6.8464
	(1.97)	(2.03)	(2.45)	(1.07)
SHAREMAN	0.0968	0.0872	3.7738	7.4860*
	(0.66)	(0.60)	(1.13)	(1.76)
INST	-0.1100	-0.1154	-2.3277	0.3133
	(-1.34)	(-1.31)	(-0.84)	(0.06)
HERF	-0.1145	-0.1179	-5.1839***	-7.1237*
	(-1.23)	(-1.23)	(-2.60)	(-1.88)
Observations	3027	3027	3027	2957
firms.	604	604	604	603
No. of instruments	158	158	117	182
p-value no AR2	0.0184	0.0182	0.1013	0.9676
p-value no AR3	0.9619	0.9299	–	–
p-value 3-step Hansen	0.3116	0.2821	0.4091	0.2673
BIC	-746.2271	-656.3970	-541.0326	-887.4336

t statistics in parentheses; LNSALES represents the log of sales; ROA represents return on assets; ROE represents return on equity; final specifications are chosen after a sequential selection process (Kiviet (2020)) and include a constant and time dummies; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

During the process of model selection LEVERAGE and WAGES prove to cause substantial endogeneity issues in the ROA and ROE models which even Sys-GMM could not overcome. This seems reasonable because those variables can and usually are quickly adjusted if firm profitability changes. Consequently we had to exclude them and end up with a very basic model with only few variables. SHARESUP as representing our main hypothesis has a strong positive effect on ROA but not on ROE. This can be a hint on owners focusing merely on the former or are more capable of affecting it. To sum up most specifications we are able to confirm the results of Audretsch et al. (2013) and also generalize them to non-family firms, thereby assigning high value to monitor ownership whereas managerial ownership still has ambiguous effects. Furthermore there is no effect of shares held by institutional investors on any performance measure. Even though there is reason to believe they are more engaged in monitoring, heterogeneity among institutional investors with different amounts of capital invested and different objectives could hamper decision making processes (Çelik & Isaksson (2014); Hoskisson et al. (2002); Zahra et al. (2000))

The coefficient for patent grants is positively significant in column (1) but this does not hold for most prior (not displayed) specifications. For this variable adding instruments decreases standard errors such that we can say that there is probably a patent effect. Citations show a much more precise performance effect in all our production function estimations. The smaller coefficient is nevertheless not surprising for firm's citations stock is on average three times as high as their grants as shown in table 4.1, resulting in a comparable absolute effect. As A. Jaffe & de Rassenfosse (2017) also conclude from prior research, citations are probably the best innovation output measure we can draw from patent statistics as it to some extent also represents quality and marketability. We can support these findings and our results also fit those of Löfsten (2014) because we also find patents to increase performance but not profitability. On the other hand Czarnitzki & Kraft (2010) report positive effect of the patent stock on return on sales. So economists should not dismiss patents as a valuable asset for firms if robustness is not tested using different measures of performance, productivity and profitability.

4.6 Conclusion

Previous studies on the effect of ownership structure on firm performance mainly focus on managerial ownership and offer inconclusive results. We analyze the effects of firm ownership in direct management positions as well as in supervisory boards on performance, where the latter appoint and monitor the former, resulting in changes in incentive structures and agency problems. We find no performance effects of managerial but positive effects of monitor ownership, indicating that firms can attract attention of part-time monitors by endowing them with shares, thereby pushing monitoring effort or efficiency. We also find that this cannot be achieved with institutional or concentrated ownership. Instead the latter proves harmful for profitability, such that informal monitoring cannot be seen as a substitute for direct monitoring, preferably by owners.

Furthermore we contribute to the discussion on the innovation-performance relation and especially the value creation of patents by considering different measures. We find that patent grants have higher predictive power for firm performance than applications and that citations are still our best bet in measuring a firm's real innovative assets. Besides recent arguments against formal intellectual property protection, patents still represent innovative assets and are valuable for the firm and the researcher.

Our empirical strategy once more shows the importance of careful model selection and robustness testing, especially in the context of GMM. Even though we were able to make use of recently developed statistical packages based on an excellent methodological background, there is still no one-fits-all approach and results may vary with performance and profitability measures. After careful model selection we find support for our hypothesis that monitor ownership has high potential for triggering strong incentive effects without usual drawbacks like entrenchment. Firms should therefore consider the possibility of endowing their monitoring authorities with shares to generate efficiency gains. Furthermore owners who want to become active players in their firm should rather seek monitoring than management positions and exploit the chances of the labor market for external managers. More research is then needed on the heterogeneity of owners and monitors. There might be differences in owners who become active players in their firm and players who become owners. Both cases can come with different consequences for the firm such that the effects we find might be more complex than our first insights may indicate, offering a promising field for future research.

5 The Effect of Innovation on Survival during the Life Cycle of the Firm

The Effect of Innovation on Survival during the Life Cycle of the Firm

Tim Grünebaum

(unpublished)

5.1 Introduction

When their existence is at stake, firms seek for strategies to prevent failure. Recent studies have found innovation to increase survival chances, but they lack a sophisticated analysis of a firm's market position and development since entry what might be highly relevant to choose an adequate survival strategy. I will revise this link for Germany as its firms exhibit extensive R&D efforts compared to other European countries and are even top spenders and performers. In 2017 average R&D intensity of German firms was 150% of EU average (Eurostat (2019b)). Concerning marketable intellectual property rights the innovative performance of German firms is even stronger as they are the top applicants of European patents in the EU (European Patent Office (2019b)). Besides the well-known positive effects of such innovative assets like profitability (Czarnitzki & Kraft (2010)) or labor productivity (Lang (2009)) several researchers have estimated positive effects on survival probability (Cefis & Marsili (2012), Buddelmeyer et al. (2010), Esteve-Pérez & Mañez Castillejo (2008), Audretsch (1995)), a view straight in the tradition of Schumpeter's *Creative Destruction* (Schumpeter (1942)) as non-innovative firms are at risk of being replaced.

However, in bankruptcy statistics Germany does not display an outstanding position. In 2017 on average 62 out of 10,000 companies were forced to exit, which is only slightly below EU average (Eurostat (2019a) Creditreform (2018)). Thus, even though innovative firms seem to fail less frequently, the link might be more complex. I can reproduce the results from earlier survival studies but show that the innovation effect vanishes if we focus on young firms. Firm age in the sense of life cycle stages is of high relevance to govern and prevent imminent failure. Whereas young firms have many things to learn from their more established counterparts and therefore apply and improve more conventional methods, mature firms have mainly exploited such possibilities and are forced to seek new options.

With time passing by, technologies grow old. Consumers might demand and scientific progress might offer new opportunities. This means that innovation in a certain market occurs only after standard products lose attractiveness. Consequently innovation offers the highest pay-offs for firms when their products are at risk to become outdated. This argument is backed by studies like Huergo & Jaumandreu (2004) who show that firms are most likely to innovate between age 20 and 40. I show that the often found innovation premium on survival does only hold for firms in the decline stage.

The age effect has proven relevant for survival in most studies though shape and magnitude differ and it is mostly only of secondary interest (Ugur et al. (2016), Fernandes & Paunov (2015), Tsvetkova et al. (2014); Esteve-Pérez & Mañez Castillejo (2008), Agarwal & Gort (2002)). Only few studies take a deeper look at firm age (Coad (2018), Fackler et al. (2013), Thompson (2005)). Even though a causal effect is questionable, market pressure and firm strategies should depend on how long the firm has been operating so far.

I argue that firms who have passed a stage of abundant profits offering a certain product line might catch up or even reclaim market leadership by innovating. This view fits theoretical models on competition, entry and exit by Jovanovic (1982), Ericson & Pakes (1995), Klepper (1996) and Aghion et al. (2014). If the firm will not replace its own (old) technology it will increase the risk of being replaced by (new) competitors. In the sense of Schumpeterian growth theory it does not matter whether technological progress replaces outdated firms within the market or outdated technologies within the firm. However, for the firm it matters.

In this paper I challenge the simple view of innovation supporting firm survival as a general rule and refine it by analyzing it in the context of life cycle stages for 38.000 German companies over an 8-year period. I argue and find empirically that the innovation premium on survival indeed exists but sets in only at later stages as mature firms are forced to reinvent themselves. For young firms more conventional strategies show higher pay-offs concerning entrepreneurial stability.

5.2 Theoretical Background

5.2.1 Development of Hypotheses

Exit is usually the ultimate consequence of bad performance. Whereas measures like sales or productivity only give us a small hint of the firm's long-term perspective, market exit is a definite withdrawal from future profit opportunities. The decision to leave the market includes both past achievements and future expectations. This is especially important in the sense of innovation, as innovative assets like patents or ideas mainly pay out over a long period and short-term effects on sales or productivity are difficult to measure. Therefore, a subjective variable like exit addresses the problem more than a snap-shot of the firm's recent market position.

I interpret exit in the Schumpeterian tradition, as one aspect of *Creative Destruction*, a connection mostly overlooked by researchers. Schumpeter (1942) established his theory of economic growth as a comprehensive perspective on capitalist regimes with *Creative Destruction* as a part of their developmental capabilities. He describes innovation for the firm as a major protection against unstable markets and for the economy as a force to acquire high growth rates and discover completely new fields for fulfilling peoples' needs. Therefore, innovation is both essential for the economy to evolve and for the firm to survive market turbulences.

Creative Destruction in this sense consists of two consecutive steps:

1. Non-innovative firms are more likely to fail than their innovative counterparts in a competitive environment (the contest for ideas) and
2. will be replaced by more innovative new firms.

This is part of a permanent process which fosters technological progress, giving market economies a major advantage over other systems in terms of growth. Firms may thus hedge against a forced exit (failure) by innovating. In this sense it makes no difference to the rate of technological progress whether 'lazy' firms are being replaced by new ones or whether this kind of competition pushes firms to innovate.

An extensive review of the valuable contributions of Schumpeterian growth models is offered by Aghion et al. (2014). Beside industry-level dynamics they also derive some useful and intuitive predictions for the firm-level that can be tested. A typical empirical observation is that new and small firms exit earlier, as age and size are usually highly correlated. This also fits the authors' theoretical hypotheses. As I will show later, the crucial parameter for survival and the effect of innovation and, therefore, *Creative Destruction* is age in the form of progress and not size. More recently, Ugur et al. (2016) develop a survival model building on Aghion et al. (2014) which allows for scale effects in R&D spending and complementarities between innovation and market concentration, and consequently competition intensity. The authors predict positive but decreasing returns on R&D concerning survival rates, which matches their later empirical examination.

There is, however, a scarcity of formal models. Most empirical studies lack a clear theory beside the heuristic that innovation – if successful – always benefits the firm's competitiveness. One relevant model in this context is the Industrial Revolution Model by Klepper (1996). He focusses on the product life cycle which includes entrepreneurial failure. In his model, firms may conduct product and process innovation besides selling a standard product equal to all firms. The model describes the product life cycle in an evolutionary setting with both entrants and incumbents, thus entry and exit are included and determined by market structure and entrepreneurial decisions.

By innovating firms may strengthen their competitive position. Exit is necessary for the market to clear as new firms enter and remaining (innovating) firms grow. Applying these predictions to this paper's topic we can see that ongoing innovation is a necessary condition to avoid forced exit, in the sense of Klepper (1996), meaning negative expected profits[1]. Moreover, new firms may only enter if they innovate, and survival is determined by a firm's (exogenous) innovation expertise.

A related theoretical approach is the evolutionary theory promoted e.g. by Jovanovic (1982) and later Ericson & Pakes (1995). This body of literature attempts to give theoretical justification to the empirically observed fact that firm behavior is heterogeneous irrespective of similar industry-

[1] This heuristic even motivates the popular approach by Olley & Pakes (1992) of estimating production functions. Only firms whose expected profits exceed their liquidation value decide to stay in the market. This decision is indirectly based on firm productivity, which I argue can be increased by innovation (only) when the firm's competitive position is on decline, linking innovation to the exit decision.

and firm-specific attributes. My hypothesis fits this debate and takes account of passive and active learning. The former can be attributed to Jovanovic (1982). He develops a stochastic model of firm development after market entry where the firm draws its initial productivity from an a priori known distribution. The longer the firm operates in the market, the more it learns about its own productivity. More productive firms gain market share and their counterparts exit the market as they realize they are unable to keep up with their competitors.

Ericson & Pakes (1995) extend this view by offering firms the chance to enhance their accumulated information about their productivity (as well as productivity itself) by making active investments. So they are able to directly influence their survival time. The process of shifting productivity is still stochastic and a firm can thereby still be forced to exit despite high investments. This means that – as in practice – innovation can fail. Thus, high R&D expenditures alone do not safeguard from failure with certainty. This argument supports my choice of variables in the upcoming empirical analysis. I will analyze the effect of granted patents on the probability of survival, as they measure successful innovation projects as an innovative asset, making a direct effect visible.

The product life cycle theory can easily be extended to the firm per se (Hoy (2006)). In this setting a firm will grow after entry as it gains more customers over time, and establishes a market strategy as well as ties with retailers and suppliers. Alike the market itself, which is subject to necessary renewal from time to time through firms or products, a firm can only avoid downturn by establishing new concepts. Customers do not care if such concepts come from new or old firms. Consequently, a firm has to innovate to avoid the typical cycle of entry and exit. This aspect is often referred to as strategic renewal, which has proven to be part of the managerial decision portfolio and by definition occurs late in a firm's history (Agarwal & Helfat (2009)). Early after entry, growing older triggers a learning-by-doing effect, which is usually non-innovative (Agarwal & Gort (2002)).

Figure 5.1 shows a typical stylized life cycle for two different firms in two different markets. Despite the similarity that a firm's market share evolution is mainly concave, both lifetime and size can differ. I focus mainly of firm age as a life cycle indicator but I will also test a different stage classification independent of age to account for heterogeneous life cycles like firm 1 and firm 2 in this illustration. In all cases the basic stages are in order: *growth*, *maturity* and *decline*[2]. As can be seen I argue that in the decline stage innovation becomes relevant to avoid losing market share. This (third) stage can for instance be triggered by entry of new (more innovative) firms. Therefore I will also include market growth in terms of net entry rates as well as a measure of innovation competition to account for market characteristics threatening the firm.

Some theoretical considerations about age and survival are summarized by Esteve-Pérez & Mañez

[2]Jaafar & Halim (2016) summarize the discussion on stage classification.

Castillejo (2008). They point out that indeed younger firms face higher risk as they are inexperienced and do not know their relative competitive capabilities, as examined by Jovanovic (1982) and Ericson & Pakes (1995). But after a certain (unknown) point in time after entry the remaining firms have exploited most relevant market information such that simply growing older does not further increase survival chances.

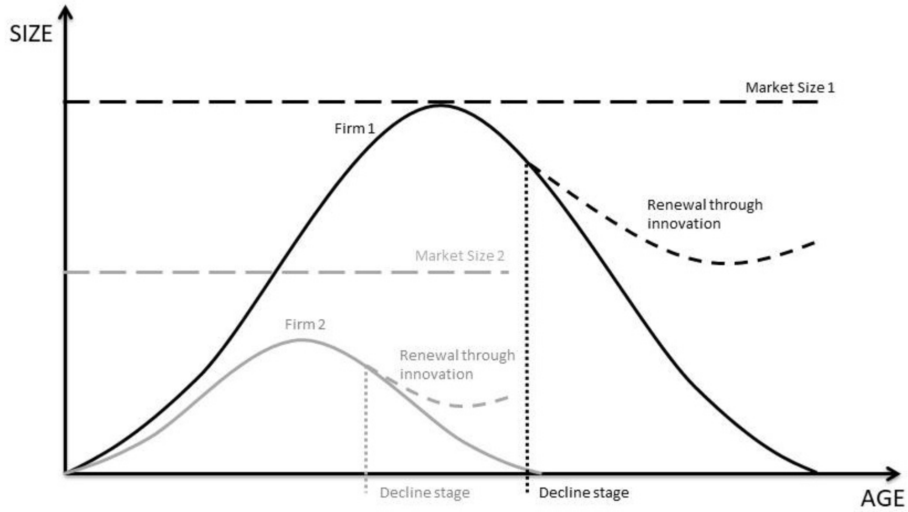


Figure 5.1: A stylized life cycle for different firms and different markets

This paper is the first to combine two famous theories of the firm when it comes to survival, namely the Schumpeterian idea of *Creative Destruction* and the life cycle theory of the firm. In a nutshell, life cycle theory would predict a positive effect of firm age on its probability of surviving the next year up to a certain point where a *senility effect* or obsolescence of initial endowment (Agarwal & Gort (2002); Agarwal & Audretsch (2001)) sets in and firms have exploited their growth potential through conventional (non-innovative) methods. At that point Schumpeterian growth theory becomes dominant and firms are forced to replace their old technology (by innovation) to avoid being replaced by (potential) competitors.

Combining those two arguments in the context of firm survival I test the following hypotheses:

H1: Firm age increases a firm's survival chances in a non-monotonic way. Young firms benefit from growing older and establishing themselves in a market, whereas mature firms have already exploited traditional growth potentials.

H2: The innovation premium on firm survival is present only for mature firms as they are forced to reinvent themselves to keep up with (new) innovative competitors.

In the next section I will provide a review of the main empirical results on the role of age and innovation in survival. Both aspects have been analyzed by several scholars, but the literature lacks a straightforward examination of their interaction, potentially leading to biased results.

5.2.2 Review of Empirical Literature

Several studies deal with the effect of innovation on firm survival, each of them with slightly different objectives, data or methods. Nearly all of them confirm the innovation premium and argue that innovating offers a firm a significant competitive advantage over non-innovators, leading to a stabilized market position. This holds for different industries and countries. Table 5.1 offers a summary of relevant studies finding similar effects using different samples and measures. The only studies with no significant innovation effect are those for Scandinavian countries (Børing (2015); Ebersberger (2011)).

In a comprehensive study on New Zealand Buddelmeyer et al. (2010) compare different innovation measures and find the number of patent applications to decrease expected survival time, whereas the stock of patents has the opposite effect. Abundant applications might indeed harm the company if they are not well developed, inducing more costs than benefits. Furthermore, applications are a long way from a marketable product as it might take many years for legal authorities to decide upon a grant, making a direct influence on the firm's performance difficult to measure. The sunk costs of investing in radical ideas without direct payoffs might make companies more vulnerable in the short term. Beside these examples the innovation premium on survival is widely accepted, encouraging firms to innovate and policy makers to foster innovation.

Only few scholars differentiate between firm categories. For example Cefis & Marsili (2006) and Cefis & Marsili (2005) estimate the innovation effect for size and age classes and find that innovation is most beneficial for young and small firms. However, they define mature firms as being more than 10 years old and still find an effect for every class. German firms tend to exist over decades, indicating that a ten-year firm history is not much [3]. Earlier, Audretsch (1995) investigates the effect of different corporate and market attributes on firm survival and growth. He observes that innovation fosters long-term survival. More specifically, he separates his sample of more than 11,000 US enterprises into two subsamples of young and mature firms, whereby only the latter show significant positive effects. He therefore concludes that surviving the first few years (in this case 8 years) is a condition for innovative assets to have an effect on survival. However, he only observes industry-level data, so a closer look at both the innovation and age effect on the firm level is needed.

Concerning the effect of firm age on survival it is mostly agreed upon a significant positive effect, in some cases with decreasing marginal returns. This also points into the direction of a nonlinear development during a life cycle. In most studies firm age is included in some transformation in the empirical analysis but it is seldom discussed in detail, even though it is of high relevance and a deeper look in age mechanisms is needed. I believe that simply controlling for age is not sufficient,

[3] Firm age in my sample reaches from 2 to 731 years with a mean of 35 and a median of 23. The oldest firms are breweries, such that these numbers are reasonable.

as the effects of other firm characteristics – such as innovation – on firm performance and survival chances may change over time as a firm develops.

One study finding destabilizing entrepreneurial effect of innovation is Hyytinen et al. (2015). They focus on start-ups, also challenging the common opinion of an innovation premium for firms at every age. They find that innovativeness decreases survival rates for start-ups, highlighting risk that comes with R&D as they use a survey-based ex-ante measure for innovation that – unlike patent data – also covers unsuccessful attempts.

Table 5.1: Empirical studies on the innovation-survival link

Author(s)	**Year**	**Innovation measure**	**Innovation effect**	**Age effect**	**Country**
Agarwal and Gort	2002	industry technological intensity	negative on industry level	inverted-U	U.S.
Audretsch	1995	number of innovations in industry	positive for mature firms	–	U.S.
Børing	2015	product/process innovation, R&D, patents	none	–	Norway
Buddelmeyer et al.	2010	patents/trade marks	positive (negative for applications)	–	New Zealand
Cefis and Marsili	2012	product/process innovation (survey)	positive	positive	Netherlands
Cefis and Marsili	2005	product/process innovation (survey)	positive	positive	Netherlands
Cefis and Marsili	2006	R&D	positive	positive	Netherlands
Ebersberger	2011	patents	none	none	Finland
Esteve-Pérez and Mañez-Castillejo	2008	R&D	positive	inverted-U	Spain
Fernandes and Paunov	2015	product innovation	positive	none	Chile
Helmers and Rogers	2011	patents	positive	–	UK high-tech start-ups
Lin and Huang	2008	R&D	positive	positive	Taiwan
Ortega-Argilés and Moreno	2007	R&D	positive	inverted-U	Spain
Ortega-Argilés et al.	2007	R&D	positive	inverted-U	Spain
Shanling et al.	2010	patents	positive	positive	U.S. internet firms
Tsvekova et al.	2014	patents	positive	inverted-U	UK start-ups
Ugur et al.	2016	R&D	inverted-U	inverted-U	UK
Wagner and Cockburn	2010	software patents	positive	–	U.S. internet firms
Zhang and Mohnen	2013	R&D, new products	positive	positive	China

Notes: "-" means age effect not tested.

Despite the findings summarized in table 5.1 some studies have a clearer focus on firm age and should therefore be discussed here. For example Fackler et al. (2013) find significant differences not only in baseline hazard rates but also in determinants of exit for young and mature German firms over a 30-year period. They show that both young ($\leq$ 5 years) and small firms have higher exit rates and encourage policy makers to support such firms as higher exit rates do not necessarily mean low productivity. Esteve-Pérez & Mañez Castillejo (2008) observe a nonlinear relationship between firm age and hazard rates in Spain. Exit risk rapidly increases during the first years and later decreases after reaching a maximum at about 20 years of market activity. Surprisingly, after 60 years it again increases rapidly, reaching another, even higher, local maximum at age 100. The authors also find support for the hypothesis that innovation increases a firm's survival chances. They distinguish between buying innovative capital from other entities and conducting one's own R&D effort. Whereas firms benefit from both strategies to a similar extent, they are more effective within high-tech industries. The age effect has thus proven to be quite volatile.

A similar pattern is found by Agarwal & Gort (2002). They also interpret this result in the sense of life cycle theory and find that both, the firm and the product life cycle are important to determine a firm's lifespan. The latter can be interpreted in the sense of aging technologies or – as the authors call it – obsolescence of initial endowments. However, innovation is only of secondary interest in their work. Even though they include technological intensity in their empirical model, this variable is only measured at the industry level. The results indicate that industries characterized as highly innovative regimes increase exit hazard on the firm level, indicating a harsh competition for ideas. Consequently one would expect firm-level innovation to counter this effect. I will later include both industry- and firm-level innovation to contribute to this debate. A positive effect of age on survival of Spanish firms is also highlighted by Ortega-Argilés & Moreno (2007) and Ortega-Argilés et al. (2007) with decreasing returns. The authors estimate a maximum at age 50, but they only include few age dummies making the identification of a structural break cumbersome. Basically, they find support for the hypothesis of a decreasing marginal effect of age on survival. Furthermore, the authors find that R&D positively affects survival chances but do not attempt to link both effects.

There are also studies that question the age-survival relationship in general. Thompson (2005) attributes it to selection since firms might differ in their abilities before they enter the market. After controlling for pre-entry experience the age effect vanishes. The results are interpreted in the sense that firm age has no particular effect and firms do not gain notable experience after entry. My data do not provide pre-entry quality measures but statistical methods allow me to control for unobserved heterogeneity which I will apply in later robustness tests. Following this argument, simple firm fixed effects should be sufficient to eliminate the age effect.

A recent combination of theoretical arguments and empirical evidence on the complex role of age is given by Coad (2018). He states that most firm-level variables are only indirectly affected by age even though age is important as a proxy for stages of aging, being associated with different entrepreneurial strategies. He identifies three stages. The first stage is the harsh struggle against early exit during the first few years after entry. During the second stage firms evolve routines and become established. During the third stage firms are settled and are at risk of missing new fertile business opportunities which can be countered by actively innovating. These ideas strengthen the necessity of a sophisticated empirical test.

Even though firm age has proven to significantly correlate with survival probability, there is a lack of straight theories for a causal effect. Firm age is of high importance in the sense of life cycle theory and a possible path-dependent innovation premium. It will therefore play a major role in my upcoming empirical analysis, although I am aware that there is not necessarily a causal effect. Moreover it should be attributes that come with age, an argument in line with theories about learning (Jovanovic (1982), Ericson & Pakes (1995), Agarwal & Gort (2002)).

To the best of my knowledge no study has analyzed the innovation-survival relationship in the sense of the life cycle theory and both aspects, innovation and firm age, have been mainly treated as independent. In recent studies the innovation effect is mostly positive no matter how innovation is measured. I will therefore estimate a model comparable to others and in a next step account for life cycle stages to test my hypotheses.

5.3 Empirical Analysis

5.3.1 Data and Variables

I analyze a dataset of 38.000 German companies over the period 2008-2015, excluding industries that are usually non-innovative in nature to prevent biased results (services, real estate, energy supply, health care, education, arts or public administration). I use patent grants over applications to measure innovation because the former represent successful ideas with a high degree of novelty authenticated by the patent office. An effect on company financials and eventual exit decisions should be clearer for confirmed innovation. For example in Germany only about 40% of all applications receive a grant examination (Deutsches Patent- und Markenamt (2018)). Such a decision made by the patent office can take several years. This might cause a bias for applications if the data is collected “too early” before the final decision whether to grant or reject the patent is made. Furthermore Buddelmeyer et al. (2010) shows that patent grants have a positive survival effect whereas applications can destabilize the firm. Patent data is taken from the PATSTAT database by the European Patent Office (EPO), spring 2018 edition.

Company financials are taken from the Dafne database by Bureau van Dijk and merged to the PATSTAT data using company names. Dafne contains basic operational information helpful to explain firm-specific survival chances. First, I include the natural logarithm of employees (LNEMP) and its square to control for (non-linear) size effects. Larger companies might have more stable structures, better access to capital to cushion short-term downturns, and alternative strategies beside closure. A model to explain and predict the exit decision of a firm must also include a measure of performance. I will use profits (PROFIT). Highly profitable firms will be more likely to survive, i.e. firms that are about to exit show significantly worse performance shortly beforehand (Griliches & Regev (1995)). This measure can be treated as an index of the overall health of a firm and includes relevant information like sales and costs. I also tested cash-flow instead to rule out "creativity in accounting" as cash-flow definitions are more explicit. The results were similar but information on profits was far more abundant so I stick to profits to increase sample size.

Next, I account for human capital using average wages, also in natural logarithm (LNWAGES), defined as total personnel expenses divided by employees. Highly skilled employees should secure a firm's market position and be able to find flexible solutions to business problems. Furthermore, a firm has a broader scope to cut wages in decline if average wages are high and therefore prevent exit. On the other hand, labor sometimes cannot be adjusted easily due to long-term contracts, inducing high personnel even if demand is low, making the firm vulnerable. As another input factor I include capital intensity (CAPINT), defined as total assets divided by total sales. Capital-intense firms may be more resistant to economic shocks as they are able to liquidate their assets to counter financial shortages. On the other hand, such firms might be less flexible because assets could cause fixed costs over time even if unused due to low demand. Furthermore, I include leverage (LEV), defined as liabilities divided by shareholder equity. This variable may also influence firm exit in different ways. High leverage increases risk and can be an indicator of economic contraction during the previous years, pointing towards forced market exit. On the other hand, increasing debt offers the firm financial scope for necessary investments, enabling it to survive in a volatile market, such that the net effect is unknown at this point.

Furthermore the model includes – as key variables in this analysis – the natural log of age in years (LNAGE) as well its patent stock (PATENTS). The patent stock is constructed with the perpetual inventory method as a function of the patents granted in year t plus the depreciated value of its lagged value:

$$PATENTS_{it} = PATENTS_{it} + (1-\delta)PATENTS_{i,t-1}. \tag{5.1}$$

A firm's patent history is observed back to the year 1980 with the initial value being just grants. This horizon should be enough to measure innovative assets and mismeasurement is – if any exists – capped at 1% given the common depreciation rate of $\delta = 0.15$. A firm might thus build up innovative assets over time that might become relevant the time they face new competitors or their product line becomes outdated.

I also include two market-level variables. First the industry-year median of patent grants in order to proxy the innovative pressure within an industry and thus the presence of *Creative Destruction* (MEDIANPATENTS). Ugur et al. (2016) establish the relevance of this measure in a theoretical model reaching back to Schumpeter (1942). We would expect this variable to decrease survival chances of (non-innovative) firms. The second market-level variable is the relative net industry growth, measured in total firm entries minus total firm exits divided by the total number of firms in the industry to account for changes in overall competitive pressure (NEWFIRMS).

I also include a dummy for firms in eastern Germany (EAST), since such regions may still be affected by structures dating from the former German Democratic Republic and exit faster (Almus (2004)), and finally a set of year dummies. Most of these variables have been used widely in firm survival analysis (e.g. Fernandes & Paunov (2015)). I take a one-year lag for every dependent variable to avoid a possible bias, as firm information in the year of exit might be distorted due to ongoing liquidation[4].

The dependent variable LEAVE is binary and takes unit value if a firm exits in year t and zero otherwise. The Dafne database offers information on the last year a firm appears in it or, more specifically, the last year it reports financial data to public authorities. Furthermore, we observe its legal status in/after this last year. Having this information, I am able to determine the year a firm exits the market. However, one problem could not be solved perfectly: Some firms only report as their last legal status the term “deleted”. German company law does not further define the reason for such deregistration, thus simply treating such events as business failures could cause problems. Some firms’ history were manually checked via their official websites and many simply merged with other companies. Even though the legal status, “merged”, exists in the registers, some “deleted” firms also fall under this definition with no clear attribution. Consequently, we do not know whether they failed or not. Unfortunately, such cases are not rare. About 40% of all deregistrations are referred to as “deleted”. The rest can clearly be denoted as closure. As there is no easy way to identify business failures for these firms, I decide to estimate the model later without such firms as closure, similarly to Schwartz (2009)[5]. The results will be part of the robustness tests later in this paper. As a comparison, by applying a competing-risk model Ebersberger (2011) does not find significant differences in the effect of patent stock on exit by failure or exit by merger.

To complete the data summary, table 5.2 shows descriptive statistics for the variables used before taking natural logarithms. We see – besides the above discussed exit properties – that in general the dataset is quite comprehensive in representing all kinds of firms: big and small, profitable and unprofitable, firms with high and low overall wages, high and low capital intensity (measured as fixed assets per employee), high and low external financing, eastern and western Germany, and of course innovative- and non-innovative as well as young and mature firms. Market attributes represented by MEDIANPATENTS (overall innovation intensity in the industry defined as the industry median of a firm’s patents stock per employee) and NEWFIRMS (industry growth defined as net entries divided by the total number of firms) also display a comprehensive picture.

[4]Potential endogeneity problems due to input and strategy adjustments shortly before exit are discussed in the results section 5.5.

[5]There are indeed more elegant approaches to deal with such problems, like matching methods or using linked employer-employee data to identify whether workers moved from the deregistered company to another, indicating an acquisition, as done e.g. by Mueller & Stegmaier (2015) or precisely described by Geurts (2016) and Hethey & Schmieder (2010). Information on this level is not available in this study and proving robustness of the results in two subsamples should be sufficient here

Table 5.2: Descriptive statistics

variable	mean	sd	min	max
LEAVE	.0101878	.1004196	0	1
EMP	231.9182	452.7436	2.043505	5359
PROFIT	2863.875	7533.177	-13762.98	86664.74
WAGES	49.87947	18.89298	10375.12	145666.21
CAPINT	65.01797	201.5403	.0860067	3971.044
LEV	7.104584	19.5368	.0960615	243.9962
EAST	.1342433	.3409146	0	1
MEDIANPATENTS	.0089952	.005126	04	.0169928
NEWFIRMS	-.0071841	.0236626	-.0376687	.2033226
AGE	33.8633	33.9988	1	730
APPLN	.8383166	9.767926	0	1155
GRANTS	.4377325	4.419298	0	461
PATENTS	2.430507	22.60649	0	1995.601
N	162362			

I also offer different patent measures in order to contribute to the debate of sensitivity of econometric modeling to unclear measure selection (Moser et al. (2018); Lhuillery et al. (2016); Bakker et al. (2016); De Rassenfosse, Schoen, & Wastyn (2014)) and for robustness. APPL represent patent applications, referring to the application year, and GRANTS patent grants, referring to grant year. Here we can also see that application counts are almost double the amount of grant counts, an observation that matches descriptive analyses from section 2.3. The baseline variable for my standard models PATENTS represents the patent stock as explained in equation 5.1 relying on patent grants in order to measure effects at the time a firm is allowed to commercially exploit an innovation. The overall results will later be challenged by using sole application and grant counts to test sensitivity to patent measures.

There is however a problem with sample selection. The data used in this study – alike most other databases provided by Bureau van Dijk – is based on annual reports. This has the advantage of reflecting actual business dimensions but there could be a problem with representativeness for specific firm classes, mainly young and small firms. If firms exit very early they sometimes do not report financials to statistical offices at all. This can be seen in quite low exit rates in the sample compared to official statistics who report exit rates of around 7% on average for Germany over all sectors. Thus, especially for start-ups more focused studies are needed and available as many start-ups are very innovative (see section 5.2.2)[6]. For patents this will not be much of a problem

[6]For a discussion on utilization of Bureau van Dijk data in various countries see Gal (2013). I furthermore apply – as a robustness check – regression models with weighted observations as done in the very same study to increase the number of small firms in the sample. Comparison to official statistics on size classes indeed reveal underrepresentation of small firms, however, my sample behaves better than ORBIS as used by Gal (2013). Table 5.5 in the appendix offers a comparison of my sample to official statistics (*Unternehmensregister*) and shows that – whereas my sample is close to population coverage in case of big firms, the sample lacks several small firms. However, even

because of the in most cases lengthy examination process (Harhoff & Wagner (2009)) such that most young firms are not able to build up a significant patent stock. In order to make the results independent of possible mismeasurement and selection issues in firm age, an alternative definition of life cycle stages based on capital growth rates is applied in the later results section.

5.3.2 Method

The data are structured as an unbalanced panel on a yearly base. On average each firm is observed for 4 years with the typical right-censoring for non-completed spells. This is not a problem in the context of survival analysis. As time is (intrinsically) discrete, continuous survival models like the popular Cox proportional hazard model are inadequate, and coefficients and standard errors can be biased if a clear ordering of exits within one year is not possible. Therefore, I apply discrete survival analysis as promoted by Jenkins (2005) and Jenkins et al. (1995). He shows that typical (and computationally less complicated) maximum likely approaches fit discrete survival data very well. My dependent variable is of binary nature with unit value if firm i exits in period t. This leads us to our objective function, the hazard rate $h_i(t)$. It is defined as the probability that firm i exits the market in t, conditional on having survived until $t-1$, thus

$$h_i(t) = Pr(T = t \mid T > t-1; X), \tag{5.2}$$

where T denotes the time of exit if the spell is complete and X_j a vector of $j \in (1, ..., J)$ explanatory variables x_{it}. The parametric form of the hazard function is defined as

$$h_i(X) = h_0 + \beta' X_{it} + \varepsilon_{it} = 1 - exp[-exp(\beta' X_{it} + \varepsilon_{it} + \gamma)] \tag{5.3}$$

with $\gamma = log[-log(1-h_0)]$, parameter vector β, an *iid* error term ε_{it} and h_0 as the baseline hazard rate which is estimated non-parametrically, based only on survival time. If we treat time as discrete, we can define an indicator variable y_{it}, which has unit value if firm i exits in t, thus $T = t$ and zero otherwise (which includes operating firms and incomplete spells). Then the corresponding log-likelihood function becomes

$$L = \sum_{i=1}^{N} \sum_{t=1}^{M} y_{it} \cdot log(\frac{h_{it}}{1-h_{it}}) + \sum_{i=1}^{N} \sum_{t=1}^{M} log(1-h_{it}), \tag{5.4}$$

with N firms and M being the last sample year. This approach is known as the complementary log-log model or simply *cloglog*. The focus then lies on the marginal effect of each explanatory variable on the hazard function. They can thus be interpreted as vertical probability shifts of the baseline hazard and thereby determining expected time of exit. This approach is more straightforward than continuous time models and even overcomes major drawbacks of continuous survival models if they are used for interval data as discussed in detail by Fernandes & Paunov (2015). In

for very small firms the sample behaves much better than the ORBIS database used by Gal (2013). Results on the weighted dataset show no significant changes to the results presented in this paper and are available upon request.

applied research where the end of a spell is a very rare event, the baseline hazard is very small and the estimates of the *cloglog* model are very similar to those of a simple logit model.

Furthermore, I account for unobserved heterogeneity of firms, often called frailty in survival analysis. Consistent estimation of fixed effects models is not possible in short panels and the frailty model assumes random intercepts for each firm. Alternative population-averaged models are available but assume stable frailty over time for a firm, what might be too restrictive (Cameron et al. (2009); Cameron & Trivedi (2005)). In the context of survival analysis using random effects basically means that even the yet unconditional baseline hazard rate h_0 varies over firms i and even randomly within the firm by adding a normally distributed firm-specific component to 5.3. This allows us to drop the rather strong assumption of a constant exit risk for all firms – which is affected by firm-level variables – and even allow for different starting or baseline hazards[7].

In order to test the main hypothesis of this paper I will – in a first step – estimate the model with patents and firm age as well as an interaction term. This will test the standard hypotheses of age and innovation contributing positively to firm survival regardless of the firm's life cycle as explained in section 5.2.1. Then I will construct reasonable subsamples depending on firm age and an alternative life cycle definition.

5.4 First Insights

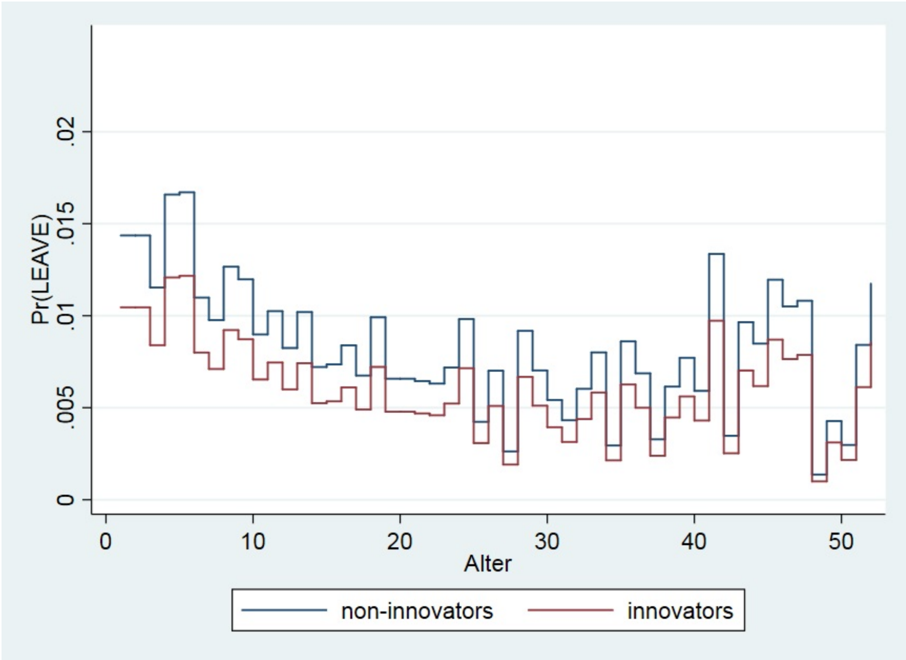
Several studies have pointed out that innovators per se have lower hazard rates (see section 5.2.2). I argue that these results mainly come from not considering different life cycle stages of firms. Innovation might have different effects on survival depending on a firm's experience of operating in a certain market and competitors' abilities to catch up with current strategies and products. I will start with a general analysis of baseline hazard and survival rates to show that the positive innovation effect indeed exists but only applies for mature firms that have already reached a steady-state-like condition with their standard products.

Figure 5.2 shows (discrete) estimated baseline hazard (without random effects in this section) rates for innovators and non-innovators. The former are defined as firms that were granted at least one patent within the observed period. The current state of research would expect (successful) innovation to lower hazard rates, which is actually visible. In general, hazard rates are quite small at an average of 1% each year and quite stable even after age 50 (not shown)[8]. Decreasing rates are common and my results match earlier results (e.g. Hsieh & Klenow (2014), Buddelmeyer et

[7] All later results also hold in simple *cloglog* models.

[8] Hazard rates are significantly smaller than reported for Germany by Fackler et al. (2013), indicating selection as explained above, but are similar for firms with at least 4 employees. This is reasonable because very small establishments are usually not obliged to publish their financials. Thus if there is a survivorship bias in the data with missing early exits, the sharp decline in hazard rates in figure 5.2 would be even stronger, supporting my hypothesis of a declining age effect on survival.

Figure 5.2: Baseline hazard rates

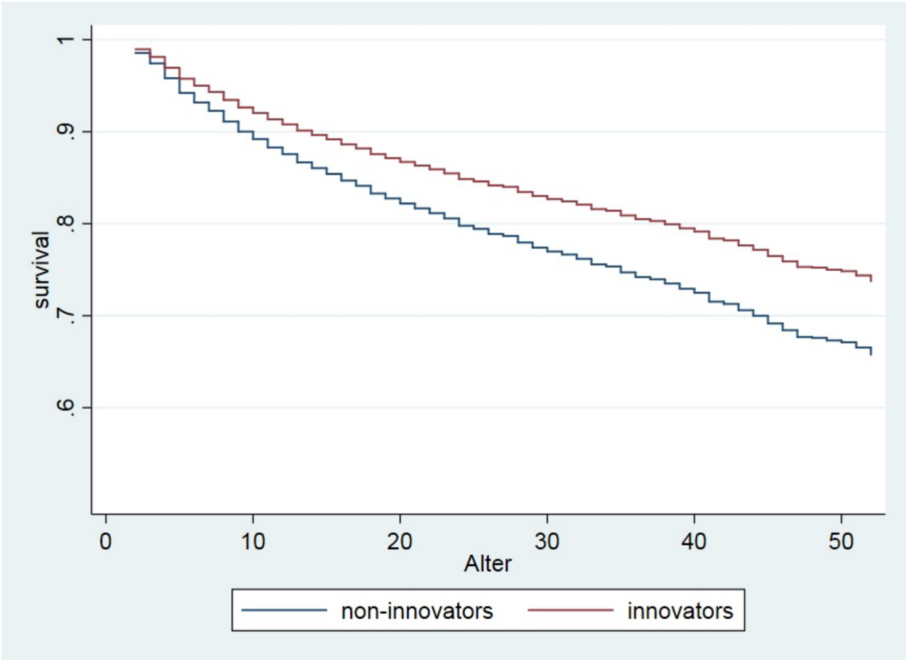


al. (2010), Esteve-Pérez & Mañez Castillejo (2008)). My sample thus can be compared to samples for other countries or other periods. The difference in hazard rates between innovators and non-innovators is significant at the 5% level, indicating that innovation is helpful to prevent exit.

Survival functions in figure 5.3 show similar patterns which are in line with prevalent studies. Since they are cumulative they are monotonically decreasing. Innovators survive longer and the difference becomes stronger with age. One important motivation for my hypotheses is the decrease in hazard rates during the first few years after market entry. We can observe slightly decreasing rates for the first 15-20 years after which hazard seems to vary non-systematically around a constant rate. For statistical reasons, I only show results up to an age of around 50. Estimation of the baseline hazard and survival rates requires observations for all possible groups (innovators, non-innovators, leavers, non-leavers) in every age category, whereas only few firms grow very old.

These descriptive statistics motivate my approach to test a structural break at an age of 15-20. A first look at baseline hazard rates reveals that the difference between innovators and non-innovators (the innovation premium we are looking for) is not significant at the 10% level for companies up to an age of 16, whereas it is highly significant later with the point estimate almost doubled. Estimating a model for the full sample shows a slightly significant innovation effect. The fact that the premium exists for the whole sample shows that it is not surprising for earlier studies to come up with such a result. However, this could be deceptive as this approach unnecessarily restricts the point estimate to be equal for all companies and over the whole life cycle, a contestable statement.

Figure 5.3: Survival rates



5.5 Results

Table 5.3 shows the results of a complementary log-log estimation with frailty using the variables explained in section 5.3.1. The first two columns show results for the full sample. Column (1) displays results in line with most empirical studies, where high innovative effort is associated with a lower probability of exit. One could end investigation here and draw a conclusion of a positive age and innovation premium. However, taking a more detailed look into the innovation-age relationship based on previously explained theory by including an interaction term in column (2) challenges the statement of a stable effect throughout a firm's life cycle. The interaction is negative and significant, whereas the sole effect of PATENTS disappears. This is a first hint on the innovation premium depending on age.

In columns (3) to (5) I estimate the model for three subsamples based on my assumption of a diminishing effect of age on survival. I decide to split the sample above age 15 and 29 because at the first point the innovation premium seems to set in according to descriptive insights and the resulting three subsamples divide the sample into three groups of reasonable size. Discussions on regime changes in the innovation-survival relation are given by Wagner & Cockburn (2010) and Esteve-Pérez & Mañez Castillejo (2008) and fit my approach. Later I will apply a different stage classification independent of age to challenge my results.

Looking at the subsamples, the age effect changes by category, which is in line with previous studies finding decreasing marginal effects (Ugur et al. (2016), Buddelmeyer et al. (2010), Ortega-

Argilés & Moreno (2007), Ortega-Argilés et al. (2007), Esteve-Pérez & Mañez Castillejo (2008))[9]. Thus, for young firms in column (3) growing older (which means just getting through in some way) increases their survival chances for the next year, even with a strongly higher point estimate. For such firms the risk of failure decreases with age, implying that firms need some time to gain a foothold in an industry and surviving itself facilitates survival. This can be interpreted as the *growth stage* of the life cycle.

Establishing business structures necessary to support long-term survival is complicated and lengthy. This includes several crucial aspects like developing a suitable range of products, an adequate pricing policy, reliable connections to suppliers and retailers, a capable work force, a marketing strategy and many more. All such dimensions are very important for new firms and depend on financial and human resources. On the other hand, innovation is very costly and all other factors usually show higher marginal returns directly after market entry. Furthermore, new firms are more vulnerable to shocks due to lower financial resources and innovation is per se risky.

Column (4) shows the same model for firms with $15 < \text{age} \leq 29$. Both the age and the innovation effect become insignificant, indicating the *mature stage* of the life cycle where firms have settled and competitive pressure is mediocre. Here innovation seems not to be necessary yet to stay in the market (but sure can have other effects besides this paper's topic). In the last stage for firms of age 30 and older, column (5) exhibits a relatively strong innovation effect and even a harmful age effect. As time goes by, products and technologies loose value and hazard rates increase. This depicts the *decline stage* in figure 5.1 where strategic renewal is necessary.

The results fit the study of Wagner & Cockburn (2010) who find declining hazard rates up to a minimum of 15-18 year old firms, whereas they seem to contradict Cefis & Marsili (2006) and Cefis & Marsili (2005) who find an overall innovation premium that was strongest for young firms even though their age classes are very different: 0-4 years, 5-10 years and more than 10 years. I am furthermore able to enhance work by Audretsch (1995). He does not use firm- but industry-level innovation and finds that mature firms (age>8) have a higher probability of surviving in a more innovative industry. I show that this effect is most likely to be observed on the firm level and should encourage mature firms to innovate.

Concerning the hypotheses of this paper the results support both. Innovation becomes relevant only at later stages of the business life cycle when opportunities from conventional allocation processes in the firm (represented by age as a proxy) have largely been exploited. Either new products or new production methods can secure a firms market position. Studies on the determinants of innovation like Huergo & Jaumandreu (2004) show that firms are most likely to innovate between age 20 and 40 which is rational given my results.

[9]Estimating the full sample model with an additional square-term on LNAGE supports this conjecture.

Table 5.3: Estimation results

	(1) full sample	(2) full sample	(3) age $\leq$ 15	(4) 15 $<$ age $\leq$ 29	(5) 29 $<$ age
LNEMP	-0.0053***	-0.0053***	-0.0044**	-0.0067***	-0.0035**
	(-4.98)	(-5.02)	(-2.10)	(-5.17)	(-2.23)
LNEMP^2	0.0005***	0.0005***	0.0004	0.0007***	0.0004**
	(4.49)	(4.54)	(1.54)	(4.90)	(2.21)
PROFIT	-0.0000***	-0.0000***	-0.0000**	-0.0000	-0.0000
	(-4.26)	(-4.24)	(-2.12)	(-0.21)	(-0.38)
LNWAGE	-0.0031***	-0.0030***	-0.0043***	-0.0030***	-0.0013
	(-4.22)	(-4.21)	(-2.91)	(-2.71)	(-1.63)
CAPINT	-0.0000***	-0.0000***	-0.0000*	-0.0000	-0.0000***
	(-2.65)	(-2.65)	(-1.91)	(-1.14)	(-2.97)
LEV	0.0001***	0.0001***	0.0001***	0.0000***	0.0001***
	(6.23)	(6.27)	(3.38)	(3.23)	(2.68)
EAST	0.0001	0.0001	0.0001	0.0003	0.0035**
	(0.09)	(0.10)	(0.06)	(0.35)	(2.42)
NEWFIRMS	-0.0065	-0.0063	-0.0159	-0.0251	0.0182
	(-0.43)	(-0.42)	(-0.54)	(-0.95)	(1.00)
MEDIANPATENTS	0.2817***	0.2838***	0.2415	0.1987**	0.2967***
	(3.90)	(3.93)	(1.55)	(2.01)	(3.01)
LNAGE	-0.0016***	-0.0015***	-0.0024***	-0.0002	0.0011*
	(-5.48)	(-5.33)	(-2.83)	(-0.11)	(1.88)
PATENTS	-0.0001***	0.0000	-0.0000	-0.0000	-0.0002**
	(-2.73)	(0.95)	(-1.52)	(-1.03)	(-2.56)
LNAGE·PATENTS		-0.0000***			
		(-3.05)			
Observations	162362	162362	46922	51486	63954
Number of firms	38350	38350	14754	14738	14474
Number of exits	1657	1657	663	430	564
Log-pseudolikelihood	-9010.4866	-9009.389	-3416.2627	-2426.2163	-3110.5861

z statistics in parentheses; table displays marginal effects at the mean of a random effects *cloglog* model; the binary dependent variable LEAVE is 1 in the year of firm exit and 0 otherwise; LNEMP^2 represents LNEMP-squared; standard errors are clustered at the firm level; all specifications include year dummies; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

If we go from qualitative to quantitative interpretation the overall effect of the patent stock on survival looks quite small at first sight. A marginal effect of 0.0002 for example implies that a firm needs on average a knowledge stock of 50 to decrease the probability of a failure in the subsequent year by 1%[10]. However, as the parameter estimates can be interpreted as linear probability shifts of the baseline hazard rate, this 1% is quite high given the baseline hazard of around 1% from figure 5.2. So firms with reasonable knowledge stocks have a crucial competitive advantage compared to non-innovators.

Concerning control variables, the results fit theoretical expectations. For most specifications there is a strong size effect with diminishing returns, implying that larger firms have higher chances of survival, fitting e.g. Coad et al. (2013). We could think of firms employing more workers to exhibit various strategies to absorb shocks, like cutting wages or labor, selling capital goods, closing down plants, adjusting products and prices, as well as better access to external financing[11]. As a proxy for financial performance I include profits. Firms are usually profit-maximizing units and exit is in most cases a consequence of lacking profit or excess losses. Even though the point estimate is very small – logs cannot be applied due to negative realizations – the effect is positive. Splitting the sample reveals it to be strongest for young firms, indicating that acquiring liquidity early after exit is most stabilizing for firms with low financial reserves. This result can be seen in the context of Coad & Kato (2018) who proof that low sales growth rates are an effective predictor of market exit. Similar results are shown for human capital, measured in average wages. Firms that employ highly qualified workers have a higher probability of surviving, a result comparable to Ebersberger (2011) who use the share of highly skilled workers. Mature firms seem to benefit least from qualified workers who in such cases mainly put their employer at expense, possibly due to highly remunerated long-term contracts.

Further firm-level characteristics shaping managerial strategies are capital intensity and leverage. The former also increases survival chances (albeit to a very small extent). Firms with a large amount of non-human capital at their disposal can either adjust the production process more drastically, liquidate machinery to absorb shocks or simply have a cost advantage (Lin & Huang (2008), Audretsch & Mahmood (1995), Doms et al. (1995)). Leverage is mostly associated with vulnerability to economic shocks or an overall bad performance over the past few years. It is therefore a very precise indicator of a firm's condition. One could also expect that borrowing money from capital markets might help firms to avert imminent market exit, but the results indicate that the former argument is much more likely. Furthermore old firms from Eastern Germany seem to still be at higher exit risk.

[10] Note that this stock also includes past patents and average patent stock is 5.5 times as high as grant counts, indicating that the value of each grant will be higher.

[11] Recalling the argument of Aghion et al. (2014) if age and size are highly correlated (which is not the case here with a correlation coefficient r=0.0527 for natural logs) both effects should be barely distinguishable. If the age effect is still persistent after controlling for size this argument is weakened and my hypothesis supported.

The coefficients for the technological regime (MEDIANPATENTS) also shows expected signs. Some authors state that it is difficult to survive under stiff innovative competition. For example, Lin & Huang (2008) test three such indicators for young and mature Taiwanese firms and find that – even though results are weak – younger firms usually have higher survival rates in industries characterized by an innovative entrepreneurial regime. This holds in the analysis conducted here, because the competition for ideas seems to not affect young firms which is also in line with the findings by Ugur et al. (2016), Agarwal & Gort (2002) and Audretsch (1995). We can thus expect that innovation is necessary for mature firms and keeping up with innovative competitors indeed pays. For Spain, Esteve-Pérez & Mañez Castillejo (2008) do not report any such effect. As argued by Manjón-Antolín & Arauzo-Carod (2008) industry-level variables often display ambiguous results concerning firm survival. The coefficient for NEWFIRMS is not significant, indicating that innovative competition is more severe for firms than the pure number of competitors.

When talking about life cycles one quickly faces the issue of how to define the stages. To support my findings I test an approach of stage definition mostly motivated by Jaafar & Halim (2016). Basically they state that “firms can enter the decline stage at any age”, refining e.g. Dickinson (2011) who builds a life cycle classification based on cash flow patterns as he argues that “firms can enter decline from any of other stages.” Here I define stages according to capital growth rates. An increasing (declining) capital stock would suggest an early (late) stage as in figure 5.1. In doing so I furthermore account for possible biases from age mismeasurement and selection as mentioned earlier by completely omitting age from this specification. Similar to Gal (2013) capital expenditures are measured by percentage investment growth rate

$$\%\Delta I_{it} = \frac{(K_{it}^{BV} - K_{i,t-1}^{BV} + DEPR_{it}^{BV})/PI_t}{K_{i,t-1}^{BV}/PI_t}, \tag{5.5}$$

where K_{it}^{BV} and $DEPR_{it}^{BV}$ are the book value of fixed tangible assets and depreciation respectively of firm i in year t and PI_t is a price index which cancels out in the growth rate expression. To account for market characteristics I then divide this rate by the average investment growth rate of the industry j the firm operates in (Jaafar & Halim (2016)):

$$rel\%I_{it} = \frac{\%\Delta I_{it}}{(\sum_{i=1}^{N_j} I_{it})/N_{jt}}, \tag{5.6}$$

with N_{jt} being the number of firms observed in the industry in each year. The definition of the stage depends on the 33% percentiles of $rel\%\Delta I_{it}$. As a result each observation is assigned a particular life cycle stage, allowing more dynamic stage switches during firm history.

Table 5.4: Estimation results for life cycle stages

	(1) growth stage	(2) mature stage	(3) decline stage
LNEMP	-0.0073***	-0.0051***	-0.0043***
	(-3.66)	(-2.95)	(-3.22)
$LNEMP^2$	0.0007***	0.0005***	0.0004***
	(2.81)	(2.65)	(2.88)
PROFIT	-0.0000*	-0.0000	-0.0000
	(-1.93)	(-1.57)	(-0.03)
LNWAGE	-0.0050***	-0.0025**	-0.0019**
	(-3.78)	(-2.06)	(-1.98)
CAPINT	-0.0000*	-0.0000***	-0.0000*
	(-1.93)	(-3.16)	(-1.68)
LEV	0.0001***	0.0001***	0.0000***
	(4.67)	(4.29)	(3.51)
EAST	0.0003	0.0001	0.0007
	(0.18)	(0.12)	(0.81)
MEDIANPATENTS	0.2509*	0.1673	0.3204***
	(1.86)	(1.53)	(3.39)
NEWFIRMS	0.0325	0.0472**	-0.0319*
	(0.89)	(2.17)	(-1.85)
PATENTS	-0.0001	-0.0002*	-0.0001**
	(-1.06)	(-1.87)	(-2.01)
Observations	61454	51207	49700
Number of firms	18975	22045	20131
Number of exits	438	493	578
Log-pseudolikelihood	-10908.631	-11194.726	-13120.947

Model set-up like in table 5.3. Due to convergence issues clustered standard errors could not be applied to column (1), what is yet not utterly needed in random effects models following Cameron & Miller (2015).

Table 5.4 depicts the results using the same method and variables as for the baseline model in table 5.4. For depreciation $DEPR_{it}^{BV}$ is not available for all firms the total number of observations is a little smaller. The innovation premium becomes more relevant throughout the stages what is exactly what we expect from theory. Other controls only exhibit minor changes. This specification improves the upper analysis and shows that stage classification is still on debate but in this case does not change the implications.

An issue worth mentioning is the so-called *shadow of death* (Almus (2004), Griliches & Regev (1995)). This is basically a matter of endogeneity, even though reverse causality does not seem very plausible, since firms cannot adjust any business parameters after exit. However, imminent failure might influence managers' decisions even a few years before the exit finally occurs, such that using lags for the explanatory variables might not be sufficient. Carreira & Teixeira (2011) show this empirically for productivity in Portuguese manufacturing firms and Coad & Kato (2018) for sales growth in Japanese firms. Similar effects on other firm-level variables seem plausible. Handling this topic econometrically is difficult, since finding instruments for most variables is not easy. The consequences might be biased coefficients for some variables. But the main tests should not be affected by this for the following reasons. First, age is a clear exogenous variable that cannot be influenced by the firm. Second, I use patent grants to measure innovation.

Beside the above-mentioned advantage of being an indicator of successful marketable innovation, it takes years for the patent office to decide upon a patent application (Harhoff & Wagner (2009)). If the *shadow of death* is prevalent, I argue that a firm might indeed adjust values like R&D investment or possibly patent applications, but grants will prove to be more difficult. If a firm observes its own downturn and decides to undertake actions to avoid imminent exit, patents capable of serving this purpose should have been handed to the patent office long ago and cannot be maneuvered any more. This argument is even stronger in case of the here used patent stock, an index evolving over the complete firm history.

For variables like profits, employment, capital and leverage a bias might indeed occur. Wage, employment and capital cuts as well as increased leverage are typical actions to avoid bankruptcy. Even though profits already fall a few years before exit, this should mainly be a driver of exit and not a consequence. Thus, the coefficients for these variables should be interpreted carefully. However, they are only control variables with a clear hypothesis for affecting survival and should not influence the main focus of this paper. In the next section I will provide some modifications to my model in order to further support my results.

5.6 Robustness Tests

In section 5.3.1 I mentioned that there might be a problem in defining the LEAVE variable as only consisting of survival (0) and failure (1). The baseline model from table 5.3 is therefore re-estimated without those firms. The results are shown in table 5.6 in the Appendix and reveal similar coefficients even though we lose some observations for completed spells. The results are similar with the innovation effects becoming weaker but more precise what leaves the main implications unchanged. The same is true for the age effect. Second, table 5.7 shows results without the years 2008-2010. They might affect the results as they were characterized by very special economic circumstances, namely the Financial Crisis and the European Debt Crisis, with possibly many unforeseen exits. The coefficients for age and innovation do not change much. There is yet a positively significant innovation coefficient in column (2), however, splitting the sample still strongly supports the main results.

Finally I provide a comparison on the predictive power of different patent measures to make my study more robust and comparable to others. An estimation of the baseline full sample model with an interaction effect as depicted in column (2) of table 5.3 yields the marginal effects plot shown in figure 5.4 in the Appendix. Beside the baseline variable of the analysis (PATENTS) I also provide results for application (APPLN) and grant counts (GRANTS). We can see that the effects of all three variables are similar in their qualitative statement but with different magnitudes and precision. Of all three variables, PATENTS yields the weakest and GRANTS the strongest effect on survival[12]. However, as the stock contains all previous grants and is on average 5.5 times as high as grant counts, the smaller coefficient is reasonable and does not invalidate using stock over counts in the baseline model. Even pure applications – which can include a significant number of future refusals – increase survival chances. However, for applications the *shadow of death* argument can apply because they refer to the application year. Grant counts refer to the year the patent office's decision is made, similar as for the baseline patent stock. We can thus say that patents are most stabilizing for the firm the year it can exploit them commercially. Other measures like citations (Nagaoka et al. (2010)) could be tested but are of uncertain value since forward citations in for the year 2015 are clearly downward biased due to PATSTAT spring 2018 is used here and the results are still robust using unweighted counts. To sum up this section, even though some effects weaken or are less precise, the results are quite robust to various adjustments.

5.7 Conclusion

In this study I test crucial hypotheses of Schumpeterian *Creative Destruction* and the life cycle of the firm which I argue are linked. Both theories offer explanations on firm entry and exit as well as entrepreneurial strategies to avoid the latter. Even though both concepts are usually seen as merely independent, I identify an important overlap of firm age or life cycle stages respectively and innovation. I show that innovation supports survival only at later stages. As time goes by and a firm settles in a market, products and production methods can become outdated, attracting potential competitors. Firms that fail to undergo necessary innovations are at risk of being replaced unless they reinvent themselves by innovating.

On the other hand innovation does not support survival chances for younger firms. At earlier stages of the life cycle there are plenty of opportunities to increase performance and secure a market position in the medium term. Gaining a foothold in a market can be achieved in many ways, e.g. optimizing production chains, improving product quality, establishing a more sophisticated product line, reaching more customer groups, acquiring firm-specific human capital and reputation as well as a market strategy and ties with retailers and suppliers. All these actions can be described as conventional or at least non-innovative and are usually most fertile soon after market entry. Innovation is necessary for survival when growth opportunities in these areas have mostly been exploited.

[12]Recall that a negative coefficient means a negative effect on exit probability

The results suggest that studies highlighting the overall supportive effect of innovation on firm survival do not sufficiently account for different life cycle stages, since a premium is visible in my analysis even for the full sample but not after accounting for stages. This paper therefore does not contradict previous findings but is able to refine economists' views on the benefits of innovation. Even though many firms undertake R&D irrespective of the time elapsed since entry, it cannot always hedge against failure. Other – more conventional – strategies are sometimes more effective in order to become an established long term market participant.

Future research should test this hypothesis for different types of innovation like process and product innovation and determine what is most effective. For younger firms a more sophisticated identification of the variables and strategies crucial to avoid rapid failure is needed. All this might offer firms a catalogue of adequate survival strategies depending on their internal characteristics and external competitive pressure.

Also a distinction between policy and managerial implications has to be made. From a policy perspective the worst-case scenario would be that patents keep unprofitable firms alive "artificially" and thus inhibit the necessary renewal of the industry. This would be the case if critics of the current patent system prove to be right that patents are mainly used to block competitors and in some cases are only poor indicators of a firm's innovative behavior. From this perspective, patents can be harmful for the process of *Creative Destruction*, one argument to reform the current system. On the other hand, the results show why firms apply for patents even if the patents-performance relationship is unclear. Patents seem to protect the firm from exiting the market, and for the firm it does not matter if this is due to (economically beneficial) innovation, hedging against competition or any other reason.

5.8 Appendix

Table 5.5: Sample comparison to official statistics by industry and size

Industry	obs	0-9 emp	10-49 emp	50-249 emp	≥250 emp
5	12				6.9
6	13			5.5	
8	538	15.9	6.8	2.5	1.2
9	58	5.7		4.2	1.5
10	4691	25.4	8.8	3.8	1.5
11	986	4.6	3.9	3.1	1.3
12	74			2.8	2.3
13	1136		4.3	3.2	1.2
14	637	7.4	4.3	2.5	1.2
15	250		3.3	2.1	1.2
16	1212	33.9	5.5	2.5	1.2
17	1564	2.5	2.8	3.4	1.5
18	1509		7.4	3.3	1.3
19	215	6.3	2.0	1.7	1.8
20	3397	2.8	2.8	2.7	1.8
21	1087	2.1	2.1	1.9	1.9
22	4532	3.1	3.5	2.7	1.3
23	2578	11.1	4.2	3.1	1.3
24	2234		2.9	3.0	1.9
25	8676	12.2	7.6	3.4	1.4
26	4528	5.5	3.2	2.4	1.4
27	3421	16.5	4.2	3.1	2.0
28	11115	4.1	3.3	2.8	1.6
29	1702	3.9	3.2	3.1	5.0
30	593		3.2	3.0	3.0
31	868		8.2	4.4	1.8
32	1713	52.6	8.8	2.9	1.3
33	642		26.2	9.4	2.3
35	5354	3.0	2.6	2.0	1.3
36	681	4.5	5.0	2.9	1.3
37	162	30.3	19.6	3.5	2.1
38	2339	11.0	6.4	3.1	1.2
39	68	8.7	6.1	2.0	
41	3398	26.9	10.0	2.6	1.1
42	1544	12.6	14.2	6.0	1.3
43	3916	191.9	36.7	3.9	1.1
45	9070	27.3	7.9	2.4	1.1
46	30442	8.4	4.5	2.1	1.1
47	8455	83.8	19.9	4.7	1.3
49	3302	40.2	14.2	3.5	1.4
50	375	11.1	6.3	2.1	1.3
51	118		11.3	6.5	8.9
52	4653	15.8	9.7	4.0	1.4
53	137		177.4	27.5	5.6
58	1223		6.8	3.7	1.2
59	436		10.0	2.8	1.2
60	195	21.8	7.6	2.9	2.0
61	468		8.7	3.9	1.7
62	4743	14.5	8.2	3.1	1.3
63	419	60.1	12.3	4.5	1.5
69	558	505.6	206.2	5.6	1.7
70	12986	7.7	3.0	1.5	1.1
71	3949	39.1	10.4	2.7	1.2
72	1392	6.5	5.7	3.7	1.7
73	953	46.4	11.7	2.8	1.1
74	1300	30.7	5.2		
	sum=162617	mean=22.3	mean=8.1	mean=2.9	mean=1.4

Notes: Weightings represent the quotient of firms in sample to firms in officials statistics (*Unternehmensregister*) by specific industry-size-class. A value of 1 would thus imply population coverage. Empty cells mean no firms available in this class. Industry definition refers to table 2.3.

Table 5.6: Estimation results without "deleted" firms

	(1) full sample	(2) full sample	(3) age $\leq$ 15	(4) 15 $<$ age $\leq$ 29	(5) 29 $<$ age
LNEMP	-0.0022***	-0.0022***	-0.0007	-0.0047	-0.0009
	(-3.30)	(-3.32)	(-0.59)	(-0.03)	(-1.15)
$LNEMP^2$	0.0002***	0.0002***	0.0000	0.0005	0.0001
	(2.78)	(2.81)	(0.13)	(0.00)	(0.95)
PROFIT	-0.0000	-0.0000	-0.0000***	-0.0000	-0.0000***
	(-1.02)	(-1.13)	(-2.99)	(-0.00)	(-10.81)
LNWAGE	-0.0031***	-0.0031***	-0.0040***	-0.0032	-0.0016***
	(-7.24)	(-7.16)	(-3.10)	(-0.02)	(-4.54)
CAPINT	-0.0000*	-0.0000*	-0.0000	-0.0000	-0.0000***
	(-1.87)	(-1.86)	(-0.74)	(-0.00)	(-3.30)
LEV	0.0000***	0.0000***	0.0000	0.0000	0.0000***
	(4.71)	(4.71)	(1.18)	(0.00)	(4.57)
EAST	0.0000	0.0001	0.0006	0.0001	0.0014**
	(0.12)	(0.13)	(0.73)	(0.00)	(2.41)
MEDIANPATENTS	0.1622***	0.1632***	0.1050	0.1651	0.1401***
	(3.98)	(4.00)	(1.11)	(0.09)	(3.45)
NEWFIRMS	-0.0101	-0.0100	-0.0218	-0.0206	0.0099*
	(-1.25)	(-1.24)	(-1.16)	(-0.07)	(1.73)
LNAGE	-0.0007***	-0.0006***	-0.0018***	0.0012	0.0004*
	(-3.58)	(-3.45)	(-3.38)	(0.00)	(1.65)
PATENTS	-0.0000**	0.0000	-0.0000	-0.0000	-0.0001***
	(-2.00)	(1.17)	(-0.97)	(-0.00)	(-3.45)
LNAGE·PATENTS		-0.0000***			
		(-2.77)			
Observations	159920	159920	45950	50903	63067
Number of firms	37426	37426	14316	14489	14176
Number of exits	1045	1045	405	279	361
Log-pseudolikelihood	-6042.4749	-6041.6222	-2241.2407	-1667.5166	-2075.683

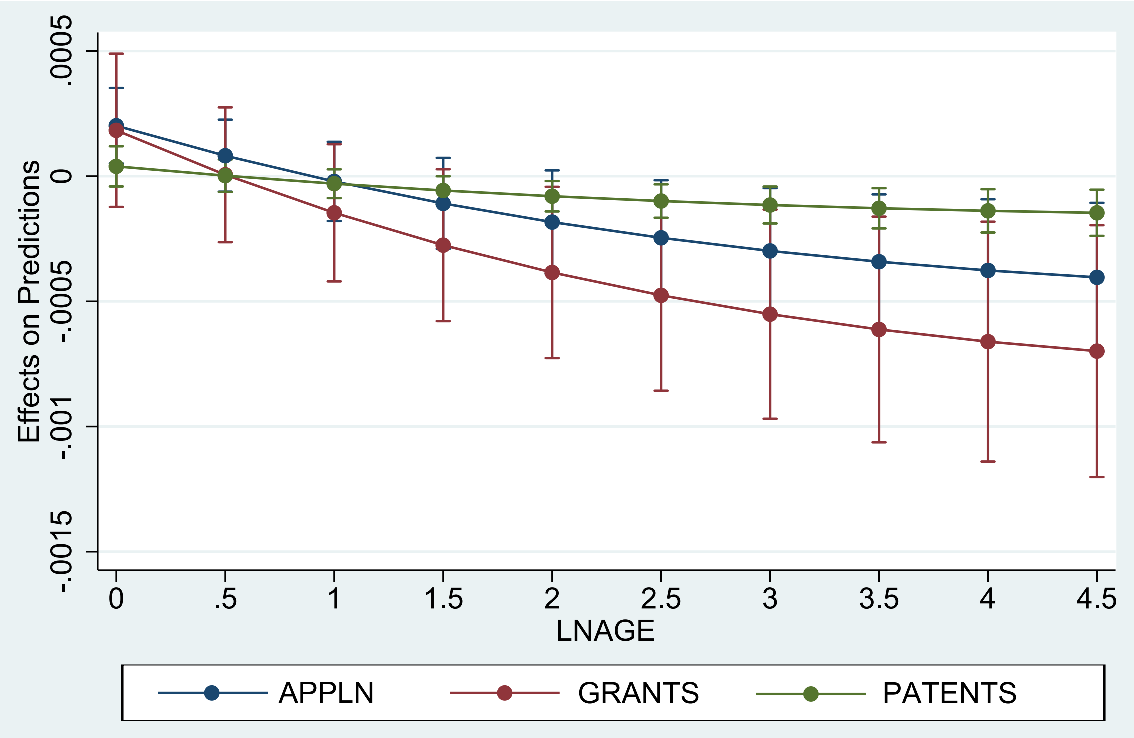
z statistics in parentheses; table displays marginal effects at the mean; the binary dependent variable LEAVE is 1 in the year of firm exit and 0 otherwise; $LNEMP^2$ represents LNEMP-squared; standard errors are clustered at the firm level; all specifications include year and industry dummies; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 5.7: Estimation results for 2011-2015

	(1) full sample	(2) full sample	(3) age $\leq$ 15	(4) 15 $<$ age $\leq$ 29	(5) 29 $<$ age
LNEMP	-0.0042***	-0.0042***	-0.0033	-0.0057***	-0.0030
	(-3.88)	(-3.86)	(-1.52)	(-3.84)	(-1.62)
LNEMP^2	0.0004***	0.0004***	0.0002	0.0005***	0.0003
	(3.16)	(3.19)	(0.87)	(3.27)	(1.43)
PROFIT	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000
	(-0.64)	(-0.14)	(-0.31)	(-0.12)	(-0.01)
LNWAGE	-0.0036***	-0.0036***	-0.0053***	-0.0041**	-0.0013
	(-4.61)	(-4.50)	(-3.30)	(-2.41)	(-1.43)
CAPINT	-0.0000***	-0.0000**	-0.0000	-0.0000**	-0.0000**
	(-2.58)	(-2.57)	(-1.52)	(-2.21)	(-2.55)
LEV	0.0001***	0.0001***	0.0000**	0.0000	0.0000***
	(4.48)	(4.20)	(2.09)	(1.60)	(3.26)
EAST	0.0003	0.0003	0.0015	-0.0001	0.0034**
	(0.44)	(0.45)	(0.94)	(-0.05)	(2.43)
MEDIANPATENTS	0.1575**	0.1588***	0.0440	0.0976	0.2469***
	(2.57)	(2.59)	(0.33)	(1.03)	(2.89)
NEWFIRMS	0.0078	0.0078	0.0216	-0.0251	0.0028
	(0.45)	(0.46)	(0.69)	(-0.65)	(0.15)
LNAGE	-0.0011***	-0.0011***	-0.0031***	-0.0004	0.0014**
	(-3.67)	(-3.52)	(-3.83)	(-0.16)	(2.55)
PATENTS	-0.0000*	0.0000**	-0.0000	-0.0000	-0.0002**
	(-1.75)	(2.36)	(-0.54)	(-0.74)	(-2.41)
LNAGE·PATENTS		-0.0000***			
		(-2.83)			
Observations	101658	101658	27352	33394	40912
Number of firms	32056	32056	10473	12010	12563
Number of exits	897	897	333	245	319
Log-pseudolikelihood	-5013.0856	-5012.1166	-1765.0906	-1409.5455	-1791.2078

z statistics in parentheses; table displays marginal effects at the mean; the binary dependent variable LEAVE is 1 in the year of firm exit and 0 otherwise; LNEMP^2 represents LNEMP-squared; number of firms and exits refer to non-artificial observations as explained in section **??**; standard errors are clustered at the firm level; all specifications include year and industry dummies; $^{*}p < 0.10,^{**} p < 0.05,^{***} p < 0.01$.

Figure 5.4: Marginal effects of applications (APPLN), grants (GRANTS) and patent stock (PATENTS; used in standard model throughout this chapter) on predicted exit probability by natural log of age with 95% confidence interval



6 Concluding Remarks

This thesis contributes to two important research fields in industrial economics and analyzes their interaction: The first is economics of innovation with a focus on patents, the second is Corporate Governance with a focus on ownership structure. Concerning the former, I am able to support and extend some of the major theoretical concepts and empirical findings. Innovation is affected by several firm-internal sources and follows a clear temporal pattern. I evaluated the concept of the Innovation Value Chain, backed by other theoretical models like those of Griliches (1984), Crépon et al. (1998) and Harhoff (1998), with a focus on Corporate Governance. R&D investments as a starting point in producing any innovative assets lead to intangible inventions which are in turn transformed into more tangible assets like patents, which then benefit the firm.

Patents have shown to help achieving entrepreneurial targets, even though results vary over both patent measure and target. Even though most studies were able to support the value of patents for the firm (Hussinger & Pacher (2019); Hall & Sena (2017); Czarnitzki & Kraft (2010); Ernst (2001); Griliches (1990); Basberg (1987)), there is also evidence that a considerable amount of innovations is not patented and is thus overlooked if research focuses on patents alone (Boldrin & Levine (2013); Moser (2012)). However, if a firm decides to patent an invention, it most likely expects higher value than if the invention is kept secret. I thus also expect to see this effect in the data. In fact I was able to qualify the statement on the value of patents by using both, different patent measures as well as different entrepreneurial targets. Alike A. Jaffe & de Rassenfosse (2017), Moser et al. (2018) and Trajtenberg (1990) among others, the measure exhibiting the most explanatory power for firm performance is patent citations, even though also grant counts show significant effects. On the other hand I was able to show that also the choice of the performance measure is important (Tangen (2005)). Whereas patents proved highly significant in boosting performance in a Cobb-Douglas-style production function, they were unable to improve profitability measures like return on assets and return on equity. This highlights the importance of choice of measures for economists that seek to demystify the innovation-performance-relationship as well as for entrepreneurs who try to target specific financial indicators.

Another entrepreneurial target is survival. Firms who are unable to stand the competitive pressure and fail to achieve their financial goals for a certain amount of time are either forced to exit or decide that operating in the market is not worth the effort. Innovation is included in various theoretical models where it is crucial to get closer to the technology frontier and stay ahead of competitors (Klepper (1996); Ericson & Pakes (1995); Jovanovic (1982)). Even though such models are complex as they aim at picturing the entire dynamic market process, they come somehow short in addressing the complexity of innovation, calling for sophisticated empirical investigation.

Most empirical studies on the effect of innovation on survival report a stabilizing effect (recall table 5.1 for an overview). This is somehow surprising given the uncertainty and risk that come with innovation. However, almost all of them fail to account for the competitive position of the firm, such that I referred to life cycle theory to test if innovation has a stabilizing effect at any time. I was thus able to support the hypothesis of innovation helping the firm to avoid forced market exit only when the firm is on the decline with conventional growth opportunities mainly exploited, not contradicting but refining former arguments. This holds for all tested patent measures, even though magnitudes and precision differ with grants exhibiting the most stable effect. These results give long needed support to earlier industry-level studies like Agarwal & Gort (2002) and Audretsch (1995).

Concerning the second focus of this thesis – Corporate Governance represented by ownership structure – this thesis aims at investigating the role of incentive schemes and skills of different investors, managers and monitors in managing the firm. As innovation is always risky and its outcome is uncertain (Holmström (1989)), the transformation process into tangible assets is very heterogeneous. It may vary not only across firms but also across different projects in one firms, making innovation management a crucial factor for success. I tested popular hypotheses from Berle & Means (1932), Alchian & Demsetz (1972), M. C. Jensen & Meckling (1976), Demsetz (1983), Fama & Jensen (1983a) and Fama & Jensen (1983b) who theoretically investigate the effects of the separation of ownership and control on the firm's strategical decision making. The results show some similarities between innovation management and overall management. Concerning the former, external managers outperform owner-managers in terms of patent applications, whereas the latter rather focus on international conformity than on novelty and thus prove risk-averse. Whereas ownership structure in general had no consistent effect on R&D intensity, external managers generate more patents from such investments. This implies that separation of ownership and control is merely beneficial for innovation management. Reasons might be found in accumulating external expertise from professional managers or entrenched owners with below-average ambition to push such projects. Strong evidence was found on monitor ownership. The higher the amount of shares held by members of a firm's supervisory board, the better the overall innovation efficiency, measured in grants and citations. Firms and Researchers should thus focus more on monitor than on managerial ownership as a mainly overlooked topic with high potential. Furthermore external monitoring via ownership concentration showed a diverse affect, with supporting some of the application and grant measures but attracting less citations. On the other hand ownership by professional institutional showed negative effects through the whole process of knowledge production. These results join the ranks of a pretty heterogeneous empirical literature with yet no dominant opinion to be found.

For performance management in general I again found comparable effects. Managerial ownership had insignificant to mediocre effects on performance, such that it at least turns out not harmful as it does for innovation. On the other hand monitor ownership showed serious positive performance effects, again labeling this Corporate Governance tool as promising. These results are interpreted in the sense of monitors who significantly increase their interest in monitoring a firm they partially own due to direct effects of their efforts on their utility. I thus conclude that, whereas managing complex and risky innovation projects should be left to external managers, internal monitors can strongly benefit the firm in both innovation management and performance in general. Monitor ownership thus shows superior to other monitoring instruments like ownership concentration and institutional ownership. The question if such structures rather stem from founders withdrawing from management into monitoring (e.g. family members), or professional monitors acquiring shares is very much a chicken-and-egg problem and should encourage further research. Solving this puzzle could offer firms fruitful insights on choosing their personal optimal ownership structure. Furthermore, even though innovation in most cases benefits the firm, heterogeneous results of different measures for innovation and entrepreneurial targets show that it is crucially important how it is managed, calling for more research efforts in understanding these processes on the firm-level.

List of Figures

List of Tables

References

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Eidesstattliche Versicherung

Ich versichere hiermit, dass ich diese Dissertation selbständig und ohne fremde Hilfe angefertigt habe, und dass ich alle von anderen Autoren wörtlich übernommenen Stellen wie auch die sich an die Gedankengänge anderer Autoren eng anliegenden Ausführungen meiner Arbeit besonders gekennzeichnet und die Quellen zitiert habe.

Dortmund, den 22. November 2021