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Green innovations and financial performance change: distinguishing internally created and acquired green innovations in an empirical analysis

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Abstract

Research interest in the field of green innovation has significantly increased. Previous literature did not conclusively define the association between green innovations and firm performance, inter alia because of a lack of data and theoretical underpinning of the concepts. This thesis contributes to previous literature by investigating the effect of green innovation on firm performance by distinguishing between green innovations created internally and those acquired. Additionally, differences in extraction capabilities of acquired green patent based on internal green knowledge, and moderating roles of total innovations on green innovations have been examined. For this, longitudinal quantitative patent data has been utilized with a fixed effects approach. The dataset used consists of 600 firms that filed or acquired at least one green patent at the USPTO between 2013-2019. During this period, the firms filed in total 5,306 green patents with 120,130 related citations, and acquired 5,311 green patents with 98,928 corresponding citations. The findings indicate that green innovation activities overall, but especially acquiring green patents, result in a significant firm performance increase. Furthermore, the results indicate the special importance of the acquisition of green innovation ideas of high quality for firms that do not have a solid green innovation knowledge base in place.

Keywords: green innovation, patents, firm performance, acquired

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Introduction

With the events of floods, forest fires, unusual weather changes, drought, and rising sea levels, the consequences of global warming are visible and tangible all over the world. In fact, human-induced warming is currently approximately 1°C higher than the period 1850-1900, referred to as "pre-industrial" levels, with a current increase of approximately 0.2°C per decade (Masson-Delmotte et al., 2018). Limiting global warming to 1.5°C helps to achieve sustainable development aspects such as eradication of poverty, inequality reduction, decrease the exposure to climate risks, reduce food and water insecurity, and prevent economic losses (Schleussner et al., 2016). Although there is no single answer to the question whether it is feasible to prevent warming to 1.5°C, ambitious mitigation measures are indispensable to achieve sustainable development goals and limit global warming (Masson-Delmotte et al., 2018).

Recently, companies are increasingly seen as a potential solution to environmental concerns because they can perform innovative activities, rather than simply being the source of pollution (Cainelli et al., 2015). According to The Economist (2020), green innovations are an essential part to meet the sustainability targets set. Firms are not only an essential part for the society to become more sustainable, Boston Consulting Group states that the decarbonization of current operations should also be the most urgent priority for firms (Griffiths et al., 2022). By investing in green innovations, firms invest in becoming more sustainable and therefore create operations that are future-proof both in terms of stakeholder needs, as well as being prepared for, and the ability to adapt to, new sustainability policies. Moreover, according to Boston Consulting Group, the fight against climate change is the number one topic for most CEOs and boards of directors (Griffiths et al., 2022). To achieve climate goals over the long term, companies need to reinvent business models, implement new technologies, redesign businesses, and offer new products and services.

While external environmental pressure and awareness has increased for firms, financial performance is a concern that many companies may not want to sacrifice easily. Therefore, the research question of this thesis states: *"Do green innovation activities provide financial benefits for firms?"*.

Although the results of previous literature that investigated the effect of eco-innovations on firm performance are not completely conclusive, most studies find a non-negative relationship, with over half of the studies concluding a positive and significant effect (Friede et al., 2015; Hojnik & Ruzzier, 2016). The first reason why green innovations may not bring firm performance improvements is potential higher costs for sustainable material (King & Lenox, 2001). In addition, the sales of environmentally friendly innovations may come at the cost of existing offerings (Hockerts & Wüstenhagen, 2010). Third, the immaturity of green markets may cause lower demands for green products (Cainelli et al., 2011; Driessen et al., 2013). Last, Dangelico (2016) indicates the crucial role of top management's attitude towards green innovations, with too little attention the costs of certain innovations may exceed the benefits.

Nevertheless, most studies find a positive effect, implying that the mentioned arguments above are probably less important than the arguments why green innovations may lead to firm performance. First, Aguilera-Caracuel & Ortiz-de-Mandojana (2013) argue that green products provide more product differentiation from competitors, for which new market segments may be served. In addition, performing green innovations enhances a firm's reputation and social approval, wherefore premium prices can be charged, or increased sales can be observed (Bansal, 2005; Marcus & Fremeth, 2009). Last, Simpson and Bradford (1996) theoretically argued that firms face lower marginal costs because of green innovation activities.

The arguments of Simpson and Bradford (1996) are also found in empirical studies. Namely, green innovations face competitive advantages such as lower production costs, increased productivity and efficiency, improved product and service quality, and better customer response (Chen et al., 2006; Chiou et al., 2011; Hart, 1995). Gürlek and Tuna (2018) elaborate on the competitive advantages and claim that organizations gain financial benefits because of improved product design and quality, while organizations also achieve cost advantages via savings of materials, energy, and water. In addition, the authors claim that new customers are attracted owing to performed green innovations. Last, due to recycling and reusing materials in the process, operating costs can be reduced (Chen et al., 2006; Aguilera-Caracuel & Ortiz-de-Mandojana, 2013).

Aguilera-Caracuel and Ortiz-de-Mandojana (2013) conclude that firms that perform green innovations face a higher firm performance increase compared to those that do not. Lee and Min (2015) found that green R&D expenditures is positively associated with financial performance. Similarly, in a study by Ar (2012), a positive and significant association between green product innovation and firm performance across 130 Turkish based manufacturers from multiple sectors has been found. Also, Hart and Ahuja (1996) found a positive relationship between proactive environmental impact reductions and financial performance of firms. Russo and Fouts (1997) conclude by stating that "it pays to be green".

Previous studies often used survey data instead of quantitative data (Ar, 2012; Chen et al., 2006; Chiou et al., 2011; Gürlek & Tuna, 2018). In addition, many studies have been performed in a certain specific country and/or industry context. Furthermore, previous studies did not utilize green patent information with a within variation estimation approach. Last, the distinction between green innovations that have been created internally within a firm, and green ideas acquired has not been made before. The fact that the distinction between the means of green innovation accumulation has noy yet been made is noteworthy, since studies in the field of growth theory argue that internal and external growth are two different strategic options (Penrose, 1959).

This thesis aims to close these gaps by using green patent data filed at the United States Patent and Trademark Office. Green patents have been identified according to the Cooperative Patent Classification, which provides a classification for green innovations since 2010. Because the Y02-classification which captures green patents is only possible since 2010, there have not been many papers using green patent data in similar studies, especially not in a panel dataset over a relatively long period. Additionally, a fixed effects approach will be used for this dataset. Furthermore, patent filing and transaction dates are used to distinguish patents in patents filed internally and patents that have been acquired.

Performing a within effects estimator for a study investigating the effect of green innovation on firm performance is relatively unique. Previous literature often used survey data for which many studies performed a Structural Equation Modeling technique to investigate potential causal effects. However, using survey data also has disadvantages, such as the arbitrariness whether the provided results in survey are completely true. In addition, some surveys use discrete answer options, for which categories of firm performance or performed innovation are provided, instead of continuous answers. Last, attrition bias is a potential concern in survey data since participants can decide to stop providing answers due to certain reasons.

Literature Review

Innovation

Innovation is considered one of the most important drivers of economic growth (Grupp, 1998). Nevertheless, literature on the effect of technological eco-innovations on firm performance is not completely conform and conclusive. Yet, economic research on innovation has become increasingly popular during the last decades. Titles containing "innovation" as a percentage of annual published papers increased from approximately 0.02% to over 0.55% between 1956 and 2008 (Fagerberg et al., 2012). This ratio increased because of important findings, the emergence of new research questions and access to new and better resources.

Innovation is the creation of new knowledge, or the transformation and creation of new combinations from existing knowledge, which is a result of both invention and commercialization (Schumpeter, 1982). As the first explicit researcher in the field of innovation, Schumpeter (1982) explained that adaptable firms that renew operations or products can outperform firms that do not. Innovation is different from invention because of the application of the invention. For example, without production facilities, knowledge, financial resources, and other essential parts of commercialization power, an invention will remain an invention and will not be an innovation since the application power is insufficient to diffuse the invention. Schumpeter (1982) categorizes innovation into five fields: new methods of production, new products, new sources of supply, new ways to organize a business, and the exploitation of new markets. In addition, Barras (1986) set the foundation layer regarding innovation research in service industries a few years later. Nevertheless, economic research is mainly concentrated on new products and methods of production, which are often referred to as "product innovation" and "process innovation" (Fagerberg, 2013). Another common innovation classification approach is the degree of radicalization of innovations. Innovations consisting of big and discontinued changes, such as completely new products or services, are called 'radical' innovations while small and continuous innovations, often a steady stream of improvements to a product or process, are called 'incremental' innovations (Freeman, 1982).

Furthermore, innovation is symbolized by several key elements. First, firms may face path dependencies, which implies that firms take previous decisions regarding innovation into account when making future decisions (Arthur et al., 1987). Second, according to Kaplan and Vakili (2015), breakthrough innovations are a sequence of diverse recombinations, accompanied by deep immersion in a narrower domain. Finally, innovation always brings unquantifiable uncertainty in the sense of potentially unexpected events, for example, outcomes of investments are often not known beforehand whilst the value of the outcome in terms of market demand is also not known with certainty (Teece and Leih, 2016).

Innovation theoretical approaches

Schumpeter (1939) laid the foundation regarding the introduction of theoretical perspectives on innovation. At the highest level, a distinction between perspectives that consider external or internal environment factors to be dominant for innovative activities can be drawn. Below the four most important theories are discussed, namely the resource-based view, the evolutionary theory, industrial organization, and economics of networks.

This study focusses on innovation as a competitive advantage for firms, which is best reflected by the resource-based view of innovation and to a less extent the evolutionary theory, both emphasizing the internal environment of firms to be dominant for innovation. The resource-based view, introduced by Wernerfelt (1984), considers a firm as a bundle of resources consisting of internal resources, and emphasizes the importance of innovation as a strategic decision of firms seeking a competitive advantage. This view also suggests that firms have their own set of resources and capabilities which are unique (Becker and Dietz, 2004). According to Grant (1991), the resource-based view is of special application to intangible assets, which are unobservable assets that do not appear in a company's financial statement. Itami and Roehl (1991) even argued that these intangible resources and people-based skills are strategically the most important resources of firms. Examples of such intangible assets are knowledge, skills, experience of employees, absorptive learning capacity, brand image, technological resources, managerial capabilities, and an organization's culture (Galende, 2006). In addition, intangible resources come with heterogeneity and imperfect transferability, which together with its scarcity, uniqueness, durability, and inimitability, make that the resources and capabilities provide a competitive advantage (Barney, 1995; Dierickx & Cool, 1989). The resource-based view explains that innovative capabilities are a result of the possession of heterogenous technological resources, and the capability to generate new resources, rather than skills of exploiting external technologies (Barney, 1991). Competitors can assess the latter easily and therefore these do not provide a sustainable competitive advantage, whereas the resources providing the ability to generate new innovations declare largely distinctions in profitability of firms operating in the same industry (Galende, 2006). What a firm can do is heavily driven by the types, amounts, and qualities of intangible resources available to the firm (Itami & Roehl, 1991).

The evolutionary theory considers the internal environment also to be dominant over the external environment. The evolutionary theory emphasizes the importance of innovation development within a firm over time, since it does not remain stable but develops over trajectories (Dosi, 1991). Key to this approach is the assumed incremental nature of innovation, a result of firms creating their own technological knowledge base on which it is building forward with previously gained skills and knowledge that is used for continuously improve products (Helfat, 1994; Malerba & Orsenigo, 1990). Often, firms confront several innovative ideas of which it must choose a few to continue with, therefore, the accumulation of the knowledge is often subject to bounded rationality (Simon, 1947). In most cases, firms focus on the ideas that are closest to their technological core knowledge to reduce uncertainty (Miyazaki, 1994). As a result, firms develop new knowledge related to already established and tend to focus on activities developed previously that condition those to be carried out in the future (Cohen and Levithal, 1990; Dosi, 1988; Teece, 1998).

The industrial organization and economics of networks approaches consider external factors to be most important for innovation activities (Galende, 2006). Industrial organization states that differences in innovative activities by firms can be explained by structural external distinctions such as industry characteristics or public policies (Mason, 1957). Last, economics of networks emphasizes the importance of economic clusters and social networks. Schumpeter (1939) argued that innovations tend to happen in clusters, implying that innovations facilitate other innovations. Such clusters may be around a specific location, linked with historical actions, or across industries. The main idea of benefits for firms to be in a cluster is because of the easiness to share ideas, ability to learn from external parties, and the availability of a specialized labor pool and financial institutions to finance ideas. In addition, social networks provide the opportunity to learn from a diverse knowledgebase.

Innovation measures

Innovation can be measured in multiple ways that can be categorized into input, intermediate output, and output measures. Input measures consist of factors necessary for innovation, without actual results towards innovation in place, such as R&D investments, the attitude towards innovation, or the fraction of employees dedicated to innovation. Intermediate output measures capture an element that points towards innovation, while the product itself is not an innovation yet, an example is a patent. Last, output measures reflect actual innovations, an example of an output measure is a new product or feature. While the maturity of an innovation increases from input to output measures, input and intermediate output measure have been used more in studies in which a quantification of innovation is necessary. Output measures are used less since these are harder to measure in a quantitative matter.

Patenting knowledge has been identified as an important strategic action in intellectual property management (Andries & Faems, 2013). In general, firms do not prefer to rely on trade secret protection if protection is an option, what patents in fact provide (Mansfield, 1986). According to Cockburn and MacGarvie (2009) the main purpose of patents is to face less hinderance of imitators in the process of commercialization of new knowledge inventions. This is supported by Arora et al. (2008) who found that effective patent protection positively effects both patenting and R&D. Also, patent protection can be performed in a broader matter to provide litigation avoidance space and make it more difficult for competitors to commercialize recombinations (Blind et al., 2009; Cohen et al., 2002). Last, patenting activities facilitate outward knowledge licensing, which can trigger licensing fees as additional revenue stream (Andries & Faems, 2013).

Mansfield et al. (1983) argue that patents increase imitation costs and therefore protect innovation ideas. This is supported by Moser (2005), who finds that in countries without patent laws, inventors tend to focus efforts on technologies where other means of protection are available, implying that innovation protection overall is important for innovation.

According to Frietsch and Grupp (2006) patents can be treated as the most important indicator of innovation as they contain standardized information about new knowledge and technological development. Patents are also commonly used as innovation indicator since the data is widely available, and since this data provides a countable measure for innovation (Acs et al., 2002). Last, since patents often are a result of investments, which is an innovation input measure, the intermediate output that patents provide, can also be considered as a success indicator of R&D investments for which not only the investments, but also the skills of R&D departments are considered (Grupp, 1998; Kash & Kingston, 2001).

Green innovation

According to Angelo et al. (2012) environmental innovations, green innovations, and eco-innovations can best be described as "organizational implementations and changes focusing on the environment, with implications for companies' products, manufacturing processes and marketing, with different degrees of novelty". Clarke and Roome (1995) define green technology as "the least damaging to physical, biological and cultural systems". The green technologies include all changes in products and processes, radical or incremental, intended or not, that tackle sustainability targets such as eco-efficiency, reduction of emissions, eco-design, recycling, or waste management (Rennings, 2000). The broader explanation including sustainability is also adopted by the European Union in their definition of eco-innovation for the Eco-innovation Action Plan, providing the following definition: "Eco-innovation is any form of innovation resulting in or aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment, enhancing resilience to environmental pressures, or achieving a more efficient and responsible use of natural resources" (European Commission, 2011).

Environment friendly innovations can be categorized in product, process, and organizational innovations, in which eco-product and eco-process innovations often are referred to as eco-technological innovations (Horbach, 2008; Kemp & Arundel, 1998). Environmental targets for reducing waste, energu and material use at the source are frequently used for emission reducations during the production process, often referred to as "eco-efficiency" (Sharma and Henriques, 2005). A commonly addressed difference between eco-innovations and standard innovations regarding eco-efficiency is the focus on recyclability, re-usability, and a focus on the lifetime of products. Emission reductions obtained through products or processes that become more durable, easier to disassemble, or reusable, in which the whole life cycle is considered, is often referred to as 'eco-design'.

Over the last years, literature highlighted the importance of green innovation determinants at the organizational level. For example, Bansal (2005) argues that not only institutional factors, but also resource-based characteristics determine corporate sustainable development success. As explained, this thesis will focus on those characteristics that are internal to a firm, an orientation that is most compatible with the resource-based view.

One of the main overarching motivations for companies to perform innovations is to obtain or expand their competitive advantage, however, reasons for an increased competitive advantage are very extensive (Miller, 2001; Eiadat et al., 2008). For example, Eiadat et al. (2008) state that green innovations provide three types of benefits that create a competitive advantage. First, after successful product differentiation because of an environmental friendlier product, a company can benefit from the innovation in terms of higher prices or higher customer demand. Second, firms are better prepared for potential stricter government regulations because of green innovations. Lastly, environmental innovations help to strengthen an organization's reputation.

Furthermore, Chiou et al. (2011) find a positive and significant relation between green innovation performance and elements representing a competitive advantage, consisting of lower production costs, increased productivity and efficiency, better customer response, and better product and service quality in their study that has been performed in Taiwan using survey data. This is in line with findings of a study by Chen et al. (2006) in which they use survey outcomes of 203 managers that work for a firm in Taiwan. The authors claim that both product and process innovations lead to a stronger competitive advantage due to increased productivity, profitability, product and service quality, and efficiency. This is also addressed by Hart (1995), one of the pioneers of the resource-based innovation view, who acknowledges that capabilities to avoid pollution generate solutions for environmental issues. Also, he continues by stating that those that ensure sustainable development obtain a competitive advantage due to lowering costs through eliminating production processes, extending life cycles through redesigning existing products, and lowering life cycle costs.

Gürlek and Tuna (2018) elaborate in their study in which employees of Turkish firms filled in a survey on the created competitive advantage of green innovations and claim that organizations gain financial benefits because of improved product design and quality, while also achieving cost advantages via savings of materials, energy, and water. In addition, the authors claim that new customers are attracted because of performed green innovations. Last, due to recycling and reusing materials in the process, operating costs can be reduced (Chen et al., 2006; Aguilera-Caracuel & Ortiz-de-Mandojana, 2013). It is important to emphasize that the competitive advantage that green innovations bring, applies to those innovations where organizations entitle a strategy that cannot be perfectly imitated by potential competitors and that a sustainable benefit is obtained compared to competitors' strategies, which is in line with the resource-based view discussed (Barney, 1991; Coyne, 1986).

Green innovation and other innovations – differences

Green innovations face in particular great uncertainty for firms due to the number and kind of resources required and the uncertain future (Tseng et al., 2013). The uncertainty on the resource spectrum may be a result of a difference between the necessary resources for developing green innovations and those needed for non-green innovations (Cainelli et al., 2015). One reason for green innovations to be more idiosyncratic than non-green innovations is that these innovations are more complex on average (Andersen, 1999; De Marchi, 2012). The complexity lays mainly in the higher levels of novelty and variety that green innovations face, the higher levels of novelty in particular lead to the need for greater internal innovation resources (Cainelli et al., 2015).

Although the awareness of environmental problems by firms, stakeholders, and consumers has grown, the environmental problems and technological requirements to tackle the problems also have grown. In line with the resource-based view, to make successful innovations firms must fill a gap between required innovation elements and the firm's resources and capabilities (Danneels & Kleinschmidt, 2001). Due to regulation and consumer demand changes, such gaps are in particular large if a firm faces abrupt environmental concerns and is not prepared sufficiently, especially compared to "normal" innovations that may arise less abrupt in case of regulations. The more diverse the necessary knowledge and skills to innovate, the higher the chances of external resources to be key for success (Nieto and Santamaria, 2007). These external resources can be obtained via collaboration, or via acquiring knowledge. Halila and Rundquest (2011) support this by stating that environmental innovative solutions often stem from an original combination of knowledge and competencies, endowed by multiple organizations, in which the network is used to solve technological problems whereas non-eco innovations use it more for financing and marketing assistance.

Cainelli et al. (2015) also emphasize the importance of original combinations of knowledge and competences by claiming that environmental innovators are characterized by more intensive external relationships, supporting the innovation theory of the economics of networks. This is reflected by companies seeking access to knowledge and fundamental resources to obtain a competitive advantage through inter-organizational relationships, networks, and alliances (Cooke, 1996; Das and Teng, 2000; Lavie, 2006). The benefits of networking for green innovations extend beyond access to knowledge and resources. Grandori (1997) indicated risk sharing benefits of networks, while Grandori and Soda (1995) argue that new markets and technologies can be assessed because of networks. Other benefits include pooling of complementary skills, and property right safeguarding when contingent contracts are not possible (Eisenhardt & Schoonhoven, 1996; Liebeskind et al., 1996).

Firm performance

In a broad way, the term firm performance implies the level and extent to which a company performs. This can be measured in financial contexts such as return on capital, profitability, cash flow, and operating costs, and non-financial contexts such as customer relationships, internal processes and learning capacity (Kaplan & Norton, 1996). Santos and Brito (2009) identify five dimensions of firm performance: financial performance, customer satisfaction, employee satisfaction, social performance, and environmental performance. The authors further argue that regarding financial performance, profitability and growth together are conceptually justified to explain financial performance. The selected indicators for profitability in the study were Return on Assets, EBITDA margin, Return on Investment, Net Income/Revenues, Return on Equity, and Economic Value Added. For growth, the market-share growth, asset growth, net revenue growth, net income growth, and the number of employee growth were selected as indicators.

The main criticism of relying on non-financial measures is the lack of reliability because of the difficulty to measure it. Therefore, accounting measures are often used and considered valid to represent firm performance. For example, Klein (1998) used Market Returns and Return on Assets, besides Jensen Productivity as firm performance measures. Similarly, Bhagat and Bolton (2008) used Returns on Assets, together with the average values of Tobin's Q and Stock Returns and the figures compared to industry peers as performance measures. Other measures that have been used are Return on Equity, Net Profit Margin, Sales Growth, Dividend Yield, and Stock Repurchases (Brown & Caylor, 2004).

Environmental innovation and firm performance

The literature regarding the effect of green innovations on firm performance is not completely conform and conclusive. Although previous literature does not provide a conclusive outcome, most studies find a non-negative relationship while more than half of the studies find a positive and significant effect. A study by Friede et al. (2015) combined the findings of 2200 individual studies examining the relationship between ESG criteria, which has similarities with environmental innovation but is not limited to this aspect, and corporate financial performance. The authors indicated that in roughly 90% of the studies a non-negative relation has been found, with 55% of the studies providing positive findings and 7.5% providing negative results. This is supported by Hojnik and Ruzzier (2016) who conclude that eco-innovations lead to improved profitability, growth, and competitive benefits by investigating 20 conceptual and 135 empirical articles.

Often investments are required for innovations, in which typically the expected costs are weighed against the expected benefits. Therefore, whether green innovations are beneficial for firms or not, depends on the observed costs and benefits of the performed innovations. Studies that find a negative association between eco-innovations and firms' performance often point towards additional effort requirements that are necessary to adapt these innovations, without the efforts yielding at least equivalent benefits.

First, higher costs are involved with eco-innovations because of more expensive sustainable materials that may require additional costs (King & Lenox, 2001). Furthermore, environmental product and process innovations may cannibalize sales of existing offerings or deteriorate previous investments in other processes or products (Hockerts & Wüstenhagen, 2010). Cainelli et al. (2011) provide another explanation in stating that early movers in green markets face a disadvantage in terms of employment and turnover change in the short term. In their study, the green market was considered a non-mature market in which early movers are not able to comprehend the complete potential benefits. The immaturity of the green market, causing low demand for green products, is also argued to be the reason for the negative association between eco-product innovation and financial performance by Driessen et al. (2013). Additionally, the double externality problem is often referred to as reason for a negative association between eco-innovations and firms' performance. Wagner et al. (2002) claim that the negative relationship can be explained because of a discrepancy between the optimal level of green activities by a firm, and the social optimal level. Furthermore, the higher complexity that eco-innovations on average face compared to other innovations, which has been discussed before, may also explain the higher costs. Last, Dangelico (2016) points towards the importance of the attitude of top management since green innovations can be negatively associated with firm performance if management has too little attention, limited time, and incomplete information about these innovations.

While the above-mentioned papers provide examples of studies that associate eco-innovations with negative implications for the financial performance of firms, most studies find a non-negative relation. Previous literature described several theoretical arguments that enable eco-innovations to have a positive impact. First, Porter and van der Linde (1995) state that green products could provide a new market segment in which a higher price can be carried, compared to other products or processes, because of its clear commitment to more environment friendlier way of operating, combined with the performance of the eco-products. One reason for this is that products are more differentiated from competitors' products (Aguilera-Caracuel & Ortiz-de-Mandojana, 2013). Furthermore, a better reputation of a product or firm is achieved with the performance of green technologies, which may be enhanced into increased reputation though external agents, which subsequently leads to better social approval and a situation in which premium prices or increased sales may be observed (Bansal, 2005; Marcus & Fremeth, 2009). Last, Simpson and Bradford (1996) theoretically analyzed firms in a Cournot duopoly setting and argued that firms face a decrease in marginal costs due to performed green innovation.

Aguilera-Caracuel and Ortiz-de-Mandojana (2013) compare firms that perform green innovations with those that do not by using patent data of firms with a high percentage of green patents filed at the European Patent Office during the past 20 years. The authors conclude that firms that perform green innovations face a higher firm performance increase compared to those that do not, however, during the period of observation, the firm performance improvement was not significantly higher.

Lee and Min (2015) used another measure of green innovation by applying green R&D expenditures, an innovation input measure, which also found to be positively associated with financial performance in Japan during 2001-2010. The authors argue for the use of R&D expenditures since it provides a commitment to green innovations in the long term by creating internal resources.

Similarly, in a study by Ar (2012), a positive and significant association between green product innovation and firm performance across 130 Turkish based manufacturers from multiple sectors has been found. Also, Hart and Ahuja (1996) found a positive relationship between proactive environmental impact reductions and financial performance of firms, using a data sample consisting of 127 firms that were part of the S&P 500. The authors used the toxic release inventory index as measure of environmental performance. A similar finding has been found by Russo and Fouts (1997), stating that "it pays to be green".

Aguilera-Caracual and Ortiz-de-Mandojana (2013) state that green innovation is one of the most proactive ways of achieving benefits of environmental development for firms. A proactive attitude leads firm to consolidate the capabilities within an organization, providing firms to be more flexible in new and complex contexts due to a deeper understanding (Aragón-Correa & Sharma, 2003).

Last, Zhang et al. (2019) investigated the influence of green patenting on firm performance of manufacturing firms in China during 2000-2010. The authors did not find a significant result when patents were used to reflect green innovations, while a positive and significant association was found when citations on green patents were used. The authors claim that citations represent the quality of green innovation activities while the number of patents does not include the quality aspect.

Literature gap

Whereas the effect of green innovation on firm performance has been studied frequently before, the studies were often performed in a survey format as described above (Ar, 2012; Chen et al., 2006; Chiou et al., 2011; Gürlek & Tuna, 2018). In addition, many studies have been performed in a specific context, such as country or industry specific studies. Furthermore, patents to represent green innovatiove has not been used frequently in a panel data setting. Last, the distinction between green innovations that have been created internally in a firm and the knowledge acquired has not been made before.

Most reasons for green innovations leading to improved financial performance described above refer to the innovations based on resource-based characteristics that are already within the firm. However, green innovation knowledge can also be acquired from an external party. Previous literature did not investigate the role of so-called hybrid resources such as the acquisition of patents or other external knowledge for environment innovations extensively. However, the growth theory initiated by Penrose (1959) argues that external growth, id est growth attained by means of acquisitions, and internal organic growth should be considered two completely different and separate strategic options, implying that the distinction between internally created patents and externally acquired patents is important.

Cainelli et al. (2015) argues that firms with reactive innovative strategies, instead of proactive strategies, are less likely to get involved in successful environment innovations to reduce their footprint. In this study, a firm's attitude toward innovation was used to define reactive and proactive strategies in which reactive was defined as firms that do not perceive the existence of a market for new products or processes. This implies that focusing on proactive innovative strategies, which result in internally produced innovations, are preferred over reactive innovative strategies, which acquired innovation ideas are.

While the role of hybrid green resources for firm performance cannot be unanimously explained, literature is united regarding the necessity of access to new information. In fact, Dangelico (2016) demonstrates that both enhancing knowledge exchange, within and outside the firm, and creating fostering networks of collaborations is beneficial for green product innovation. This finding has already been explained by Schumpeter (1939) stating that firms operating in different networks are able to learn from external parties because of exposure to a diverse knowledgebase. Later, other studies showed that having a diverse knowledge source allows companies to enhance new combinations of existing knowledge and technologies, whilst the exposure to diverse knowledgebases also enables firms to choose technological paths (Nelson & Winter, 1982; Metcalfe, 1994). Furthermore, for inventions overall, diffusion and time to market of ideas benefit from external relationships (Almeida & Kogut, 1999; Baptista, 1999). Last, new ideas and knowledge generated internally is path dependent and close to the current knowledge of the firm, while acquired knowledge engages 'resource learning' and may lead to the exposure to non-path dependent knowledge that allows for new (re-)combination possibilities (Lockett et al., 2011; Mahoney, 1995). In fact, the increased diversity of resources and ideas expands a firm's productive opportunity set[1] (Harrison et al., 2001)

In addition, Singh & Agrawal (2011) investigated whether firms that hire inventors of ideas from other firms acquire not only the skills of that person, but also enhance access to the ideas of the firm and person. In their study, the authors found that firms that hire inventors, increase the use of the new recruits' hire inventions on average by 219%, with the new hire providing a persistent importance that is not significantly diminishing over time. The key idea of the study is that ideas are diffused from one firm to another firm because of knowledge spillovers through employees (Arrow, 1962). While it has not investigated yet, a similar effect of firms acquiring green innovation knowledge through ideas from other firms can be expected.

Reasons to acquire certain green ideas can be compared to the reasons for firms to make corporate venture capital investments described by Ma (2020). Namely, firms can make these investments to "fix the weaknesses", but also to "build on strengths". If a firm is performing inadequate, acquiring green innovation knowledge can increase their performance via dedicate external knowledge resources which helps to strengthen internal innovation. In contrast, firms that are already a leading firm in terms of green innovation knowledge may use the information to identify beneficial other innovation knowledge bases to strengthen their position.

[1] The productive opportunity is a set of opportunities for investment in growth (Penrose, 1959). Examples of such opportunities are changes in technology, the introduction of new products, changes in organization structure, geographic expansion, or the acquisition of additional management (Neck, 2001).

In previous literature, green innovations are dominantly argued to provide a competitive advantage in terms of reduced costs and improved products or processes, yielding the opportunity to ask higher prices, face higher demand, or retain higher margins. Most papers argue that green innovations lead to increased financial firm performance. This thesis hypothesizes that firms that perform higher levels of green innovation, measured by green patents and citations on green patents, face better financial firm performance changes. Additionally, this thesis makes the distinction between green patents that have been filed by the firm itself, and patents that have been acquired.

Hypothesis 1a: Total green innovation activities are positively related to financial performance changes.

Hypothesis 1b: Green innovations created internally in a firm is positively related to financial performance changes.

Hypothesis 1c: Green innovations acquired by a company is positively related to financial performance changes.

The abovementioned hypotheses distinguish green innovations into different subcategories, namely internally created and acquired. However, it may be that both types of activities are not carried out separately. Since previous research did not distinguish between both categories, there are no previous findings regarding a potential moderation effect between green innovation acquired and green innovation filed. However, other authors did investigate potential indirect impacts between environmental innovations and firm performance. For example, Ar (2012) investigated managerial environment concerns as moderation variable while Aguilera-Caracuel and Ortiz-de-Mandojana (2013) considered the role of environmental regulations and normative levels of environment. While many papers investigated potential moderators, all moderators where related to variables omitted in fixed effects models due to collinearity, such as environmental regulations, or variables gathered through surveys, such as managerial environment concerns. In addition, most moderators do not provide statistically significant and persuasive findings.

Despite the absence of previous research on moderator effects regarding multiple ways of gathering green innovations, a moderator effect of internally produced patents on the relationship between acquired patents and firm performance is not inconceivable. Namely, the process towards filing a patent internally demonstrates a company's commitment to environmentally friendly innovation. Furthermore, the ability of filing a patent internally also indicates a company's ability to perform green innovations and knowledge in the field of a certain green innovation, providing an advantage regarding the absorption of new ideas, and potentially a more targeted search for knowledge in a particular sub-section.

Lockett et al. (2011) confirms that there is a difference in the impacts on future growth between previous internal organic growth and acquisitive growth. The authors indicate that previous internal growth constraints current internally growth, while previous growth gained through acquisitions positively influences current internal growth. The most important aspects of differences in growth presented by Penrose's growth theory are the adjustments costs and productive opportunity sets that firms face (Penrose, 1959). Penrose

(1959) considered people to be the most important resource in any business and explains that expanding activity success depends on the managerial capabilities and their ability to work together. In fact, managers decide on deployment of resources and decide on firm activities (Penrose, 1960). The capabilities and resources created and available at firms can be used for future growth (Lockett et al., 2011).

Therefore, this thesis hypothesizes a positive moderating effect of internally filed green patents on the relationship between acquired green patents and firm performance.

> **Hypothesis 1d:** The relationship between green innovation acquired and financial performance changes is moderated by green innovations filed internally at a firm.

Moderating role of total innovations on green innovations

Little research has been performed regarding the implication of a potential moderating role of a firm's overall innovation activities on the relation between green innovations and financial performance.

Tseng et al. (2013) argued that a firm's ability to formulate green projects with suitable programming, resource, and budget allocation is important to ensure green practices. In line with this, Dangelico (2016) argues that the attitude of top management regarding green innovations is crucial. In fact, the author argues that if there is too little attention and limited time, green innovations may not provide the expected benefits. Furthermore, Amit and Schoemaker (1993) state that identifying, enhancing, protecting, and exploiting key resources and capabilities within a firm is a crucial challenge for managers. These actions are key to extract the competitive advantage that the valuable, rare, non-substitutable, and intangible resources potentially provide, which is in line with the resource-based view (Barney, 1991). Therefore, a clear plan by managers for green innovations is crucial, whilst limited attention, time and resources are a concern. Consequently, a trade-off between green and other innovations and a trade-off between innovations overall and operational activities are expected.

When considering the rationales for performing green innovation activities found in previous literature, one can argue that several reasons for green innovations provide either a substitute for normal innovations or come at the expense of non-green innovations. For example, lower production costs, increased productivity and efficiency, and better product and service quality are elements that provide a competitive advantage because of successful green innovation mentioned by Chiou et al. (2011). These elements may also be reached through normal innovations. However, some elements that provide a competitive advantage when performing green innovations cannot be enhanced through non-green innovations. These include a more and specified differentiation of products from competitors' products, mentioned by Aguilera-Caracuel & Ortiz-de-Mandojana (2013). In addition, a better reputation of a product or a firm that may be achieved with the performance of green innovations is also harder to enhance through non-green innovations.

Furthermore, a firm's performed overall innovation practices may be beneficial for green innovations practices since intangible assets that are able to innovate are present (Galende, 2006). In fact, innovations that are not green innovations per se may be beneficial for the creation, diffusion, or practical application possibilities of green innovations. Therefore, non-environmentally performed innovations may positively moderate the relationship between green innovation and firm performance.

Despite green innovations may come at the expense of resources, time, and focus for other non-green innovations, non-green innovation capabilities may provide benefits for green innovation creation and diffusion for firms. Therefore, this thesis hypothesizes a positive moderating effect of total innovations on the relationship between green innovations and firm performance, for overall innovations, internally created innovations, and acquired innovations.

Hypothesis 2a: The relationship between total green innovations and financial performance changes is positively moderated by total overall innovations.

Hypothesis 2b: The relationship between internally created green innovations and financial performance changes is positively moderated by total overall innovations.

Hypothesis 2c: The relationship between acquired green innovations and financial performance changes is positively moderated by total overall innovations.

To perform innovations successfully, firms must fill a significant gap between the required innovation elements and the firm's resources and capabilities, which often require intangible assets as explained by the resource-based view (Danneels & Kleinschmidt, 2001; Grant, 1991). The more diverse the necessary knowledge and skills to innovate, the higher the chances of external resources to be key for success (Nieto and Santamaria, 2007). The gap between the needed knowledge and skills for innovation and the current knowledge and skills within a firm not only depend on the complexity of the invention, but self-evidently also on the current capabilities of the firm. If the gap is relatively large, with a low level of current capabilities, acquiring hybrid resources may provide a solution. As explained, green innovations are considered to be in particular idiosyncratic since these innovations are more complex on average (Andersen, 1999; De Marchi, 2012). In addition, the more diverse the necessary knowledge and skills to innovate, the higher the chances of external resources to be key for success (Nieto and Santamaria, 2007).

Reasons for acquiring hybrid innovation resources can be compared to the reasons for firms to make corporate venture capital investments described by Ma (2020), namely firms can make these investments to "fix the weaknesses", but also to "build on strengths". If a firm is performing inadequate, acquiring green innovation knowledge can increase their performance via dedicated external knowledge resources which help to strengthen internal innovation, Ma (2020) refers to this phenomenon by "fix the weaknesses". In contrast, firms that are already a leading firm in terms of green innovation knowledge may use the information to identify beneficial other innovation knowledge bases to strengthen their position, this is referred to as "build in strengths". Ma (2020) explains that firms create corporate-affiliate venture capital programs to systematically invest equity in innovative startups to boost innovation knowledge within a firm.

An important difference between corporate venture capital and the acquisition of innovation knowledge represented by patents is that firms that are top performers in terms of internally created green innovations may not only acquire knowledge to build in strengths. Namely, patents are already an intermediate output product of innovation, whereas corporate venture capital programs are investments in innovations, and therefore an input of innovation. This implies that with patents, there is already more certainty about innovation success, protection, and inimitability of an idea, and consequently more scarcity, compared to corporate venture capital programs. Because of these reasons, top performing firms do not solely have reasons to acquire patents to "build in strengths" but may also want to ensure that external ideas are kept away from competitors to ensure the knowledge is not used by others, regardless of whether they will or will not do anything with it themselves. The other way around, because of the increased certainty regarding innovation success, the protection of ideas, the inimitability and consequently scarcity of ideas, for underperforming firms the rationale for acquiring patents may be even stronger than in the case of innovation investments.

The abovementioned arguments are supported by findings of research in the field of behavioral theory of the firm. Underperforming firms challenge their practices that are related to the status quo and seek solutions by problemistic search[2] (Cyert & March, 1963). Gavetti et al. (2012) argue that the problemistic search of underperforming firms leads to innovative activities. The main argument for these firms to perform innovative activities is to explore new strategic options (Bromiley, 1991; Chen & Miller, 2007; Shinkle, 2012). Namely, underperforming firms face continuously failure of local solutions, for which relying on local knowledge is ineffective (Yu et al, 2019). As a result, for underperforming firms that want to compete and keep up with technological changes the opportunity cost of acquiring knowledge externally decreases (Cloodt et al., 2006; Tushman et al., 1986). Furthermore, Gavetti et al. (2012) explain that those underperforming firms pursue strategies by seeking external innovation knowledge to overcome performance shortfalls. It is important that only firms that are far away from bankruptcy consider external innovation acquisitions, as firms threatened by bankruptcy are not likely to seek alternatives (Chen & Miller, 2007).

Therefore, for underperforming firms, the rationale for acquiring patents is expected to be more directed towards achieving firm performance growth compared to firms that are already top performers.

In contrast, studies showed that having a diverse knowledge source allows companies to enhance new combinations of existing knowledge and technologies, whilst the exposure to diverse knowledgebases also enables firms to choose technological paths (Nelson & Winter, 1982; Metcalfe, 1994). However, to convert external knowledge into internal knowledge and successfully commercialize the ideas firms need to be able to absorb the new knowledge and commercialize it. The absorptive capacity of firms, represented by the ability of firms to realize benefits from new information, depends on the ability to tap into new and potentially more complex sources of information, and the strength of a firm's internal knowledge base (Benson & Ziedonis, 2009; Cohen & Levinthal, 1990). Following this reasoning, one would expect firms that are already performing good in terms of internal created innovations and therefore have more and better internal green innovation knowledge and capabilities to commercialize these, to be better in absorbing new external information and translate it to firm performance improvements.

[2] Problemistic search refers to the specific case where search for alternatives is triggered because of an encountered problem at an organization and ceases when a satisfactory solution is provided (Cyert & March, 1963; Simon, 1955)

One of the key elements that symbolizes innovations is path dependency that firms may face, which implies that firms take previous decisions regarding innovation into account when making future decisions (Arthur et al., 1987). Because the development of new product and process creation is path dependent, firms tend to focus on activities develop previously that condition those to be carried out in the future, since choices made in the past determine largely which innovation(s) the firm continues with (Dosi, 1988; Teece, 1998). This implies that firms that are top performers in terms of internal created innovations are more likely to already have selected or chosen the innovations to further develop, whether the choice was made consciously or not. In contrast, firms that have not performed internal green innovations, but are seeking these innovations, are more likely to be open for acquired ideas since relying on local knowledge has been ineffective due to continuously failure of local solutions (Yu et al, 2019).

Lockett et al. (2011) argues that overall, acquisitive growth creates new combination possibilities and provide an opportunity to include non-path dependent resources. In fact, Harrison et al. (2001) explains that the increased diversity of resources and ideas gained through external acquisition expands a firm's productive opportunity set. Lockett et al. (2011) explain that the increase is especially expected for small and medium enterprises since these firms have limited knowledge and resource bases, for which the acquired knowledge leads to a non-incremental increase of their firm's productive opportunity set. By dividing firms in top and non-top firms in terms of internally created innovations over the last three years, the arbitrary statement that small and medium enterprises have limited resource and/or knowledge bases can be determined more factually by considering the actual number of activities over the last few years, whilst agreeing on the underlying idea.

Following previous literature in terms of firm's internal knowledge capabilities and the arguments for acquiring external knowledge, this thesis hypothesizes that firms that do not belong to top performing firms in terms of internal created green innovations three years prior to the acquisition of a green innovation, face a higher increase in firm performance from acquiring green patents, compared to top performing firms.

Hypothesis 3: Firms that do not belong to top performing firms in terms of internally created green innovation activities, face a higher increase in firm performance because of acquired green innovation activities, compared to top performing firms

Data and methods

Datasets used

To scrutinize the research idea, both financial performance data and green innovation information data are needed at firm-level. For the financial performance data, Bureau van Dijk's Orbis (2022a) database has been used. This dataset consists of financial data of 400 million companies worldwide. The service provides an ID number that identifies each firm. For the firms in the database, financial, accounting, and organizational data for the years 2013 until 2022 is available. Examples of financial information that is provided are data on revenue, profits, share prices, and expenditures are represented in detail at firm-level for every year from 2013 to 2022 of which the data is available. In addition, several interesting financial and non-financial information that may affect a company's decision to invest in green innovations or not can be found.

Despite a lot of information is available, the only innovation measure available in Bureau van Dijk's Orbis (2022a) is R&D expenditure, however, even this figure is not known for most of the firms. Therefore, other databases are considered to gather patent data. Patent data and characteristics of a patent can be found in multiple datasets, of which most are not publicly available for free. Patent offices such as the European Patent Office (2007) (hereafter: EPO) and United States Patent and Trademark Office (2018) (hereafter: USPTO) provide detailed data for European and American patents, respectively. However, these databases often contain detailed information of patents, instead of an overview of the number of patents on a patent owner level, or basic information of patents.

First, Orbis Intellectual Property, an extension of the offering of Bureau van Dijk (2022b), is used to gather the total number of patents filed by a firm for the years 2013 till 2019. The database links global patent data to companies in which the same ID numbers are used to indicate companies as in the financial database. The database includes 146 million patents of 2.4 million companies, of which 113 million patents are live or granted. For every patent, information of the owner(s), applicant(s), inventor(s), the classification level, dates, acquisitions, oppositions, and the profile can be identified. To find certain patents, the database also provides search elements for assigned companies such as the size, geographical information, activities, industry classifications, ownership, or financials. In the database, information of multiple patent offices is combined. For example, major offices such as the EPO, USPTO, and WIPO are in the database, but also smaller offices accounting for a single country are included. The website allows users to extensively search across the database and combine this data in an easy matter with the financial data of Bureau van Dijk's standard Orbis (2022a).

While the number of total patents filed by a company for a certain year provided by the intellectual property extension of Bureau van Dijk (2022b) corresponded with other data sources, the patent data of individual patents providing information of a single patent significantly differed from other data sources[3]. Basic information of individual patents is necessary to distinct green patents from other patents, to designate a time element in the form of the year of invention to patents, and to distinguish patents filed by a firm itself and patents acquired. Since the sum of individual patents did not correspond with other datasets, other sources have been considered.

[3] Please notice that the extension was consulted the month after it went online

For the individual patent data used to generate the number of green patents and the number of citations received on green patents, both for patents filed by a firm itself and acquired, The Lens[4] (n.d.) has been used. The search facility started in 1998 and is a collaboration between Cambia and Queensland University of technology with the aim of providing a more transparent access to patent literature as non-profit organization. The Lens (n.d.) has over 137 million worldwide patent records and more than 370 million patent series and is one of the largest indexes available (Tay, 2018). The data of The Lens (n.d.) is already cleaned, merged, and normalized, and provides both PatSeq Database patents, as well as patents declared by patent offices such as the EPO, USPTO, and World Intellectual Property Organization (hereafter: WIPO). The website allows users to extensively search across the database with several filters, of the most important ones will be discussed.

First, the data range of the published date or filing date can be selected. Second, flags can indicate information that a patent must contain, which is a significant feature since only patents where a company has done the application can be selected. In addition, it is possible to search specifically for a set of patent classifications. Selecting patents based on a classification code makes it possible to focus on a subset of patents, which is crucial for this thesis that focusses on green innovations. Other filters contain the legal status, the document type, and the document family of a patent.

After selecting the search criteria, the website automatically provides information of the patents that meet the requirements. The information of main interest in the export file are the publication date, the application date, owners, citations, and CPC classification. The table dashboard is of particular interest since it is possible to export this format to a CSV file, with a restricted number of documents included in one file of 50,000. For this reason, all green patents filed or transacted between 2013 and 2019 have been extracted in several downloads, in which each file contains individual patent information. The date criteria have been used to extract the data such that the files with the extracted patents are mutually exclusive, whilst capturing all patents such that all downloaded data are exhaustive but do not contain the same patents due to double downloads. The period 2013-2019 has been selected since this corresponds with the availability of financial data in Orbis.

Compilation of the data

This study uses firms that have filed or acquired at least one green patent during the period between 2013 and 2019. Patent document types that have been included are patent applications, granted patents, and design rights. This is the main threshold for a firm to be part of the dataset or not, implying that first the green patent data has been extracted. The extracted files form the basis of a newly created dataset that counts the number of green patents for each company, for every year. One of the key advantages of the raw data is that all current owners, including the date since when they became owner, are provided. In combination with the filing date of the patent, the distinction between patents filed by a firm itself, and patents that have been acquired or transacted can be made. Namely, by comparing the filing date with the date since when an organization is the owner of a patent, the distinction between patents filed by the organization itself, and patents acquired by the organization can be made. Similarly, for citations the distinction between citations on patents

[4] Link to the patent search facility of The Lens: https://www.lens.org/

filed by a firm itself, and citations on patents acquired could be drawn. This way, a dataset in a panel data format has been created containing of the number of patents filed by a firm itself, the number of patents acquired by a firm, the number of citations on patents filed by a firm itself, and the number of citations on patents transacted, for every company for the years 2013 till 2019. Please notice that no distinction can be made in terms of the type of transaction. For example, the transactions can be a result of research partnerships, retrospectively assignment of a collateral, corporate acquisition, or an M&A, but the type of acquisition has not been indicated.

With the newly compiled panel dataset regarding green patents, a list of unique firms with at least one filed or acquired green patent during 2013 and 2019 could be drawn. This list has been used to look for the information of interest on Orbis (2022a). Orbis (2022a) provides the option to search for 500 company names simultaneously. When the website finds a match with a certain match threshold, it automatically selects the corresponding company. However, when the search engine is not sure which company to select, the user needs to select one of the retrieved companies by hand (or not if the user does not find a match). Last, if the search engine cannot find a company name that corresponds with the search term, no results will be provided, this is common if a patent is owned by a person, for which Orbis does not have financial information. After searching for all the firms of interest in Orbis, and extracting the variables of interest, the data has been transformed to a panel dataset layout. Orbis provides company information with the company as unit, in which all other information is presented in separate columns. This implies that the information of a variable for different years is presented by distinctive columns, whereas a panel data layout needs to have multiple observations for different years for every unit.

Similarly, the number of total patents filed in a year is retrieved from Orbis Intellectual Property (2022b). Since companies share the same identifier, information of the extension has been matched with the other information using the identifier.

Since both the patent information dataset and the financial data are in the same and correct panel data format, they can be merged. However, since there exist discrepancies between company names indicated in the datasets of Orbis and The Lens, the names in each dataset need to be matched to the corresponding name in the other dataset. For this, the FuzzyWuzzy package by Mouselimis (2021), using a string-matching loop developed by Inc (2014) has been ran in R (2022) to string match the potential differences in company name style of writing. Since the base company names were the names extracted from The Lens, and Orbis searched for the best match to this name, the Orbis-name that is closest to the name in The Lens has been determined by the FuzzyWuzzy loop. On top, the similarity between the company name of The Lens to the closest Orbis-name has been determined using the Jaro-Winkler similarity method, of which the formula can be found in Appendix B1. For the string match a maximum character distance of 20 characters has been used. To reduce the computational burden, all companies without basic financial information have been removed from the dataset before running the FuzzyWuzzy string matching loop. The output file of the FuzzyWuzzy string matching loop provided the company name as presented by The Lens, the closest company name of Orbis, and a similarity score between both names. If the similarity score was higher than 0.94, the default was that the Orbis company name matched the name of The Lens, whereas a score equal or lower than 0.94 returned no match. Afterwards, all companies with a score between 0.98 and 0.88 have been checked manually whether the names corresponded. In addition, similarities between organization names have been checked, such as “university”, which may lead more often to false matches. Similarly, common words that are used frequently as abbreviations are looked up to find matches that had not been identified, examples of such words with abbreviations are “LTD” instead of limited and “GMBH” instead of “Gesellschaft Mit Beschränkter Haftung”, the full list of the abbreviations that have been checked can be seen in Table A2 in the Appendix. After these manual checks, the Orbis names of the corresponding companies have been added to the Lens data if the match was validated, after which the datasets were merged. It is important to mention that matching the companies has been performed in a conservative way since false positive matches provide wrong financial information and is a major problem. In contrast, false negative matches lead to a lower sample size, but the financial information of the companies in the dataset is correct.

To be considered to exist in the final dataset, firms need to have filed or acquired a green patent during the period 2013-2019. In addition, financial information of the variables in the model of the year in which the patents have been filed or acquired, and two years later should be available. Last, the companies needed to be matched according to the approach described.

Regression models

The models to test the hypothesis are presented below. The models will be followed by an explanation of the variables and econometric approach.

(H1a) $ROEchange = \beta_1 \log(Green\ patents\ overall) + \beta_2 \log(Firm\ leverage) + \beta_3 \log(Company\ age) + \beta_4 \log(Sales) + \beta_5 \log(ROE) + \varepsilon_t$

(H1b) $ROEchange = \beta_1 \log(Green\ patents\ filed) + \beta_2 \log(Firm\ leverage) + \beta_3 \log(Company\ age) + \beta_4 \log(Sales) + \beta_5 \log(ROE) + \varepsilon_t$

(H1c) $ROEchange = \beta_1 \log(Green\ patents\ acquired) + \beta_2 \log(Firm\ leverage) + \beta_3 \log(Company\ age) + \beta_4 \log(Sales) + \beta_5 \log(ROE) + \varepsilon_t$

(H1d) $ROEchange = \beta_1 \log(Green\ patents\ acquired) + \beta_2 \log(Green\ patents\ filed) + \beta_3 \log(Green\ patents\ acquired) * \log(Green\ patents\ filed) + \beta_4 \log(Firm\ leverage) + \beta_5 \log(Company\ age) + \beta_6 \log(Sales) + \beta_7 \log(ROE) + \varepsilon_t$

(H2a) $ROEchange = \beta_1 \log(Green\ patents\ overall) + +\beta_2 \log(Total\ patents\ overall) + \beta_3 \log(Green\ patents\ overall) * \log(Total\ patents\ overall) + \beta_4 \log(Firm\ leverage) + \beta_5 \log(Company\ age) + \beta_6 \log(Sales) + \beta_7 \log(ROE) + \varepsilon_t$

(H2b) $ROEchange = \beta_1 \log(Green\ patents\ filed) + +\beta_2 \log(Total\ patents\ filed) + \beta_3 \log(Green\ patents\ filed) * \log(Total\ patents\ filed) + \beta_4 \log(Firm\ leverage) + \beta_5 \log(Company\ age) + \beta_6 \log(Sales) + \beta_7 \log(ROE) + \varepsilon_t$

(H2c) $ROEchange = \beta_1 \log(Green\ patents\ acquired) + +\beta_2 \log(Total\ patents\ acquired) + \beta_3 \log(Green\ patents\ acquired) * \log(Total\ patents\ acquired) + \beta_4 \log(Firm\ leverage) + \beta_5 \log(Company\ age) + \beta_6 \log(Sales) + \beta_7 \log(ROE) + \varepsilon_t$

($H3$) $ROEchange = \beta_1 \log(Green\ patents\ acquired) * Top\ 30\%\ patents\ filed + \beta_2 \log(Firm\ leverage) + \beta_3 \log(Company\ age) + \beta_4 \log(Sales) + \beta_5 \log(ROE) + \varepsilon_t$

Variables

Dependent variable: ROE Change

As explained, firm performance implies the level and extent to which a company performs. This thesis uses a financial measure for firm performance.

Financial firm performance is often expressed in accounting performance measures. A commonly used accounting measure is return on assets (hereafter: ROA), this measure is calculated by dividing earnings before interest and taxes (hereafter: EBIT) by the total assets (Baer & Frese, 2003; Hull & Rothenberg, 2008). To analyze firm performance changes, Aguilera-Caracuel and Ortiz-de-Mandojana (2013) measure the change in ROA over two years during 2008-2010. ROA represents the ability of a firm to generate profit from its assets (Artz et al., 2010). In addition, return on equity (hereafter: ROE) is also often used as financial accounting measure (Dezsö & Ross, 2012; Ilyukhi, 2015; Richard et al., 2003). In fact, ROE represents not only how profitable a company employs its own assets, but also its financial leverage. Therefore, ROE can be considered as ROA multiplied by leverage, as presented in Appendix B2. Last, some papers use the Profit Margin (hereafter: PM) as financial firm performance measure, which represents EBIT divided by Operating Income (Cefis & Ciccarelli, 2005; Chan et al., 2016).

Santos and Brito (2009) identified financial performance as one of the five dimensions of firm performance. For this dimension, the authors argued that ROA, EBITDA margin, Return on Investment, ROE, Net Income/Revenues, and Economic Value Added are valid indicators of profitability. There are other studies that also emphasize on multiple measures of firm performance, in which there is no single best option to go with. For example, Chan et al. (2016) use ROA, PM, ROE, and profit divided by losses as four measures of firm performance. In the studies mentioned, other firm performance measures were used as robustness checks. Zhang et al. (2019) argue for the use of a firm performance measure that satisfy a measure for profitability and growth. The authors use net profits, which is part of the ROE ratio.

This thesis uses ROE as financial firm performance measure in the main analysis, while PM and ROA are used for robustness checks.

Patents and firm performance – time lag

Because of innovation imitations, innovations protected via patents will rarely lead to a competitive advantage for the complete patent validity period; about 60 percent of patented innovations are imitated within four years (Mansfield et al., 1983). This is supported by more recent studies, for example Cefis and Ciccarelli (2005) explained that the positive effects of innovation on firm performance are often temporally because of mitigations or imitations by other firms. This is in line with Schumpeter (1982) who stated that innovations provide a competitive advantage till the moment competitors imitate or improve the idea. Since patents will not lead to firm performance immediately, and since patent will not provide a competitive advantage permanently, time lags are used between the moment of filing a patent and the firm performance change.

Another explanation for introducing a time lag between the moment of the patent activity and firm performance is that innovation commercialization processes to convert inventions into innovations take time (Ernst, 2001). In fact, the time needed to put an idea into increase firm performance can be compared with the knowledge production function, in which patent activities are the cause that lead to changes within a firm, which effectively lead to performance increases (Pakes & Griliches, 1984). An example of an element that is part of the innovation process in which an invention is converted to an innovation is the diffusion of an innovation (Brockhoff, 1999).

While there has not been extensive research on the time lag between green patents and firm performance, Ernst (2001) argues that for patents overall, without focusing on a certain classification, the increase in firm performance is most likely to happen between 2 to 3 years after the activity. The most frequently used time lag between the moment of patent registration and firm performance is 2 two years. For example, Aguilera-Caracuel and Ortiz-de-Mandojana (2013) used the improvement of financial performance by taking the average improvement during the two following years, while they also performed a model in which they used a 3-year period. In contrast, Belderbos et al. (2010) use Tobin's Q as firm performance measure in their study, with a time lag of one year.

This thesis follows previous literature and selects two years as time lag between the moment a company files a patent, or the moment of acquisition, and the potential firm's performance change. The formula for the dependent variable is as follows. The change in ROE in percentage points equals the difference between the ROE in the year in which a patent is filed or acquired and two years later for firm f. The exact formula for ROE can be observed in Appendix B2.

$$ROE\ change\ 02_f = ROE_{f2} - ROE_{f0}.$$

Please notice that the difference in ROE between two years is calculated by taking the difference of both percentages. This implies that the change in this ratio is in percentage points. The rationale for subtracting both figures is that problems arise when the relative percentage difference is taken. This leads to problems when a company moves from a negative ROE to a positive ROE, or vice versa. In addition, outliers of the variable have been removed, because incorrect information, exceptional events in one of the two years of interest, or usage of the financial situation of a certain firm for accounting purposes, are likely in these cases.

Independent variables

Patents and citations

This thesis uses the CPC scheme which has a classification symbol for patents in the direction of new technological developments (Y), in which a subset (Y02) captures technologies or applications for mitigation or adaptation against climate change (European Patent Office, 2007). Subsequently, these classifications can be subdivided into two more ordered classifications, of which an example can be found in the Appendix in Table A1. The specific classification makes it possible to distinguish between patents that have something to do with eco-innovations and those that are primarily related to another category.

The Y02-classification is a result of a cooperation of the United Nations Environmental Program, the International Center on Trade and Sustainable Development, and the EPO in 2010 (Angelucci et al., 2018). The classification scheme has been used since the classification definition distinguishes patents that have something to do with green innovations better, compared to other commonly used classification schemes such as the International Patent Classification (IPC) or the United States Patent Classification Systems (USPC).

This thesis uses patents that have been filed at the USPTO. The USPTO has the most green patents of which an owner is known during the time period of interest with 419,675 patents, followed by the EPO with 54,188 patents, according to The Lens (n.d.).

To determine the number of patents filed and related citations, a date of a patent needs to be known. However, several dates can be used, such as the publication date, filing date, earliest priority date or granted date. The dates that can be indicated during the patenting process are roughly the same for all patent offices, the most important dates are as follows determined at the USPTO (2018). First, if the application contains all needed documentation, the approval will provide a filing or priority date. During the 12 months following this date, adjustments and deployment to other countries can be performed. After filing and a provided search report, the application will be published 18 months after the filing date, which ensures a prior art against any future patent applications from other inventors for similar inventions. If the patent office decides that the invention and application meet the requirements, the patent can be granted, which is effective from the date of publication.

Griliches et al. (1986) argued that the application year should be preferred over the grant year, since the application year is superior because it represents the actual timing of an innovation. Nevertheless, arguments contrasting this view are that firms cannot immediately diffuse an invention from the application date. This study uses the filing date, which is in line with previous literature. Additionally, this date provides also the most patents in our results whereas other dates are not known for more patents. As mentioned before, it is important to emphasize that an application has only been used if a company applied for a patent itself. In case a company acquired a patent, the transaction date has been used.

When using patents as measure of innovation to investigate whether innovation leads to performance outputs, not only the number of innovations, but also the quality of innovations may be important. Trajtenberg (1990) explained that patent citations indicate technological importance of a patent, which as a result is also informative about the economic value of an innovation. Namely, if a firm has a lot of new ideas that do not really provide a competitive advantage, the beneficial effect of these ideas can be argued. Specially, patents that have been cited a lot imply that a patent has been important for following inventions, in other words the patent is of high quality. This is supported by DeCarolis and Deeds (1999) who also use citations, after arguing that patent counts lack representing knowledge value as its main limitation.

The difference between green patents and citations on green patents is quite significant as the number of patents indicates the number of ideas, while citations include the quality of patents. Zhang et al. (2019) also uses citation counts to present innovation quality, for which the authors argue that using citations is preferred over R&D expenditures or patent counts. This is supported by Albert et al. (1991) who also emphasized on the usage of patent citations to reflect the quality of an innovation since the number of citations found to be correlated with patent value according to experts. Additionally, Harhoff et al. (1999) found that patent citations are associated with patent renewal rates.

An example of a study performing a similar approach is that of Conti (2014), who measures the value of an inventions by looking to the number of citations a patent received. Patents that receive a lot of citations are called “inventive breakthroughs” in his paper. Conti (2014) indicates those patents that are in the top 5 percent of citations within the application year and patent classification as breakthrough inventions. A patent is considered a failure if the patent received no citation.

Moreover, Hall et al. (2005) used patent citations to quantify the importance of patents and investigated the effect on a firm's stock market valuation. Using all three million patents granted in the United States of America during the period 1963 – 1999, and the associated 16 million citations, the authors find a positive and significant effect between citations and stock market valuation with one additional citation per patent boosting market valuation by approximately 3%.

In summary, following the argumentation mentioned above, by using the patent citations, instead of the number of patents, the importance evaluation and quality of an innovation is used on top of the patent count. Therefore, this thesis uses the number of green patents and the corresponding citations to represent green innovation in all hypotheses, the models will be run separately with both measures of innovation.

In the data, the distinction between green patents internally filed and acquired has already been performed. Afterwards, the overall patents have been calculated by adding the green patents filed internally to the green patents acquired in the same year. Similarly, the citations on patents overall have been computed as the sum of citations on green patents acquired and citations on green patents filed internally.

Top performing firms

For H3, dummy variables indicating whether firms belong to the top 30% in terms of internally created green innovations during three years prior to the year of acquiring a green patent have been created. The dummy variable indicates whether a firm belongs to the top 30% in terms of number of green patents filed, or citations on green patents filed, depending on the total number of patents or citations during the three years prior to the year of acquisition.

Control variables

Prior financial performance: ROE

Previous literature analyzing the effect of innovation on firm performance included lagged values of financial performance to control for previous performance (Belderbos et al., 2010). The authors argue that using the prior financial performance accounts for the baseline level of performance of the firm, but also capture potential firm performance effects of previous patent activities, for which a potential reverse causality issue is overturned. In addition, the authors claim that controlling for the baseline variable controls for any unobserved heterogeneity across firms in terms of financial performance. Similarly, Aguilera-Caracuel and Ortiz-de-Mandojana (2013) uses the average of the firm performance, measured with ROA, value for 3 years before the patent activity to control for the financial firm performance at the start of the period from which the change in firm performance is calculated.

The variable ROE_{ft} represents the ROE of firm f in year + t, in which t is relative to the year in which the patents have been filed or acquired for t = -1 or 0.

Firm size

Empirical studies provide evidence that SMEs engage less in patenting activities compared to larger firms (Blind et al., 2006; Kortum & Lerner, 1999). In contrast, Mansfield et al. (1981) finds no evidence that patent protection is considered more likely to be essential for innovations carried out by smaller firms. Despite no aligned and significant findings in previous literature with regards to differences in the willingness to engage in patenting across large firms and SMEs, one may argue that because of differences in resources and capabilities, the two subgroups may face other benefits and costs of patenting. Andries and Faems (2013) found that both large firms and SMEs benefit from patenting in terms of commercialization of product innovations. Also, for both firm groups, increased innovation performance contributes to higher profit margins and patenting should be considered a viable strategy for both groups. These findings are in contrast with earlier suggestions of Blind et al. (2006) and Kortum and Lerner (1999) stating that the benefits of patenting activities in terms of protecting innovations from imitation may be limited for SMEs. A potential key part of the contrary results is that patenting cost implications are too small to influence the profitability gains of innovations for firms significantly, implying that a firm's size does not make a big difference in undertaking patenting activities and its effect on firm performance (Andries & Faems, 2013; Encaoua et al., 2006; Teece, 1996).

A widely recognized economic theory is the advantage of economies of scale, referring to larger firms having advantages in terms of production efficiency because of the ability to produce larger quantities, and therefore perform more efficient (Chen et al., 2018). Additionally, Schumpeter (1982) argued that large firms are most accountable for innovation because of their dominant role in markets and their more efficient ways of operating compared to smaller firms. This is supported by larger firms to have more resources allowing them to hire employees or consultants that can implement beneficial governance ideas (Azeez, 2015). Moreover, Penrose (1959) proposed that larger firms have more potential for firm expansion because of increased productivity due to the wide diversity of resources they compromise. In fact, not only for generating and commercializing ideas firms benefit of a larger size, also maintaining patents and dealing with the administrative part firms benefit (Chen et al., 2018).

In contrast to the advantages of economies of scales large firms benefit from, for innovation specifically large firms also must deal with disadvantages. Schumpeter (1982) first argued that small firms are most accountable for development of the economy through innovations. These firms can innovate in a more radical way, use spillovers of larger firms, and often have more time available. In addition, larger firms may face organizational discrepancies and inefficiencies that affect small firms less (Klapper & Love, 2004).

Studies that investigated the effect of green innovations productivity often used the number of employees as firm size measure, a non-financial measure (Arora et al., 2008; Chen et al., 2006). However, other studies that look to firm performance often use a financial measure of firm performance. Specifically, some studies used revenue as measure of firm size (Aguilera-Caracuel & Ortiz-de-Mandojana, 2013; Aragón-Correa & Sharma, 2003). Another measure of firm size that is commonly used is total assets (DeCarolis & Deeds, 1999). Finally, often the total or net sales of a firm are used to represent their size (Arora et al., 2008; Ehie & Olibe, 2010; Huang & Hou, 2019; Mansfield, 1986).

Because of the importance to control for firm size, the use of sales in previous literature, no vigorous argumentation for the preference to use a specific measure for firm size, and the availability[5] of the variable sales in Orbis, this thesis will control for firm size using sales data. Because of the requirements to exist in the final dataset used by in thesis, in which the financial information is part of the restrictions, firms are more likely to be large firms than SMEs because of the higher likelihood of strictly reporting financial information.

The variable used in this thesis is $Sales_{ft}$, representing the sales of firm f in year + t, in which t is relative to the year in which the patents have been filed or acquired.

Firm leverage

The third control variable used in the model is firm leverage. There has been widespread research to firm leverage and its impact on firm performance, with ambiguous results. Some studies argue that a negative relationship exists between firm leverage and firm performance (Chen, 2004; Zeitun & Tian, 2007). Jensen (1986) argued that increased debt affects firm performance due to reduced free cashflow. In addition, firms with a high leverage are also more firmly controlled by debt providers, who may enforce sanctions to improve firm governance (Broberg et al., 2010). These findings are in line with the pecking order theory, considered one of the most important theories of corporate firm leverage, stating that firm leverage and firm performance are negatively related. Myers (1984) argues that firms prefer internal over external finance due to adverse selection, but when external funds are needed, debt is preferred over equity since the information costs for debt are lower. Therefore, the pecking order theory considers internal funds to be preferred over debt, for which firm leverage is a subordinate alternative for financing.

On the other hand, previous literature also found no significant, or even a positive relationship (Azeez, 2015; Brick & Ravid, 1985). Margaritis and Psillaki (2010) argued that higher leverage is positively associated with firm performance due to lower agency costs and increased efficiency. In addition, Campello (2006) finds that modest debt is positively related with sales of a firm, compared to its competitors while for the product market it leads to underperformance. A positive association is supported by the signaling theory (Connelly et al., 2011). Namely, in the presence of asymmetric information, debt is a positive indicator for investors on the prospects of future firm performance (Ross, 1977; Harris and Raviv, 1991).

A higher firm leverage is of relevance for innovation factors since a higher debt to equity ratio increases the risk for investors for which innovation decisions are affected (Nemlioglu & Mallick, 2021). Therefore, firm leverage is included as control variable. The variable is conducted by dividing the long-term debt over the total assets, which is the most common explanation of firm leverage (Azeez, 2015; Campello, 2006; Chen, 2004; Ehie & Olibe, 2010; Margaritis and Psillaki, 2010; Nemliogly & Mallick, 2021; Zeitun & Tian, 2007).

The formula below indicates the computation of a firm f's firm leverage in year t, in which t is relative to the year in which the patent(s) have been filed or acquired.

[5] The variable revenue has also been considered to include to control for firm size. However, the variable sales led to less missing values while the correlation between sales and revenue is 0.996.

$$\text{Firm leverage}_{ft} = \frac{Long\ term\ debt_{ft}}{Total\ assets_{ft}} * 100.$$

Company age

Age is a commonly used control variable when investigating effects on firm performance. In studies where companies used are publicly traded, age represents the number of years since the firm's stock can be traded publicly (Azeez, 2015; Mashayekhi & Bazaz, 2008). However, in most studies age is calculated as the number of years since the firm has been established (Coad et al., 2016).

The effect of firm age with respect to firm performance is inconclusive. On the one hand, older firms on average have more experience and gained cumulative experience-based learnings, for which a better absorption capacity in terms of operational approaches benefits a firm's performance (Huang & Hou, 2019). In addition, older firms are better in converting sales growth into productivity and profit growth (Coad et al., 2013). On the other hand, older firms are less capable of gaining expected growth rates of productivity, profits, and sales, and are also less efficient in translating employment growth into productivity, profit, and sales growth (Coad et al., 2013).

Without elaborating too deeply on differences in innovation practices for different company age, it is important to mention that the type of innovations that companies carry out are also different for younger and older firms. In fact, Coad et al. (2016) found that younger firms perform riskier innovation activities that come with higher upward benefits if successful, but also larger losses if unsuccessful compared to older firms. Older firms tend to pursue incremental innovations whereas younger firms pursue radical innovations, for which the riskier innovation approach of younger firms can be explained. In addition, older firms have more experience and a more diversified portfolio of R&D activities, for which the risk is also smaller for more mature firms.

Because of the importance of firm age with regards to firm performance, this thesis will adopt firm age as control variable. The company age of firm f in a certain year has been computed as the difference between the patent year and the year of incorporation, in which p is the year in which patent(s) have been filed or acquired, for p = 2013, 2014, 2015, 2016, 2017, 2018, 2019.

$$\text{Company age}_{pt} = \text{Patent year}_{p} - \text{year of incorporation}_{f}$$

Data cleaning and transformations

For all variables used in this thesis, an investigation has been performed to test whether the variables are skewed or not. In case a variable faced skewness, a log transformation has been performed on the original values. To account for the transformation of a log on observations with value 0 as original value, one has been added to the value. In addition, all variables have been checked for outliers, in which the outliers for the variable change in ROE is the most important one. For the change in ROE over two years, outliers were detected if the base value of ROE for period 0 or 2 was suspicious compared to other firms, but also to the firm itself. Namely, if a firm significantly under- or overperforms other firms in terms of ROE, the firm may just be an under- or overperformer, as a result the change in ROE over two periods will not be significantly different to other firms and periods. However, if a firm has exceptional high or low ROE figures for a certain year, while in other years the values are more towards the confidence interval of normal figures, the values of the exceptional year heavily influence the ROE change value. Reasons for such exceptional differences in the value for ROE change may be incorrectly reported figures by the firm, incorrectly stored or calculated data by the data provider, but another reason may be that a company does not aim to create value but simply serves as an outcome for a parent company to distribute or circumvent financial obligations. However, the proportion of all cases where exceptional outliers in terms of ROE change are valid is small, with innovative startups with rapid growth being a valid group that is not included. Because of these reasons, and outlier checks, observations with a ROE change that is lower than -150% and those greater than 150% are excluded.

Earlier in this thesis the inclusion of the total number of patents overall as control variables for the effect of green patents in previous literature has been discussed. While some papers include it as control variable, including these control variables to control for the level of innovation of a firm is not a unanimous design. The results may be biased since the overall number of green patents (overall/filed/acquired) are included in the number of patents (overall/filed/acquired), leading to biased results. In addition, the models without the total number of patents resulted in a better fit. Therefore, the variable total number of patents has not been included in the models.

Econometric approach

The dataset consists of individual unit dimensions in the form of companies, and a time dimension of years. The dataset is an unbalanced panel dataset, implying that not all individual unit dimensions are observed in every year. In a panel dataset, the overall variation in a variable can be divided into within variation, referring to the variation that exists within an individual unit over time, and between variation, referring to the variation between the mean of individual units. The distinction in the type of variation because of the addition of the time dimension to the unit dimension, is also reflected in the possibility to decompose the error term. Namely, we can now distinguish the error term, u, into unit heterogeneity, α_i, referring to the time-invariant error that is the same for all observations of an individual unit, and idiosyncratic error, ε_{it}, referring to the time-variant error that is unique for every time observation for a unit.

A pooled OLS model is the starting point in terms of model selection since this method exploits between and within variation and is the best linear unbiased estimator if the zero conditional mean assumption, and the no serial correlation assumption hold. However, the estimates of the approach are often biased since it is not likely that the zero conditional mean assumption hold in observational studies. In addition, the serial correlation assumption is also unlikely in some panel data settings. Within effects estimators such as Fixed Effects, Least Squared Dummy Variables, and First Differences can cope with violation of the zero conditional mean assumption by eliminating the between variation, and therefore focusing on within variation. In contrast, between variation estimators such as Random Effects and Correlated Random Effects can cope with violation of the serial correlation assumption by accounting for it. These models use both between and within variation.

Along with the theoretical information provided above, the best econometric model has been determined with the help of several tests that have been performed on the final dataset in Stata, which is the analysis tool that has been used for the analysis from the merged dataset onwards (StataCorp, 2021). First, an F-test that all u_i are equal to 0 has been performed to determine whether (time) fixed effects are preferred over pooled OLS. The result of the test indicates Prob > F = 0.000, implying that the null hypothesis that states that all years are jointly equal to zero is rejected at the 1% significance level. Therefore, the fixed effects approach is preferred over pooled OLS. Similarly, the Breusch-Pagan Langrangian multiplier test for random effects indicates a statistically significant Prob > $\chi 2$, indicating that the random effects model is preferred over the pooled OLS method. To choose between Fixed Effects and Random Effects, a Hausman test is performed. The null hypothesis of this test states that the difference between the coefficients of both econometric approaches is not systematic, implying that the fixed effects is not necessary and that random effects is more efficient. However, the Prob > $\chi 2$ value is 0.000. Therefore, we reject the null hypothesis at the 1% significance level, this implies that the Fixed Effects model is preferred over the Random Effects model.

In addition, other tests have been performed. First, a modified Wald test has been performed to test for groupwise heteroskedasticity. The obtained p-value of this test is smaller than 0.05, implying that the model faces heteroskedasticity. To account for this, robust standard errors have been performed in all models. Furthermore, since the dataset that is used in this thesis is unbalanced, an attrition test has been performed to see whether the missing observations are at random, or whether there is a selected sample. Certain attrition often happens when panel data is gained via surveys, in which subgroups may drop out for a reason. Although this thesis works with patent and financial data that is available on online sources, firms cannot choose whether they participate in the study or not, and whether to quit at a certain point in time. However, it is still relevant to test attrition because the availability of data from one to another year may be because of a reason. A common method to test for attrition in a fixed effects model is to create a binary variable that indicates whether the unit is present in the next period. Afterwards the binary variable is included as covariate. If the variable is statistically significant, it implies that the missing observations are not at random. In the dataset of interest, the coefficient of the binary variable is 0.534 with a p-value of 0.547, implying that we do not reject the null hypothesis stating that the missing observations are at random. Despite the insignificant p-value, it is important to take the high coefficient into account since it would imply that firms for which there is data available in the next wave, a higher change in ROE is expected. This would mean that firms that have better firm performance increases, are more likely to remain in the dataset, which would lead to bias. However, since the p-value is insignificant, and we are dealing with financial company data in which firms do not have a choice of sharing the data or not, in contrast to survey data, the current situation is not urgent per se.

For Hypothesis 1 and 2 using Fixed Effects does not bring any limitations. However, for Hypothesis 3 a constraint is introduced because of the within variation approach. Please remind that Hypothesis 3 states that firms that do not belong to top performing firms in terms of the number of green patents filed face a higher increase in firm performance, compared to top performing firms. Therefore, a dummy variable that indicates whether a firm belongs to top performing firms or not needs to be introduced. The patent filing performance is based on the firm's activities during the three years before. As a result, firms that belong to the top 30% firms in terms of filed patents (or citations) in a certain year, are also more likely to belong to the top 30% for the previous and/or next year as the variable is conducted as the sum of patents or citations for the last three years. Subsequently, the within variation that Fixed Effects aims to address is reduced drastically. Therefore, for H3 a fixed effects model has been ran for both subsamples separately, since the within variation is too small and multicollinearity is an issue if it is included as dummy variable. Afterwards, the coefficients of interest can be compared with each other.

As explained, performing an OLS regression with the dataset used for this thesis would not be the best choice considering the assumptions that need to hold. This is in line with the approach of Ilyukhin (2015) who also performed fixed effects because of the unbalanced panel dataset used.

Similarly, Huang and Hou (2019) argued for the use of fixed or random effects for unbalanced panel datasets that study the potential causal relation between innovation activities and firm performance. Specifically, the authors argue that fixed effects is preferred unless one can measure all time-invariant factors correlated with other regressions with certainty. Since the authors obtain a large N value and a small T value, they performed additional models using the system generalized method of moments (SGMM) dynamic panel (Blundell & Bond, 1998). They provide strong evidence that the causal direction from innovation activities to firm performance exists, while R&D expenditure are not significantly Granger-caused by firm performance and weak evidence exists for the causal direction of firm performance to innovation activities.

Despite not many studies performing the fixed effects approach in studies investigating green innovation effects on firm performance, the econometric assumptions are most valid for this approach. Since the classification for green innovations following the CPC approach has only been in place since 2010, longitudinal green patent data has only been available since a few years. In addition, previous literature arguing the use of fixed or random effects support the reasoning presented in this thesis. Last, the use of fixed effects is in line with statistical tests.

Empirical Results

Descriptive statistics

Table 1 provides the overview of the descriptive statistics of the main variables. The main variables in Table 1 are presented in the form how they are used in the models, while Table A3 in the Appendix provides the descriptive statistics for all variables in the basic form. The descriptive statistics include the number of observations, mean, standard deviation, minimum value, and maximum value. Furthermore, both tables reveal that the variables Top 30 filed patents and Top 30 filed citations are the only dummy variables in the dataset.

Overall, the dataset consists of 2,567 observations of 600 unique companies. The average company age in the dataset is approximately 50 years, however, this variable is right skewed with a median value of 36. The oldest company exists for 176 years, and the minimum age of a company is 0 years. On average, firm leverage equals 15.38%, the ROE is 18.86%, and the change in ROE is -0.537%. The average sales are approximately \$7.7 billion, while the minimum sales equals \$17 million, and the maximum sales equal to \$373.1 billion dollars. Again, the sales variable is right skewed with a median value of \$1.46 billion.

Table 1. Variable descriptive statistics including the number of observations, mean, standard deviation, minimum value, and maximum value

Variable	N	Mean	Std. Dev.	Min	Max
ROE change	2,567	-0.537	16.061	-138.431	142.679
ln (Green patents overall)	2,567	0.738	1.019	0	5.649
ln (Green patents filed)	2,567	0.397	0.809	0	5.613
ln (Green patents acquired)	2,567	0.486	0.838	0	5.298
ln (Green citations overall)	2,567	1.822	2.184	0	8.909
ln (Green citations filed)	2,567	1.026	1.850	0	8.889
ln (Green citations acquired)	2,567	1.217	1.906	0	8.443
ln (Patents overall)	2,567	4.720	2.091	0	10.299
ln (Patents filed)	2,567	4.78	1.925	0	10.136
ln (Patents acquired)	2,567	2.789	1.873	0	9.694
ln (Firm leverage)	2,567	1.932	2.057	-21.021	4.431
ln (Company age)	2,567	3.659	0.817	0	5.176
ln (Sales)	2,567	14.068	2.107	2.858	19.737
ln (ROE)	2,567	2.600	0.887	-3.963	5.771
Top 30 filed patents	2,567	0.094	0.292	0	1
Top 30 filed citations	2,567	0.093	0.290	0	1

While the figures indicate that a broad range of different companies in terms of age, firm leverage, and ROE are in the dataset, for sales the range is as well broad given the high standard deviation, but also tends to be surrounded across larger firms. Table 2 represents the division of firm size according to the total assets and operating revenue, two measures also used by Bureau van Dijk (2022a). One can observe that most firms in the dataset are classified as “Very Large” following the classification. For the assessment of the firm size classifications, the same classification as suggested by Bureau van Dijk 2022a) has been used, which is represented in the Appendix in Table A4. The high percentage of very large firms in the dataset implies an overrepresentation of larger firms relative to smaller firms in the sample, compared to the population.

One potential reason for the high appearance of very large companies is that this thesis only considers those companies for which the necessary financial information is known. Since larger firms are more likely to have external investors, and even may be listed, it is more likely that the necessary information is known for these companies. Another potential reason may be that larger firms are more engaged in green innovation activities or are more likely to file green innovation activity ideas. As explained in the Data and Method section, there are no aligned and significant findings in previous literature with regards to differences in the willingness to engage in patenting across large firms and SMEs. If it is true that larger firms are more engaged in green innovation activities or are more likely to file green innovations, the results of this thesis should be interpreted with caution.

Table 2. Dataset firm size distribution according to the firm size classification of Bureau van Dijk. (2022a)

Firm size classification	Total assets		Operating Revenue	
	N	Percentage	N	Percentage
Very Large	2,117	82.44%	2,289	89.14%
Large	371	14.45%	218	8.49%
Medium	75	2.92%	49	1.91%
Small	5	0.19%	12	0.47%
Total	2,568	100.00%	2,568	100.00%

Previous literature already investigated overrepresentation of older firms in datasets. Often very young firms are under-represented in firm-level databases, with slightly older firms being the most numerous in a dataset, from which on the number of firms decreases as age increases (Coad et al., 2013). In fact, for firm-level innovation databases the issue may be severe since firm disappearance of the sample due to attrition or death is likely to be correlated with low productivity growth (Huergo & Jaumandreu, 2004). The authors explain that this implies that older firms that are left in the dataset have survived previous years and are likely to be overperformers in terms of productivity growth.

Figure A1 in the Appendix indicates that in the dataset used a similar trend as Coad et al. (2013) described can be observed. While the performed test for attrition did not indicate attrition in the dataset, the underrepresentation of very young firms and right skewed distribution of company ages should be noticed. A particular reason for the composition of the dataset may lead to bias, for which the results should be interpreted with caution.

In addition to the variable descriptive statistics, Table 3 indicates how often a firm appears in the dataset. We can observe that for only 17.17% of the companies, information for all the years is available. This confirms that the dataset used is (highly) unbalanced. In addition, Table 4 provides the number of companies, the total number of green patents filed, the total number of green patents acquired, the total number of citations for green patents filed, and the total number of citations for green patents acquired for every year. On top of the absolute numbers, the percentage as part of the total number is also provided. We can observe that especially for 2019 and to a less extent 2018 the numbers are lower. Last, Table 5 provides the number of firms by country of origin and the number of green patents filed, green patents acquired, green citations on patents filed, and green citations on patents acquired by country. The most noteworthy information provided by Table 5 is the relatively high number of average green patents filed by American firms, and relatively high number of average citations per patent and per company for Korea, Taiwan, and Switzerland. The high number of patents by firms from the United States of America may be caused since the USPTO is used. A potential reason for the high average number of citations by Korea, Taiwan, and Switzerland may be the explicit presence of technology firms in the Asian countries, and chemicals, drugs, and medicine industries in Switzerland as these industries are known to be research-intensive industries (Arora et al., 2008). Table A5 in the Appendix indicates the same information as Table 5; however, the information is aggregated by sector instead of countries. Table A5 indicates that especially the Industrial, Electric & Electronic Machinery and Transport Manufacturing industries had significantly more green patenting activities compared to other industries.

Table 3. Allocation of firm appearances

Appearance	N	Percent	Cum.
1	77	12.83%	12.83%
2	74	12.33%	25.17%
3	75	12.50%	37.67%
4	82	13.67%	51.33%
5	66	11.00%	62.33%
6	123	20.50%	82.83%
7	103	17.17%	100.00%
Total	2567	100.00%	

Table 4. The number of companies, green patents filed, green patents acquired, and citations on these patents per year, both absolute and relative to the whole dataset.

Patent year	Companies		Green patents filed		Green patents acquired		Green citations filed		Green citations acquired	
	Freq.	Percent	Freq.	Percent	Freq.	Percent	Freq.	Percent	Freq.	Percent
2013	386	15.04%	994	18.73%	784	14.76%	22,035	18.34%	10,760	10.88%
2014	396	15.43%	779	14.68%	852	16.04%	18,293	15.23%	15,629	15.80%
2015	402	15.66%	802	15.11%	599	11.28%	18,880	15.72%	9,740	9.85%
2016	422	16.44%	913	17.21%	921	17.34%	20,178	16.80%	18,287	18.49%
2017	388	15.11%	1,097	20.67%	974	18.34%	30,989	25.80%	23,099	23.35%
2018	344	13.40%	444	8.37%	551	10.37%	6,758	5.63%	11,688	11.81%
2019	229	8.92%	277	5.22%	630	11.86%	2,997	2.49%	9,725	9.83%
Total	2,567	100%	5,306	100%	5,311	100%	120,130	100%	98,928	100%

Table 5. Firm occurrence and detailed descriptive statistics by country, including green patents filed, green patents acquired, green citations filed, and green citations acquired

Country	Frequency		Green patents filed		Green patents acquired		Green citations filed		Green citations acquired	
	Abs.	Rel. (%)	Abs.	Rel. (%)	Abs.	Rel. (%)	Abs.	Rel. (%)	Abs.	Rel. (%)
Australia	1	0.17	0	0.00	1	0.02	0	0.00	20	0.02
Austria	28	4.67	64	1.21	250	4.71	1,219	1.01	4,736	4.79
Belgium	5	0.83	29	0.55	149	2.81	1,210	1.01	6,648	6.72
Bermuda	1	0.17	0	0.00	2	0.04	0	0.00	30	0.03
Canada	4	0.67	5	0.09	3	0.06	55	0.05	38	0.04
China	17	2.83	40	0.75	180	3.39	1,457	1.21	2,743	2.77
Denmark	8	1.33	15	0.28	98	1.85	204	0.17	1,609	1.63
Finland	15	2.50	35	0.66	82	1.54	975	0.81	2,001	2.02
France	60	10.00	426	8.03	532	10.02	8,278	6.89	6,840	6.91
Germany	89	14.83	455	8.58	679	12.78	8,066	6.71	14,569	14.73
Hong Kong	3	0.50	11	0.21	5	0.09	30	0.02	16	0.02
India	21	3.50	19	0.36	70	1.32	330	0.27	648	0.66
Italy	2	0.33	4	0.08	4	0.08	36	0.03	27	0.03
Japan	148	24.67	1,391	26.22	2,114	39.80	21,675	18.04	34,147	34.52
Korea	27	4.50	162	3.05	157	2.96	2,293	1.91	2,919	2.95
Kyrgyzstan	1	0.17	16	0.30	14	0.26	483	0.40	350	0.35
Malaysia	2	0.33	0	0.00	4	0.08	0	0.00	44	0.04
Norway	8	1.33	3	0.06	22	0.41	37	0.03	370	0.37

Poland	2	0.33	3	0.06	3	0.06	6	0.00	29	0.03
Singapore	3	0.50	4	0.08	2	0.04	40	0.03	47	0.05
Sweden	13	2.17	37	0.70	82	1.54	801	0.67	1,398	1.41
Switzerland	5	0.83	19	0.36	19	0.36	1,798	1.50	1,209	1.22
Taiwan	41	6.83	284	5.35	109	2.05	3,108	2.59	777	0.79
United Kingdom	4	0.67	42	0.79	92	1.73	1,292	1.08	1,903	1.92
United States of America	92	15.33	2,242	42.25	638	12.01	66,737	55.55	15,810	15.98
Total	600	100.00	5,306	100.00	5,311	100.00	120,130	100.00	98,928	100.00

Furthermore, Table 6 presents the correlations matrix in which no alarming correlations can be observed. The variables with high correlations (> 0.70) are such that one of the two variables is conducted with the help of the other variable. For example, green patents overall is the sum of green patents filed and green patents acquired. In addition, these variables will not be present in the same regression, for which the high correlation between these variables is not worrying. Last, Table A6 in the Appendix is the output of an additional test for multicollinearity for the models used for H1[6]. In addition to the correlation matrix which did not indicate potential issues, and the robust standard errors that were used in the regressions, the Variation Inflation Factors are all lower than 1.25, implying there is no multicollinearity problem (Hair, 1995).

Table 6. Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) ROE change	1.000													
(2) ln (Green patents overall)	0.072	1.000												
(3) ln (Green patents filed)	0.064	0.804	1.000											
(4) ln (Green patents acquired)	0.061	0.849	0.441	1.000										
(5) ln (Green citations overall)	0.055	0.918	0.702	0.756	1.000									
(6) ln (Green citations filed)	0.051	0.743	0.919	0.378	0.753	1.000								
(7) ln (Green citations acquired)	0.043	0.779	0.361	0.928	0.799	0.330	1.000							
(8) ln (Total patents overall)	0.046	0.450	0.381	0.361	0.422	0.373	0.330	1.000						
(9) ln (Total patents filed)	0.046	0.443	0.383	0.350	0.412	0.373	0.317	0.990	1.000					
(10) ln (Total patents acquired)	0.066	0.386	0.296	0.343	0.361	0.294	0.315	0.701	0.635	1.000				
(11) ln (Firm leverage)	0.019	0.009	0.004	0.018	0.005	0.001	0.022	0.045	0.043	0.113	1.000			
(12) ln (Company age)	0.023	0.044	0.020	0.064	0.033	0.014	0.057	0.142	0.158	0.034	-0.063	1.000		
(13) ln (Sales)	0.072	0.303	0.267	0.249	0.270	0.260	0.216	0.661	0.658	0.493	0.140	0.216	1.000	
(14) ln (ROE)	-0.360	0.023	0.039	0.012	0.036	0.053	0.025	0.048	0.044	0.081	-0.018	-0.035	0.072	1.000

Regression results

Table 7 presents the regression results for the models to test Hypothesis 1 and 2 when the number of patents is used to represent green innovation activities. The results when citations on green patents is used as dependent variable, are displayed in Table 8. Furthermore, Table 9 provides the regression results for Hypothesis 3, for both scenarios in which patents are used, as well as the usage of citations.

Since all explanatory variables are log transformed, while the dependent variable is in levels, to get an interpretable number in terms of change in the explanatory variable, we need to convert the coefficient. Namely, the coefficient of the log transformed variable needs to be multiplied by ln (1.01) to get the change in ROE in units for a 1% change in the explanatory variable.

[6] Please notice that VIF is of best application in OLS regressions, and factor variables are not allowed. Therefore, only for the models used in H1 the VIF values have been computed

Columns 1, 2 and 3 of Table 7 and Table 8 refer to Hypothesis 1a, H1b and H1c, respectively. Column 1 of Table 7 shows a significant and positive effect with a coefficient of 1.347 for green patent activity (filing and acquiring) that is statistically significant at the 5% significance level. So, on average, controlling for firm characteristics and yearly fixed effects, filing one percent more patents increases the ROE of a firm by 0.013 percentage points, ceteris paribus. Similarly, Table 8 indicates a positive sign with a coefficient of 0.278 for the log transformation of citations on green patents overall (i.e., filed and acquired). However, the coefficient is not significant at the 10% significance level.

Next, we can observe a positive sign for H1b in Table 7 with coefficient 0.193, however, this coefficient is not statistically significant at the 10% level. Similarly, the coefficient for H1b is insignificant when citations are used, which can be observed in Table 8. Therefore, Hypothesis 1b needs to be rejected.

Furthermore, for green patents acquired a positive coefficient of 2.165 for the log transformation of green patents acquired that is statistically significant at the 1% significance level can be observed in Table 7. Similarly, the coefficient for H1c in Table 8 is 0.565 which is also statistically significant at the 1% significance level. This implies that on average, controlling for firm characteristics and yearly fixed effects, acquiring one percent more green patents increases ROE of a firm by 0.022 percentage points, ceteris paribus. Furthermore, we can conclude that on average, controlling for firm characteristics and yearly fixed effects, one percent more citations on green patent acquired increases ROE by 0.006 percentage points, ceteris paribus. Therefore, the results support H1a and H1c, while H1b is rejected.

In addition, the interaction term investigating the potential moderation effect of green patents filed is not statistically significant at the 10% level in Table 7 and Table 8. Therefore, H1d needs to be rejected.

Next, both in Table 7 and 8 the coefficients for the moderation effect of total patents on green patents are not statistically significant at the 10% level. Therefore, we fail to reject the null hypothesis for H2a, H2b and H2c, for which we need to reject the hypotheses.

Please notice that for the results of H1d and H2, the coefficients of ln (Green patents overall), ln (Green patents filed), and ln (Green patents acquired) cannot be interpreted in the same way as in Hypothesis 1a, H1b and H1c. Because of the introduction of a product term, the interpretation of the effect of the variables changes from unconditional effects to conditional effects. Therefore, one should perform additional analysis to investigate the conditional effect of these variables for certain circumstances. For example, average marginal effects or conditional marginal effects can be performed. The average marginal effects of the variables included in the product term, without the control variables, of all models are provided in Table A7 in the Appendix.

Table 7. Regression results for H1 and H2 when green patents are used to represent green innovations. Estimated coefficients and standard errors are provided.

	(H1a)	(H1b)	(H1c)	(H1d)	(H2a)	(H2b)	(H2c)
ln (Green patents overall)	1.347**				0.886		
	(0.548)				(1.598)		
ln (Green patents filed)		0.193		-0.557		0.433	
		(0.522)		(0.380)		(2.048)	
ln (Green patents acquired)			2.165***	1.889**			2.099
			(0.705)	(0.896)			(1.510)
ln (Green patents acquired) *				0.474			
ln (Green patents filed)				(0.896)			
ln (Total patents overall)					-0.808		
					(0.501)		
ln (Total patents filed)						-0.811	
						(0.586)	
ln (Total patents acquired)							0.450
							(0.531)
ln (Green patents overall) *					0.107		
ln(Total patents overall)					(0.267)		
ln (Green patents filed) *						-0.016	
ln(Total patents filed)						(0.371)	
ln (Green patents acquired) *							0.001
ln(Total patents acquired)							(0.308)
ln (Firm leverage)	0.090	0.108	0.075	0.070	0.079	0.019	0.325
	(0.348)	(0.345)	(0.344)	(0.343)	(0.346)	(0.355)	(0.737)
ln (Company age)	-9.398**	-9.466**	-9.815**	-10.011**	-9.703**	-10.288**	-12.502**
	(4.439)	(4.370)	(4.494)	-4.475	-4.437	-4.571	-5.671
ln (Sales)	-0.646	-0.503	-0.691	-0.660	-0.426	-0.009	0.652
	(2.399)	(2.404)	(2.393)	-2.391	-2.388	-2.527	-2.824
ln (ROE)	-14.181***	-14.237***	-14.189***	-14.202***	-14.210***	-14.300***	-15.589***
	(1.294)	(1.307)	(1.294)	-1.295	-1.285	-1.368	-1.837
Constant	78.639***	77.902**	80.789***	81.242***	80.442***	78.275**	74.447**
	(30.262)	(30.153)	(30.277)	-30.249	-30.440	-32.589	-36.242
R-squared within	0.274	0.272	0.277	0.278	0.275	0.267	0.265
R-squared between	0.028	0.027	0.024	0.025	0.025	0.023	0.046
R-squared overall	0.087	0.085	0.084	0.084	0.083	0.079	0.082
Observations	2,567	2,567	2,567	2,567	2,567	2,445	1,639

The estimated coefficients are shown together with the standard errors (SE) in parentheses. Estimated thresholds are not shown.
In all models fixed effects with companies representing the entities or panels, and years representing the time entity have been performed.
*** p value ≤ 0.01; ** p value ≤ 0.05; * p value ≤ 0.10

Table 8. Regression results for H1 and H2 when citations on green patents are used to represent green innovations. Estimated coefficients and standard errors are provided.

	(H1a)	(H1b)	(H1c)	(H1d)	(H2a)	(H2b)	(H2c)
ln (Green citations overall)	0.278				-0.078		
	(0.201)				(0.573)		
ln (Green citations filed)		-0.007		-0.199		-0.278	
		(0.198)		(0.218)		(0.678)	
ln (Green citations acquired)			0.565***	0.486			0.470
			(0.256)	(0.303)			(0.566)
ln (Green citations acquired) * ln (Green citations filed)				0.068			
				(0.088)			
ln (Total patents overall)					-0.726		
					(0.497)		
ln (Total patents filed)						-0.796	
						(0.585)	
ln (Total patents acquired)							0.417
							(0.523)
ln (Green citations overall) * ln(Total patents overall)					0.078		
					(0.100)		
ln (Green citations filed) * ln(Total patents filed)						0.059	
						(0.123)	
ln (Green citations acquired) * ln(Total patents acquired)							0.055
							(0.117)
ln (Firm leverage)	0.106	0.109	0.090	0.086	0.094	0.015	0.350
	(0.347)	(0.345)	(0.344)	(0.343)	(0.346)	(0.356)	(0.740)
ln (Company age)	-9.428**	-9.477**	-9.715**	-9.849**	-9.606**	-10.190**	-12.361**
	(4.406)	(4.368)	(4.463)	(4.452)	-4.402	-4.577	-5.633
ln (Sales)	-0.562	-0.497	-0.627	-0.615	-0.387	-0.029	0.561
	(2.403)	(2.404)	(2.396)	(2.396)	-2.388	-2.521	-2.815
ln (ROE)	-14.214***	-14.241***	-14.218***	-14.240***	-14.252***	-14.310***	-15.623***
	(1.298)	(1.307)	(1.298)	(1.296)	-1.289	-1.366	-1.841
Constant	78.104**	77.949***	79.943***	80.465***	79.680***	78.212**	75.728**
	(30.231)	(30.141)	(30.241)	(30.180)	-30.385	-32.470	-36.188
R-squared within	0.272	0.272	0.274	0.275	0.273	0.267	0.263
R-squared between	0.027	0.027	0.024	0.024	0.025	0.024	0.046
R-squared overall	0.085	0.084	0.083	0.083	0.083	0.079	0.082
Observations	2567	2567	2567	2,567	2,567	2,567	2,567

The estimated coefficients are shown together with the standard errors (SE) in parentheses. Estimated thresholds are not shown.
In all models fixed effects with companies representing the entities or panels, and years representing the time entity have been performed.
*** *p* value ≤ 0.01; ** *p* value ≤ 0.05; * *p* value ≤ 0.10

The regression results for H3 using patents are provided in Table 9. Remember that H3 stated that firms that do not belong to top performing firms in terms of internally created green innovation activities, face a higher increase in firm performance because of acquired green innovation activities, compared to top performing firms. As explained, for H3, two separate fixed effects regressions have been run since within variation is too much reduced to perform one model with Fixed Effects in which the top 30% is introduced as dummy variable. Therefore, two subgroups are created that can be observed for the scenario in which patents are used, and the case in which citations on green patents are used to reflect green innovation activities.

Table 9 reveals that the log transformed variable of green patents acquired has a positive sign that is statistically significant at the 5% significance level for both datasets consisting of top performing firms and non-top performing firms. The coefficient for non-top 30% performers is 2.143 while the coefficient for top

30% observations is 2.252. Therefore, the coefficient for top 30% is slightly higher. However, a seemingly unrelated test has been performed, which tests whether the coefficients are different from each other. The test had a prob > $\chi2$ statistic of 0.822, which implies that these coefficients are not significantly different at the 10% significance level. Therefore, H3 should be rejected when green innovation is measured by patents.

Similarly, the log transformed variable of green patents acquired when using citations also shows a positive sign for both groups. However, the coefficient for the regression with the top 30% performing firms in terms of citations on green filed patents is not statistically significant at the 10% level. In contrast, the coefficient for firms that do not belong to the top 30% is 2.358 and statistically significant at the 1% significance level. Therefore, the results when citations are used support H3, and there is a discrepancy in results for this hypothesis between the usage of green patents, and citations on green patents.

Table 9. Regression results for H3, both when green patents and citations on green patents are used to represent green innovations.

	(H3) **(patents)**		(H3) **(citations)**	
	Top 30%	Not top 30%	Top 30%	Not top 30%
ln (Green patents/citations acquired)	2.252**	2.143**	1.626	2.358***
	(1.108)	(0.867)	(1.211)	(0.879)
ln (Firm leverage)	-0.257	0.016	0.428	0.046
	(0.487)	(0.382)	(0.334)	(0.423)
ln (Company age)	13.497*	-11.335**	-11.353	-11.243**
	(7.333)	(5.055)	(10.588)	(5.353)
ln (Sales)	-14.873*	-0.102	3.826	-0.762
	(7.984)	(2.571)	(15.435)	(2.562)
ln (ROE)	-10.274**	-14.621***	-10.997**	-14.462***
	(4.274)	(1.354)	(5.473)	(1.346)
Constant	203.591*	79.108**	12.516	87.199***
	(112.390)	(33.711)	(215.929)	(32.596)
R-squared within	0.168	0.290	0.113	0.292
R-squared between	0.004	0.022	0.058	0.019
R-squared overall	0.001	0.088	0.042	0.083
Observations	241	2,326	238	2,329

Discussion of results

Hypothesis 1

The thesis finds support for Hypothesis 1a that overall green patenting activities lead to a significant firm performance increase at the 5% significance level when using patents. This is in line with previous literature such as the findings of Lee and Min (2015) who found green innovation measured by R&D expenditures to be positively associated with financial performance, and the conclusion of Russo and Fouts (1997) stating that "it pays to be green". When citations on green patents are used, no support is found for H1a. This implies that the findings of H1a differ when using green patents and citations on these patents. Therefore, we may observe that for green patents overall, the quantity of the green innovation activities on average could lead to significant firm performance increase, while the quality of the green innovation activities does not lead to a significant increase.

In contrast, no support is found for Hypothesis 1b, in which the association between green innovations filed by a firm itself and firm performance change has been investigated. While a positive sign is found, the result is not statistically significant at the 10% level in both cases when patents are used, and when citations are used. This in line with findings of Aguilera-Caracuel and Ortiz-de-Mandojana (2013) who also found a positive but not significant coefficient for firms that perform green innovations compared to firms that do not.

For Hypothesis 1c, the thesis finds support at the 1% significance level both when patents are used as innovation measure and when citations on green patents are used. Acquiring green patents has a positive effect on firm performance change. While not a lot of research on the acquisition of green patents on firm performance has been performed, the findings are in line with previous findings of acquiring new knowledge. Because of the exposure to other knowledgebases, firms can choose the technological paths, and enhance new combinations of existing technologies (Nelson & Winter, 1982; Metcalfe, 1994). Furthermore, acquired knowledge engages 'resource learning' and leads to the exposure to non-path dependent knowledge that allows for new (re-)combination possibilities (Lockett et al., 2011; Mahoney, 1995). The results of this thesis imply that the benefits of access to new knowledge also applies to the acquisition of green innovations.

Furthermore, the potential interaction between green patents created internally and green patents acquired is not statistically significant at the 10% level, both when using patents and citations as measure of green innovation activities.

Hypothesis 2

The results indicate that Hypothesis 2a, 2b and 2c all are rejected, both when using patents as well as citations to represent green innovations. This implies that for any kind of green innovation activities, total patenting activities do not significantly moderate the relationship between green innovation activities and firm performance. As explained, little research investigated the implication of a firm's focus of green innovations relative to overall innovations performed. Previous literature argued that the attitude of top management towards green innovations is crucial, a structural focus on green innovations is necessary to remain ahead of competitors, and green innovations may be argued to be a substitute or improvement relative to non-green innovations (Aguilera-Caracuel & Ortiz-de-Mandojana, 2013; Bansal, 2005; Chiou, 2011; Dangelico, 2016; Eiadat et al., 2008; Miller, 2001). Nevertheless, the arguments are not reflected in the moderating effect of total innovations on green innovations according to the results of this thesis.

Hypothesis 3

For Hypothesis 3 both top performing firms in terms of internally filed green patents as well as firms that are no top performers have a positive and significant increase in firm performance after acquiring a green innovation when patents are used as innovation measure. However, the estimates are not statistically significant different from each other. In this scenario, H3 needs to be rejected, for which firms that "build on the strengths" and firms that "fix the weaknesses" may have equally good firm performance changes from green patent acquisitions (Ma, 2020). In contrast, when using citations as green innovation measure, H3 finds support since firms that are no top performer benefit significantly from the acquisition of quality green patents, whereas top performing firms do not.

One reason for the discrepancy between the results of both measures of green innovation activities may be explained that ideas of high quality are particularly chosen by underperforming firms to increase firm performance instead "normal" ideas and the acquisition of broad patents. This is in line with finding of Cyert and March (1963) stating that underperforming firms challenge themselves by seeking solutions by problemistic search. Similarly, the finding that non-top performing firms benefit from quality patents is in line with the explanation of Lockett et al. (2011) that an increase in growth due to acquisitions is especially expected for firms that have limited knowledge and resource bases.

Overarching discussion

The results indicate that acquired green innovation knowledge provides a statistically significant firm performance improvement while the association between green patents filed internally and firm performance change are not statistically significant, both for patents and citations. This is a remarkable outcome as it intuitively contrasts with findings of Cainelli et al. (2015) who argued that firms with reactive innovative strategies, instead of proactive strategies, are less likely to get involved in successful eco-innovations.

An important remark that must be made, however, is that this thesis investigates the effect on firm performance change. It may be that firms that have a lot of internal green knowledge structurally perform better, for which new filed ideas or ideas of quality do not increase firm performance radically since these firms perform structurally good and gain incremental increases in firm performance.

Another potential reason for the difference between the effect of green patents filed by a firm itself and green patents acquired is a potential difference regarding the period in which the difference in firm performance occurs. The rationale for such difference lays in the moment when a firm gets access to the idea. Figure 1 indicates an example of idea development, finalizations, and usage in which the general trend, and difference in the access to idea content for filed patents and acquired patents is of importance. Please notice that the exact development path, timings, and usage of information may be different for specific contexts. For patents that are filed by a firm, the firm has access to the idea development from the start of the idea onwards. Therefore, the company can start using (part of) the idea already during the idea development. Similarly, when the invention is finalized and the patenting process starts, the company can already implement (part of) the invention, adjust products or processes according to their knowledge, or diffuse the invention across other functions. In contrast, when a firm acquires a patent, the firm may gain some knowledge just prior to the knowledge gained through the acquisition of the patent. However, most of the idea information will be available from the moment the knowledge arrives at the company. Therefore, for acquired patents the moment from which a company can use an idea is much more set in stone during the year of acquisition, compared to the case in which the company files a patent internally for which the moment of incorporation of the idea is much more arbitrary and may be prior to the year of patenting.

This explanation regarding the process of acquiring a patent could be considered a radical increase of innovation knowledge through an idea and related information and data, while a green innovation created internally is an incremental increase of innovation knowledge. This would be in line with the explanation of Lockett et al. (2011) stating that firms with limited knowledge and resources face non-incremental increases of their firm's productive opportunity set because of acquired knowledge.

Last, for citations on patents acquired this thesis did not investigate the moment when the citations were performed while the number of citations represents the amount in 2022. One could argue that there is a difference regarding the impact on business performance depending on the nature of the acquired patent in terms of development and application. More specifically, there may exist a difference in firm performance change for patents of which a significant number of citations already is in place prior to the acquisition, and patents that received most of the citations after the acquisition. In fact, the first case implies that the acquired patent is valuable and considered of high quality already prior to the acquisition, while the other gains value through quality recognition after acquisition. This thesis could not distinguish between both scenarios.

The time course of citations on patents, and especially the state of a patent at the time of acquisition, may not only differ the firm performance change overall. This could also be of relevance for H3 as it may also diversify a firm's abilities to transform acquired patents to commercialization based on their knowledge characteristics. More specifically, firms that lack innovation knowledge and therefore are acquiring patents to "fix the weaknesses", as explained by Ma (2020), may benefit even more from acquiring patents that received many citations prior to the acquisition. In contrasts, firms that "build on strengths" and already have a considerable green innovation knowledge base are expected to be able to process new and potentially complex information better to eventually boost the quality of the patent after acquisition because of practical applications and supplementary ideas.

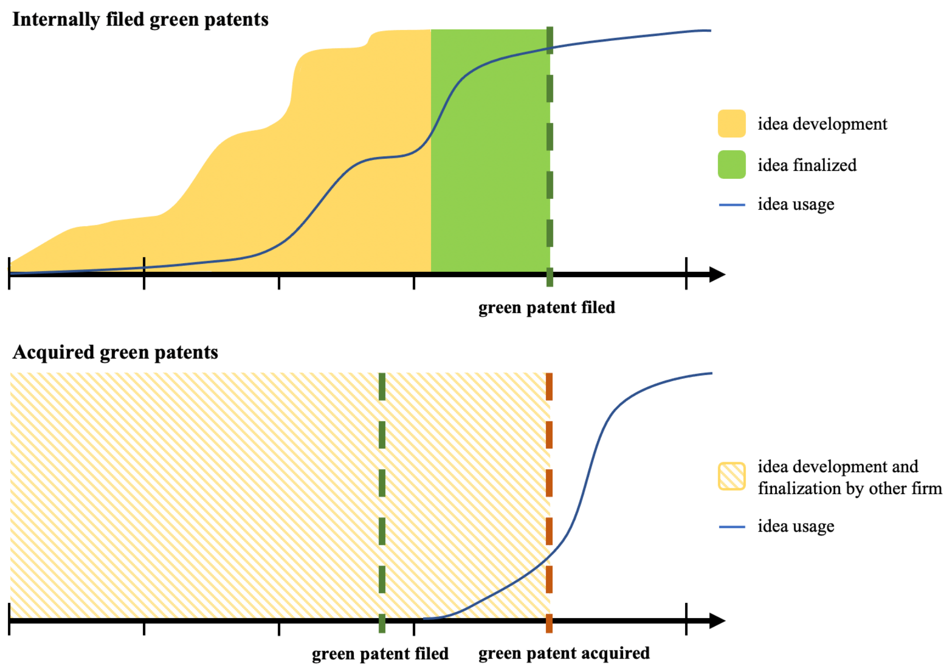

Figure 1. Access to idea content for filed patents and acquired patents

Robustness checks and additional analysis

To perform the analysis in this thesis, several arbitrary choices were necessary. In addition, while this thesis aims to address certain gaps in previous literature, there remain areas in which more research needs to be conducted. Below some robustness checks and additional checks have been performed to investigate whether the findings also hold under other circumstances by changing the arbitrary chosen parameters. Afterwards the results will be discussed with the aim to introduce some topics for future research[7]. Table 10 provides the results for the robustness checks for H1 and H2 both for patents and citations usage to represent innovation, while Table 11 provides the results for H3. In both tables column 1 provides the results of the main analysis.

Firm performance measure

First, the main analysis uses ROE as measure of firm performance, however, other commonly used financial firm performance measures are ROA and PM (Aguilera-Caracuel & Ortiz-de-Mandojana, 2013; Artz et al., 2010; Cefis & Ciccarelli, 2005; Chan et al., 2016). Therefore, robustness checks have been performed using these financial performance measures. For H1 and H2 the results for using ROA and PM instead of ROE can be observed in Table 10, column 4 and 5, respectively. The robustness results of firm performance measures for H3 are presented in Table 11 column 4 and 5. When using ROA instead of ROE, H1a and H1c still hold when patents are used at the 1% significance level. Similarly, the coefficient of H1c when citations are used is still positive and significant at the 10% significance level. When ROA is used as financial performance measure for H3 with citations used as innovation indicator, the coefficients of top performers and the contra-group are both positive and significant, which contrasts the main analysis. However, the seemingly unrelated test has a prob > $\chi 2$ statistic of 0.015 while the coefficient of non-top performers is higher, therefore H3 also holds at the 5% significance level.

When PM is used instead of ROE, only H1c holds for both the patent and citations measure scenarios at the same significance level at the main analysis. H1a with patents usage does no longer show a significant coefficient while for H3 both subsamples show a positive and significant, with the top performers even facing a higher coefficient, however the seemingly unrelated test outcomes with a prob > $\chi 2$ statistic of 0.403 indicates that the difference is not statistically significant.

Firm appearance

Another arbitrary choice that has been made is the inclusion of all companies in the dataset. Since the dataset is highly unbalanced, as indicated in Table 3, one may argue to exclude firms that appear too little in a dataset because of potential harmful reasons for exclusion leading to attrition. Although this issue may be more of a concern for datasets gathered through surveys, and the attrition test did not indicate attrition, robustness checks have been run with subsets consisting of those firms that appear at least 4 and at least 5 times in the dataset. These numbers have been chosen since firms that appear at least four times are in most of the periods available, whilst this threshold also ensures that approximately half of the firms remain in the dataset, as

[7] Please notice that the additional analysis and discussion of the corresponding future research should be considered as bridge between findings of the current study and future research. For this reason, the additional analysis is added here, on top the future research section in the conclusion.

depicted in Table 3. The results for H1 and H2 for these robustness checks can be observed in column 6 and 7 of Table 10 while the results for H3 are shown in column 8 and 9 of Table 11. The results indicate that H1a and H1c when using patents, and H1c when using citations all have a larger coefficient compared to the main analysis, while the significance level at which the null hypothesis is rejected is at least as good as the main analysis. Therefore, the results still hold with increased coefficients. Also, H3 holds when using citations.

What stands out from the results is that H3 also finds support when patents are used, and the outcome for H1a when citations are used as innovation measure also increased that is statistically significant at the 5% significance level. The higher coefficients and higher p-values regarding significance may imply that firms that appear less in the dataset have other characteristics or indeed disturb the results for a reason.

One potential reason may lay in the financial information that needs to be known and the lack of this information from certain companies. Since larger firms are more likely to have external investors, and even may be listed, it is more likely that the necessary information is known for more years for these companies. If larger firms indeed are more engaged in green innovation activities or are better in extracting financial performance increases from internally created innovations, it would (partially) explain the increased coefficients and hypothesis that no longer need to be rejected for these robustness checks. Table A8 in the Appendix provides the descriptive statistics without log transformation for the dataset with only observations of firms that appear at least 5 times. We can observe that there are some small differences in firm characteristics of both datasets, but these differences are not significantly different. Nevertheless, there may exist unobserved differences across both datasets leading to more distinct results.

Median size

Through this thesis the role of the size of a firm has been mentioned several times. Although the company size has been used as a control variable, some alerts for extra attention occurred. In fact, Braunerhjelm et al. (2018) found that the effect of employee joiners from patenting firms on a firm's patenting productivity is different for small firms than for large firms. Therefore, robustness checks with firms larger and smaller than the median size have been performed. The results for H1, and H2 are reflected in column 8 and 9 of Table 10, and the results for H3 are presented in column 10 and 11 of Table 11. We can observe that H1a for the patent-usage and H1c in both innovation measures for the subset existing of firms larger than the median size all hold at the 5% significance level. However, for the subset with firms smaller than the median size H1a and H1c only hold at the 10% significance level when patents are used as innovation measure. H1c becomes not significant at the 10% level when citations are used.

The results of H3 need to be interpreted with caution as the explanatory power of the models may have reduced since two datasets half the size of the original dataset have been used. Therefore, the top performing groups, which are assigned to the best 30%, have been reduced in size as well, for which the number of observations for these models are especially low. In fact, column 10 in Table 11 indicates that H3 no longer holds when citations are used for the subset consisting of firms larger than the median size. The coefficient for top performers and the contra-group are both positive and significant at the 10% level, however, the coefficient of non-top performers is not significantly higher than that of top performers.

To test the similarity of the coefficients of the subset consisting of firms larger than the median size and the subset with firms smaller than the median size, a seemingly unrelated test has been run. The outcomes of the prob > $\chi 2$ statistic for all variables of H1, H2 and H3 can be found in the Appendix in Table A9. The results indicate that all differences are not statistically significant at the 5% significance level.

In addition, for H3 the difference for both subgroups is only different for the subset with small firms. However, the difference across both subsamples with different firm sizes, instead of the difference within both subsamples is even more interesting. The seemingly unrelated test provides a prob > $\chi 2$ statistic of 0.438 when using patents, and 0.512 when citations are used for underperforming firms.

Especially together with the potential role of firm size in explaining low firm appearance in the dataset for certain firms and the results for the robustness checks with firms that appear often should be alerting. In fact, Penrose (1959) confirmed the potential role by stating that a firm's productive opportunity set size is positively related with a firm's ability to grow. Therefore, future research should investigate the role of firm size regarding the relationship between green innovations and firm performance in more detail.

Time lag

As explained, the appropriate time lag for green innovations on firm performance has not been argued unanimously in previous literature. In addition, Figure 1 depicts a suggested potential different period for acquired patents and those filed by a firm. Robustness checks for H1, H2 and H3 have been run in which the firm performance change has been changed to the period from -1 to +1 and from -1 to +2, both relative to the moment a patent has been filed or acquired, instead of period from 0 to +2. Column 2 in Table 10 indicates that when using patents, H1a finds support at the 5% significance level. Furthermore, H1c is also still positive and significant at the 10% significance level for both cases in which patents and citations are used. However, for both cases the coefficients are no longer significant at the 5% significance level. Also, the coefficient of green patents overall when citations are used, becomes positive and statistically significant at the 5% significance level.

Column 3 in Table 10 indicates that when the period from -1 to +2 is used, the coefficients of H1a and H1c both are positive and significant at the 5% significance level. In addition, H1b also becomes significant at the 5% significance level. Furthermore, H1c when using citations is significant at the 10% significance level. In addition, the coefficients of green patents filed, and green citations filed become statistically significant at the 10% significance level.

The reduction of p-values for the hypotheses investigating the effect of patents and citations acquired, and the increase in significant results for overall and filed patents may provide weak suspicion that the suggested theory depicted in Figure 1 may be true. However, future research should investigate this further.

Exclusion of patents filed or acquired in 2019

Table 4 in the descriptive statistics provides the number of companies, green patents filed, green patents acquired, and citations on these patents per year. The lower figures for alle columns for the year 2019 stand out. In fact, the lower number of companies implies that for relatively more companies the financial information for this year is not known (yet) according to the data available in Orbis. On top, the significantly lower number of patents filed and acquired may imply that either the initial examination of the patent application has not been finished for a significant number of patents, the patent data has not been published publicly yet, or the patent data has not been included in the database of The Lens. Regardless of the reason for the lower numbers in 2019, an additional test has been run in which 2019 was not included in the analysis.

When patents are used to represent green innovations, column 10 in Table 10 indicates that H1a holds at the 5% significance level. Similarly, H1c holds at the 1% significance level. Furthermore, when citations are used, H1c holds at the 10% significance level. In addition, when citations are used, H1c finds support at the 10% significance level.

Table 11 indicates that the effect of acquired patents on firm performance change when 2019 is excluded. We can observe that when citations are used, the coefficient of non-top performing firms remains positive with a coefficient of 2.535 and significant at the 1% significance level, while the coefficient for top performing firms is not significant at the 10% significance with a coefficient of 1.657, and thus supporting H3 when citations are used.

Table 10. Robustness checks and additional analysis for H1 and H2, both for green patents and citations. Including the main results and robustness checks in terms of time lag, firm performance measure, firm appearance, median size division and exclusion of 2019.

		main	*time lag*		*firm performance*		*firm appearance*		*median size*		*excl. 2019*
		(1) ROE$_{02}$	(2) ROE$_{-11}$	(3) ROE$_{-12}$	(4) ROA$_{02}$	(5) PM$_{02}$	(6) ROE$_{02}$ (n > 3)	(7) ROE$_{02}$ (n > 4)	(8) ROE$_{02}$ (> medsize)	(9) ROE$_{02}$ (< medsize)	(10) ROE$_{02}$
Patents	(H1a) ln (Green patents overall)	1.347**	1.235**	1.519**	0.978***	0.326	1.625***	1.728***	1.310**	1.601*	1.269**
		(0.548)	(0.654)	(0.662)	(0.364)	(0.218)	(0.608)	(0.589)	(0.641)	(0.967)	(0.636)
	(H1b) ln (Green patents filed)	0.193	0.547	1.099**	0.440	-0.176	0.434	0.810	0.496	0.079	-0.233
		(0.522)	(0.562)	(0.546)	(0.318)	(0.314)	(0.538)	(0.559)	(0.652)	(0.834)	(0.540)
	(H1c) ln (Green patents acquired)	2.165***	1.418*	1.959**	1.165***	0.670***	2.355***	2.203***	1.957**	2.660*	2.300***
		(0.705)	(0.840)	(0.888)	(0.443)	(0.214)	(0.845)	(0.829)	(0.785)	(1.378)	(0.848)
	(H1d) ln (Green patents acquired) * ln(Green patents filed)	0.474	-0.541	0.387	-0.168	0.002	0.173	-0.309	0.525	1.171	0.383
		(0.702)	(0.459)	(0.621)	(0.362)	(0.220)	(0.520)	(0.570)	(0.813)	(1.757)	(0.776)
	(H2a) ln (Green patents overall) * ln(Total patents overall)	0.107	-0.139	0.077	0.152	-0.134	0.197	-0.080	0.109	0.438	0.216
		(0.267)	(0.259)	(0.306)	(0.207)	(0.143)	(0.254)	(0.282)	(0.349)	(0.653)	(0.291)
	(H2b) ln (Green patents filed) * ln(Total patents filed)	-0.016	-0.144	0.088	0.215	-0.398*	0.282	0.211	-0.402	0.662	-0.257
		(0.371)	(0.376)	(0.388)	(0.245)	(0.219)	(0.338)	(0.345)	(0.544)	(0.801)	(0.356)
	(H2c) ln (Green patents acquired) * ln(Total patents acquired)	0.001	-0.175	-0.269	0.088	-0.104	-0.180	-0.249	-0.257	1.603	0.438
		(0.999)	(0.393)	(0.389)	(0.187)	(0.100)	(0.291)	(0.333)	(0.326)	(1.095)	(0.311)
Citations	(H1a) ln (Green citations overall)	0.278	0.496**	0.492**	0.245*	0.044	0.511**	0.575***	0.378	0.173	0.242
		(0.201)	(0.229)	(0.246)	(0.143)	(0.088)	(0.227)	(0.214)	(0.234)	(0.347)	(0.226)
	(H1b) ln (Green citations filed)	-0.007	0.308	0.438*	0.088	-0.110	0.210	0.359	0.153	-0.081	-0.085
		(0.198)	(0.231)	(0.242)	(0.117)	(0.122)	(0.208)	(0.218)	(0.242)	(0.335)	(0.208)
	(H1c) ln (Green citations acquired)	0.565**	0.491*	0.602*	0.288*	0.178**	0.740**	0.718**	0.648**	0.407	0.570*
		(0.256)	(0.284)	(0.309)	(0.172)	(0.083)	(0.315)	(0.305)	(0.648)	(0.459)	(0.294)
	(H1d) ln (Green citations acquired) * ln(Green citations filed)	0.068	-0.119	0.037	-0.032	-0.002	0.074	0.008	0.047	0.132	0.064
		(0.088)	(0.086)	(0.106)	(0.053)	(0.038)	(0.089)	(0.101)	(0.101)	(0.174)	(0.091)
	(H2a) ln (Green citations overall) * ln(Total citations overall)	0.078	-0.092	0.022	0.095	-0.036	0.107)	-0.002	0.134	0.049	0.129
		(0.100)	(0.405)	(0.133)	(0.086)	(0.056)	(0.099)	(0.108)	(0.114)	(0.208)	(0.104)
	(H2b) ln (Green citations filed) * ln(Total citations filed)	0.059	-0.001	0.106	0.121	-0.116	0.072	0.056	-0.033	0.227	0.004
		(0.123)	(0.138)	(0.153)	(0.078)	(0.091)	(0.117)	(0.125)	(0.163)	(0.277)	(0.124)
	(H2c) ln (Green citations acquired) *ln(Total citations acquired)	0.055	-0.029	-0.081	0.074	-0.026	0.011	-0.029	-0.042	0.366	0.195*
		(0.117)	(0.149)	(0.149)	(0.068)	(0.045)	(0.124)	(0.135)	(0.144)	(0.363)	(0.105)
	Similar control variables as main regression	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

The estimated coefficients are shown together with the standard errors (SE) in parentheses. Estimated thresholds are not shown.
In all models fixed effects with companies representing the entities or panels, and years representing the time entity have been performed.
*** *p* value ≤ 0.01; ** *p* value ≤ 0.05; * *p* value ≤ 0.10

Percentage

For H3 the percentage of top performing companies needed to be determined, which is an arbitrary choice. While one could argue to make the distinction between absolute top performers and the rest, choosing a low percentage also implies a smaller group of firms, and subsequently reducing the explanatory power of a model drastically. Nevertheless, since the choice for 30% is arbitrary, column 2 and 3 in Table 11 provide robustness checks for H3 in which the top 20% and top 50% are used instead of top 30%, respectively. Table 11 indicates that similar results are obtained, therefore, the hypothesis still holds using other percentages as top performing class definition.

Other period to determine top performers

In the Data and Method section the computation of the top performance firm dummies stated that firms are top performers if they belong to the 30% firms with the most filed patents or citations on filed patents three years prior to the year of acquisition. However, there is no factual reasoning or justification for the choice of three years. Therefore, robustness checks for H3 have been performed in which top performers have been determined in terms of filed patents and citations two and four years prior to the year of acquisition instead of three years. Column 6 and 7 in Table 11 show the results for these robustness checks. When citations are used, both cases support the main results.

Table 11. Robustness checks and additional analysis for H3, both for green patents and citations. Including the main results and robustness checks in terms of percentage, firm performance measure, previous years threshold, median size division and exclusion of 2019.

		main	*percentage*		*firm performance*		*previous 2/4 years*		*firm appearance*		*median size*		*excl. 2019*
		(1) ROE_{02} 30%	(2) ROE_{02} 20%	(3) ROE_{02} 50%	(4) ROA_{02} 30%	(5) PM_{02} 30%	(6) ROE_{02} 30% 2 years	(7) ROE_{02} 30% 4 years	(8) ROE_{02} (n > 3)	(9) ROE_{02} (n > 4)	(10) ROE_{02} (> medsize)	(11) ROE_{02} (< medsize)	(10) ROE_{02} 30%
(H3) patents	top	2.252**	1.751	2.684***	0.780*	1.754***	2.306	2.056**	2.107**	2.222*	1.757	1.333	3.589
		(1.108)	(1.367)	(0.954)	(0.445)	(0.556)	(1.395)	(0.961)	(0.914)	(1.156)	(1.058)	(2.137)	(2.397)
	non-top	2.143**	2.195***	1.591*	1.354**	0.568**	2.095**	2.039**	2.430**	2.305**	2.676*	2.786*	2.400**
		(0.867)	(0.805)	(0.829)	(0.559)	(0.253)	(0.868)	(0.858)	(1.044)	(1.035)	(1.458)	(1.454)	(0.970)
(H3) citations	top	1.626	1.357	1.353	0.810**	1.074*	1.945	1.647	1.092	0.480	2.422*	2.038	1.657
		(1.211)	(1.531)	(0.934)	(0.396)	(0.586)	(1.456)	(1.044)	(0.871)	(0.927)	(1.424)	(1.323)	(2.172)
	non-top	2.358***	2.382***	2.406**	1.398**	0.712***	2.286***	2.243***	2.532**	2.399**	1.801*	2.070*	2.535***
		(0.879)	(0.821)	(0.955)	(0.564)	(0.248)	(0.843)	(0.849)	(1.048)	(1.032)	(1.045)	(1.070)	(0.985)

The estimated coefficients are shown together with the standard errors (SE) in parentheses. Estimated thresholds are not shown.
In all models fixed effects with companies representing the entities or panels, and years representing the time entity have been performed.
*** p value ≤ 0.01; ** p value ≤ 0.05; * p value ≤ 0.10

Discussion

Practical implications

The results of this thesis imply that in particular acquired green patents lead to a significant firm performance change increase on average. The results for acquired green patents are considerably robust given the significance levels gathered in the main results and robustness check results, both for green patents and citations on green patents. For green patenting activities overall, the results are different for the scenarios in which patents, and citations on patents are used. The results also indicate that total innovations do not moderate the relation between green innovation and firm performance. Last, when using citations as measure for green innovations, the thesis finds that acquiring green patents is of particular interest for firms that have been underperforming firms in terms of green innovations created internally during the last three years.

These findings are important for firms that seek innovation, environmentally friendly operations, and firm performance. In particular, the thesis points to the special importance of the acquisition of green innovation ideas of high quality for firms that do not have a solid green innovation knowledge base in place.

In fact, one percent more patents (filed or acquired) increases ROE on average with 0.013 percentage points, while acquiring one percent more patents increases ROE on average with 0.022 percentage points. These figures may seem very low, however, when applying these findings to the average firm characteristics of the dataset used, we get that one additional green patent (acquired or filed) increases ROE by 0.292 percentage point, while one additional acquired green patent increases ROE for the average firm by 3.211 percentage point. Given an average ROE of 18.86 in the dataset, this would imply a 1.55% performance improvement for one additional green patent (either filed by the firm itself or acquired), and a 17.03% performance improvement for acquired green patents.

Although the results for green innovations created internally tend to indicate that there is no significant increase in financial firm performance, this does not imply there are no financial benefits from performing green innovations internally. For example, it may be that green innovations created internally lead to incremental firm performance improvements, which are captured to a less extend in this thesis, this may be illustrated by the results for the robustness check investigating the change in ROE between period -1 and +2. In fact, most studies investigating the effect of eco-innovations on firm performance find a non-negative relationship, with over half of the studies concluding a positive and significant effect (Friede et al., 2015; Hojnik & Ruzzier, 2016).

Limitations

Despite this study has been performed to the best of my knowledge, there are some important limitations to mention. Below the most urgent limitations are mentioned and described in detail.

First, this thesis uses patents and citations as measure for innovation. While Acs et al. (2002) state that patents are the most used innovation indicator because of its availability, and Frietsch and Grupp (2006) argue that patents are the most important innovation indicator, the thesis still relies completely on this validity. Nevertheless, Ted Sichelman (2009) states that approximately half of all inventions patented in the United States are never exploited commercially, while Webster and Jensen (2011) found that about 40 percent of inventions patented eventually lead to market launch and mass production. The lack of commercialization of inventions patented may be because of worthless inventions. However, Abramowicz (2006) also argues that valuable inventions may not be commercialized because patents need to be filed early in the innovation process, when an invention is still far from a finished product. While patents are still considered to be the best indicator of innovation for this study, the comments above imply that the results should be interpreted carefully. On the one hand the usage of patents as an instrument for an inventions financial value is questioned by the authors. On the other hand, the arguments are in line with the findings that green patents filed internally do not imply statistically significant financial improvements.

On top of the finding that approximately 40 percent of inventions patented eventually lead to market launch and mass production, Webster and Jensen (2011) found that previous complementary patents increase the probability of commercialization of a new patent by three to five percentage points. While this thesis considered the difference in the effect of patents for top performing firms in terms of filed green innovations and no top performing firms, this thesis did not consider the potential role of complementary patents.

Another important aspect regarding the role of previously filed patents that should not be overlooked is the potential accumulating role of previously filed patents. This thesis did account for the baseline level of performance of a firm to capture potential firm performance effects of previous patent activities to overturn a potential reverse causality issue, following Belderbos et al. (2010). However, if patents filed in previous years still account for financial performance increases during later time periods, the econometric approach of this thesis may not be valid. For example, if a green patent filed in 2012 accumulates firm performance increase during the period 2015-2017, albeit through a new complementary patent or not, the results are biased, and the econometric approach may not the most appropriate one. Namely, in that case the dependent variable serial correlates over time, for which the strict exogeneity assumption may not hold. Nevertheless, this thesis used time lags that are common in studies in the same study area, the thesis controlled for the financial performance at the start of the period, and the author thinks the performed method is the most appropriate one.

Furthermore, in the Data and Method section the rationale for the usage of fixed effects has been provided. Despite this approach to be considered the best one, it unfortunately implies that time-invariant characteristics will be omitted. This implies that the thesis could not control for, or test, these factors.

Third, as explained in the discussion, this thesis did not investigate the moment when the citations were performed, since the number of citations on patents represents the amount in 2022. One could argue that there is a difference regarding the impact on business performance depending on the nature of the acquired patent in terms of development and application. More specifically, there may exist a difference in firm performance change for patents of which a significant number of citations already is in place prior to the acquisition, and patents that received most of the citations after the acquisition. Therefore, this thesis considers the patent quality at the time of data extraction, and not the patent quality at the time of acquisition. Using the number of citations of the present may affect the results of H1 which investigates the effect of green innovations on firm performance, but also may change results for H3 as the inclusion of patent quality at the time of acquisition emphasizes on diversified firm’s abilities to transform acquired patents to commercialization based on their knowledge characteristics.

Furthermore, while this thesis did control for firm size and performed additional analysis regarding firm size, a more extensive focus on the role of firm size would benefit the research paper. First, the role of firm size and financial information availability might influence the results. Second, certain firm sizes may be beneficial for the commercialization extraction capabilities from ideas or performing green innovation activities. This is in line with findings of Hoogendoorn et al. (2015), who found a U-shaped association between firm size and green innovation practices for SME's. Also, Braunerhjelm et al. (2018) argued that the effect of employee joiners from patenting firms on a firm's patenting productivity depends on firm size.

Another limitation of this thesis is the external validity of the results because of firm size. In fact, the dataset consists of rather large firms with over 80% of the firms being classified as "Very Large" firms, as presented in Table 2, this implies that the firms are heavily skewed in terms of firm size. Furthermore, the robustness check performed with subsamples existing of firms smaller than the median size and firms larger than the median size provide weaker evidence for smaller firms compared to larger firms.

Furthermore, this thesis had to deal with data availability. Especially the limited availability of financial data, which ranged up to and including 2013, limited the usage of a longer period. More data would not only benefit the accuracy of the estimates but would also allow for a broader analysis in which broader and more in-depth questions on the subject can be investigated. An example of such question is whether firms that gain firm performance increases as a result of acquired green innovations are also able to translate the gained green innovation knowledge into successful internally created knowledge that leads to firm performance increases during later periods.

Last, since this thesis uses data of two different dataset providers, firms have been merged using a string-matching algorithm by the author. A pre-generated dataset by a professional organization where there will be more advanced techniques and knowledge about data matching would provide a more efficient matching procedure in which less firms will be lost. Because of the conservative way of matching companies, to avoid false positive matches, a significant number of firms and data has been lost.

Conclusion

This thesis examined the potential effect of green innovation activities on firm performance. Green patents filed at the USPTO between 2013 and 2019, and citations on these patents, have been used to represent green innovation activities, in which patents filed at a firm and patents acquired have been differentiated. In particular, the study investigated the effect of green innovations activities on firm performance, and the potential moderating effect of overall innovations on this association. These effects have been examined for overall green patents (id est, acquired and filed), for patents filed at a firm, and for patents acquired. Also, the models have been investigated by using green patents count and citations on green patents. In addition, the thesis examined whether firms that did not have a solid internal green innovation knowledge base in place benefit more from green innovation acquisition than firms that already have a solid knowledgebase.

The thesis aims to close the gaps in previous literature by using green patent data in a panel data setting, applying a fixed effect approach, which is relatively unique as previous literature often used survey data (Ar, 2012; Chen et al., 2006; Chiou et al., 2011; Gürlek & Tuna, 2018). Furthermore, patent filing and transaction dates are used to distinguish patents in patents filed internally and patents acquired, which has not been performed in previous papers.

The research question of this thesis stated whether green innovation activities provide financial benefits for firms. Although there is no single answer to this question, one similarity across all models is that there is no significant negative association between green innovations and financial performance change. Furthermore, the answer to the question depends on the type of innovation activity and measure.

First, the results show that there is weak evidence that green patenting activities overall lead to significant firm performance increases. However, the robustness checks are not unanimous. In contrast, the results provide relatively strong evidence that acquiring green patents result in a significant firm performance increase. The results also indicate that firms that are no top performers in terms of internally created green innovations recently, benefit more in terms of financial performance change from acquiring qualitative green innovations, represented by citations on green patents, relative to firms that have been top performers.

Furthermore, the thesis finds no support for a moderating effect of overall innovations on the relation between green innovations and firm performance. Also, the thesis finds no support for a positive effect of green innovations created internally on financial firm performance. For overall green innovation ideas, represented by patent counts, both groups benefit from acquiring the ideas, in which the benefits for underperforming firms are not significantly higher than those of top performers.

The results should be interpreted with caution since the findings are subjected to this thesis' study design in which several elements need further examination and verification. In fact, only the effect of green patents acquired on firm performance change showed positive and significant results in all robustness checks. Similarly, a lack of positive and significant results regarding the effect of green patents created internally on firm performance does not imply there is no association, nor does it imply the result is wrong per definition. In conclusion, following the example of Russo and Fouts (1997) stating that "it pays to be green", this thesis concludes by stating that according to the results obtained "it pays to acquire green patents for short term firm performance".

Future research

This thesis aims to introduce research that distinguishes between green innovations that have been filed internally by a company and innovations that have been acquired. While this thesis aims to fill several gaps in the research area of green innovations and the effect on firm performance, this is still a high-level analysis. Therefore, there are still many elements that need to be examined to get a better view and understanding.

First, the most time-efficient and high-level suggestion for future research is to invest more time in matching the companies of both datasets, and to use a dataset with a longer period of financial observations. By matching more companies, while ensuring the validity of the matches, the models will be further improved, for which the results become more robust.

Next, this thesis used patent data of patents that are filed at the USPTO. However, this thesis could be tested with patent data of other patent offices such as the EPO or WIPO to verify the findings of this thesis.

Furthermore, firms can file an idea at multiple patent offices. It would be interesting to investigate whether firms that file patents at more patent offices face higher firm performance increases than firms that file patents at only one office. This way, in theory, the number of patent offices where a patent is filed, represents the confidence and extraction capabilities of a firm prior to potential idea diffusion and quality assessment of external sources.

Fourth, this thesis proposes a potential difference in the time course in terms of the adaptation of green innovations filed within the firm, and those acquired, as depicted in Figure 1. Future research could investigate the differences in the idea usage for both scenarios. In fact, the moment from which on an idea is used, and from when on the effect diminishes for both scenarios would be an important step to better understand the differences and thus to get a more specific picture of the situation. Furthermore, the thesis discussed the potential difference in knowledge gathering in which acquired patents may be a radical increase of innovation knowledge while internally created patents are an incremental increase of innovation knowledge. Future research could investigate whether there is a difference in the increase of knowledge and whether this is also reflected in the usage of an idea and its effect on firm performance.

Furthermore, as discussed in the limitations, this thesis did not consider the potential role of complementary patents while Webster and Jensen (2011) argue that previous complementary patents increase the probability of commercialization of a new patent. One way to overcome the potential accumulating role of previously filed patents mentioned in the limitations, is by computing the average difference in firm performance over a certain period[8]. Further research could investigate the role of complementary green patents and the implications for firm performance changes.

Additionally, this thesis used firm performance change over a certain period, while controlling for the firm performance prior to the change period. However, as discussed, it may be that firms that perform internal innovations perform structurally better and achieve incremental firm performance improvements. Therefore, it would be interesting to investigate performance surrounding periods of firms that file green patents and those

[8] This thesis examined the results if the firm performance change from period 0 to the average financial performance at t+1 and t+2 (and t+1, t+2 and t+3) is used as dependent variable. All hypotheses remain unchanged in terms of direction and significance level, except for H1a when citations are used; this hypothesis becomes positive and significant at the 10% significance level.

that acquire green patents. By averaging firm performance surrounding the filing date of a patent, the potential issue depicted in Figure 1 may be avoided. Another way of achieving results related to this topic is to investigate the effects on the long-term of green patents acquired and green patents filed internally with a cumulative patent count.

Another point that could be investigated in more detailed are potential differences in the effect on firm performance change for different types of acquisition. As explained, this thesis did not consider differences regarding type of acquisition. However, there may be differences in the effect of green patents gained through a M&A, retrospectively assignment of a collateral, or other types of acquisitions.

Besides, this thesis used patents that have been filed by a company, and patents that have been acquired by a company. The effect of losing a patent has not been investigated. Braunerhjelm et al. (2018) did not find an effect for the so-called learning by diaspora effect when a R&D worker leaves a firm. While the rationale behind this theory is less applicable to patents, the effect of losing a patent has not been investigated in this study, future research could investigate this.

Last, future research could use the structure and approach of this thesis but investigate potential industry differences. Karlsson and Tavassoli (2015) for example argued that the time lag of patents varies per industry and firm size. In addition, the evaluation period for a patent application also depends on the complexity of the invention (Gerben, n.d.). Therefore, future research could investigate potential differences in more specific circumstances.

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Appendix A – Figures and tables

Table A1. Example of Y02 subclassification CPC

Classification symbol	Subdivided Classification	Title
Y02P10/00		**Technologies related to metal processing**
	Y02P10/10	Reduction of greenhouse gas [GHG] emissions
	Y02P10/20	Recycling
	Y02P10/25	Process efficiency
	Y02P10/32	Using renewable energy resources
Y02P20/00		**Technologies relating to chemical industry**
	Y02P20/10	Process efficiency
	Y02P20/141	Feedstock
	Y02P20/151	Reduction of greenhouse gas [GHG] emissions, e.g. CO 2
	Y02P20/20	Improvements relating to chlorine production
	Y02P20/30	Improvements relating to adipic acid or caprolactam production
	Y02P20/40	Improvements relating to fluorochloro hydrocarbon, e.g. chlorodifluoromethane [HCFC-22] production
	Y02P20/50	Improvements relating to the production of bulk chemicals
Y02P30/00		**Technologies relating to oil refining and petrochemical industry**
	Y02P30/20	using bio-feedstock
	Y02P30/40	Ethylene production
Y02P40/00		**Technologies relating to the processing of minerals**
	Y02P40/10	Production of cement, e.g. improving or optimising the production methods Cement grinding
	Y02P40/40	Production or processing of lime, e.g. limestone regeneration of lime in pulp and sugar mills
	Y02P40/50	Glass production, e.g. reusing waste heat during processing or shaping
	Y02P40/60	Production of ceramic materials or ceramic elements, e.g. substitution of clay or shale by alternative raw materials, e.g. ashes
Y02P60/00		**Technologies relating to agriculture, livestock or agroalimentary industries**
	Y02P60/12	using renewable energies, e.g. solar water pumping
	Y02P60/14	Measures for saving energy, e.g. in green houses
	Y02P60/20	Reduction of greenhouse gas [GHG] emissions in agriculture, e.g. CO 2
	Y02P60/30	Land use policy measures
	Y02P60/40	Afforestation or reforestation
	Y02P60/50	Livestock of poultry management
	Y02P60/60	Fishing Aquaculture Aquafarming
	Y02P60/80	Food processing, e.g. use of renewable energies or variable speed drives in handling, conveying or stacking
Y02P70/00		**Climate change mitigation technologies in the production process for final industrial or consumer products**
	Y02P70/10	Greenhouse gas [GHG] capture, material saving, heat recovery or other energy efficient measures, e.g. motor control, characterised by manufacturing processes, e.g. for rolling metal or metal working
	Y02P70/50	Manufacturing or production processes characterised by the final manufactured product
Y02P80/00		**Climate change mitigation technologies for sector-wide applications**
	Y02P80/10	Efficient use of energy, e.g. using compressed air or pressurized fluid as energy carrier
	Y02P80/20	using renewable energy
	Y02P80/30	Reducing waste in manufacturing processes Calculations of released waste quantities
	Y02P80/40	Minimising material used in manufacturing processes
Y02P90/00		**Enabling technologies with a potential contribution to greenhouse gas [GHG] emissions mitigation**
	Y02P90/02	Total factory control, e.g. smart factories, flexible manufacturing systems [FMS] or integrated manufacturing systems [IMS]
	Y02P90/30	Computing systems specially adapted for manufacturing
	Y02P90/40	Fuel cell technologies in production processes
	Y02P90/45	Hydrogen technologies in production processes
	Y02P90/50	Energy storage in industry with an added climate change mitigation effect
	Y02P90/60	Electric or hybrid propulsion means for production processes
	Y02P90/70	Combining sequestration of CO 2 and exploitation of hydrocarbons by injecting CO 2 or carbonated water in oil wells
	Y02P90/80	Management or planning
	Y02P90/90	Financial instruments for climate change mitigation, e.g. environmental taxes, subsidies or financing

Table A2. Manual similarities checked for company matching

Abbreviation	Meaning
INC.	Incorporated
CORP	Corporation
S.P.A.	Società per Azioni
PLC	Public Limited Company
AG	Aktiengesellschaft
LTD	Limited liability
S.L.	Sociadad Limitada
LLC	Limited Liability Company

Abbreviation	Meaning
OY	Osakeyhtiö
NV	Naamloze Vennootschap
AB	Aktiebolag
GmbH	Gesellschaft mit beschränkter Haftung
KFT	Korlátolt Felelősségű Társaság
KG	Kommanditgesellschaft
Co.	Company

Table A3. Descriptive statistics without log transformations

Variable	N	Mean	Std. Dev.	Min	Max
ROE change	2,567	-0.537	16.061	-138.431	142.679
Green patents overall	2,567	4.136	16.517	0	283
Green patents filed	2,567	2.067	11.321	0	273
Green patents acquired	2,567	2.069	8.584	0	199
Green citations overall	2,567	85.336	375.172	0	7,396
Green citations filed	2,567	46.798	277.753	0	7,254
Green citations acquired	2,567	38.538	183.091	0	4,642
Total patents overall	2,567	629.837	1,800.113	0	29,709
Total patents filed	2,567	549.192	1,535.955	0	25,231
Total patents acquired	2,567	80.645	368.554	0	16,213
Firm leverage	2,567	15.377	13.771	0	84.056
Company age	2,567	50.123	34.539	0	176
Sales (x 1,000)	2,567	7,698,618	23,389,253	17.422	3.731e+08
ROE	2,567	18.86	19.341	0.019	320.823
Top 30 filed patents	2,567	0.094	0.292	0	1
Top 30 filed citations	2,567	0.093	0.290	0	1

Table A4. Bureau van Dijk (2022a) firm size classification

		Very Large	**Large**	**Medium**	**Small**
Criteria	**Operating Revenue**	>= 100 million EUR	>= 10 million EUR	>= 1 million EUR	/
	Total assets	>= 200 million EUR	>= 20 million EUR	>= 2 million EUR	/
	Employees	>= 1000	>= 150	>= 15	/
	Other	Listed	Not very large	Not very large or large	Not included in other category
Notes		**Operating revenue, total assets, and employees are unknown, still included if …**			
		Level of capital is over 5 million EUR	Level of capital comprised between 500 thousand EUR and 5 million EUR	Level of capital comprised between 50 thousand EUR and 500 thousand EUR	/
		Companies with ratios operating revenue per employee or total assets per employee below 100 EUR (130 USD) are excluded from the categories Very Large, Large, and Medium.			
		The criteria for a company to be included in one of the categories below are always based on values expressed in EUR			

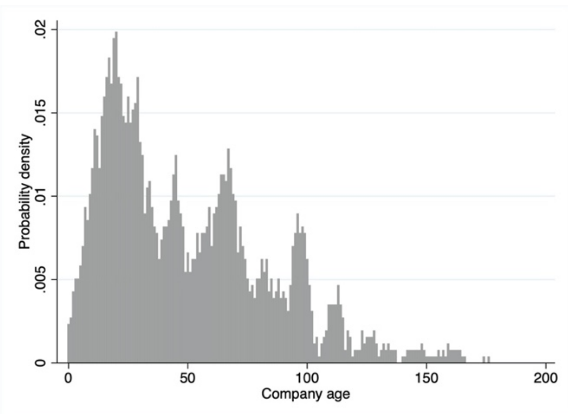

Figure A1. Company age in dataset

Table A5. Detailed descriptive statistics by sector

Industry	Frequency		Green patents filed		Green patents acquired		Green citations filed		Green citations acquired	
	Abs.	Rel. (%)	Abs.	Rel. (%)	Abs.	Rel. (%)	Abs.	Rel. (%)	Abs.	Rel. (%)
Agriculture, Horticulture & Livestock	2	0.33	2	0.04	5	0.09	1	0.00	37	0.04
Banking, Insurance & Financial Services	1	0.17	0	0.00	6	0.11	0	0.00	67	0.07
Biotechnology and Life Sciences	9	1.50	12	0.23	24	0.45	74	0.06	590	0.60
Business Services	39	6..50	96	1.81	260	4.90	1,507	1.25	6,078	6.14
Chemicals, Petroleum, Rubber & Plastic	89	14.83	307	5.79	722	13.59	9,795	8.15	14,351	14.51
Communications	24	4.00	717	13.51	466	8.77	12,580	10.47	7,321	7.40
Computer Hardware	11	1.83	153	2.88	49	0.92	1,674	1.39	539	0.54
Computer Software	4	0.67	16	0.30	30	0.56	1,211	1.01	348	0.35
Construction	9	1.50	26	0.49	50	0.94	2,187	1.82	1,474	1.49
Food & Tobacco Manufacturing	10	1.67	19	0.36	51	0.96	240	0.20	959	0.97
Industrial, Electric & Electronic Machinery	215	35.83	1,992	37.54	1,636	30.80	46,785	38.95	28,809	29.12
Leather, Stone, Clay & Glass products	9	1.50	247	4.66	146	2.75	3,787	3.15	2,466	2.49
Media & Broadcasting	1	0.17	1	0.02	0	0.00	11	0.01	0	0.00
Metals & Metal Products	37	6.17	89	1.68	357	6.72	1,517	1.26	5,238	5.29
Mining & Extraction	9	1.50	33	0.62	157	2.96	1,263	1.05	6,798	6.87
Miscellaneous Manufacturing	5	0.83	2	0.04	9	0.17	74	0.06	109	0.11
Public Administration, Education, Health Social Services	8	1.33	17	0.32	13	0.24	84	0.07	129	0.13
Retail	3	0.50	39	0.74	15	0,28	765	0.64	350	0.35
Textiles & Clothing Manufacturing	5	0.83	23	0.43	31	0.58	1,552	1.29	1,209	1.22
Transport Manufacturing	51	8.50	1315	24.78	713	13.43	31,402	26.14	13,163	13.31
Transport, Freight & Storage	7	1.17	14	0.26	15	0.28	249	0.21	293	0.30
Travel, Personal & Leisure	2	0.33	0	0.00	4	0.08	0	0.00	33	0.03
Utilities	16	2.67	32	0.60	77	1.45	749	0.62	985	1.00
Waste Management & Treatment	2	0.33	0	0.00	3	0.06	0	0.00	20	0.02
Wholesale	25	4.17	145	2.73	427	8.04	2132	1.77	6,691	6.76
Wood, Furniture & Paper Manufacturing	7	1.17	3	0.06	32	0.60	403	0.34	598	0.60
Total	600	100.00	5,300	100.00	5,298	100.00	120,042	100.00	98,655	100.00

Table A6. Variance Inflation Factors

Variable	Patents (H1a)	Patents (H1b)	Patents (H1c)	Citations (H1a)	Citations (H1b)	Citations (H1c)
ROE change	1.17	1.17	1.16	1.16	1.16	1.16
ln (Firm leverage)	1.03	1.03	1.03	1.03	1.03	1.03
ln (Company age)	1.06	1.06	1.06	1.06	1.06	1.06
ln (Sales)	1.20	1.18	1.16	1.18	1.17	1.14
ln (ROE)	1.17	1.17	1.17	1.17	1.17	1.17
Variable of interest[9]	1.11	1.08	1.07	1.08	1.08	1.05

Table A7. Example average marginal effects of hypotheses including product term

	Patents				Citations			
	(H1d)	(H2a)	(H2b)	(H2c)	(H1d)	(H2a)	(H2b)	(H2c)
ln (Green patents overall)		1.240**				0.255		
		(0.594)				(0.210)		
ln (Green patents filed)	-0.327		0.335		-0.116		-0.006	
	(0.525)		(0.558)		(0.197)		(0.210)	
ln (Green patents acquired)	2.077***			1.825**	0.556**			0.399
	(0.761)			(0.804)	(0.265)			(0.282)
ln (Total patents overall)		-0.748				-0.627		
		(0.594)				(0.542)		
ln (Total patents filed)			-0.602				-0.509	
			(0.540)				(0.527)	
ln (Total patents acquired)				0.258				0.408
				(0.338)				(0.348)
ln (Firm leverage)	0.070	0.038	0.103	0.064	0.086	0.052	0.098	0.074
	(0.343)	(0.353)	(0.345)	(0.345)	(0.343)	(0.353)	(0.346)	(0.345)
ln (Company age)	-10.011**	-10.066**	-9.704**	-9.414**	-9.849**	-9.955**	-9.626**	-9.080**
	(4.475)	(4.624)	(4.347)	(4.497)	(4.452)	(4.584)	(4.353)	(4.451)
ln (Sales)	-0.660	-0.192	-0.369	-0.765	-0.615	-0.183	-0.373	-0.750
	(2.391)	(2.493)	(2.405)	(2.383)	(2.396)	(2.493)	(2.398)	(2.385)
ln (ROE)	-14.202***	-14.115***	-14.243***	-14.176***	-14.240***	-14.161***	-14.253***	-14.202***
	(1.295)	(1.322)	(1.306)	(1.296)	(1.296)	(1.325)	(1.304)	(1.300)

[9] Notice that the variable of interest differs in each model and is as follows. (H1a) ln (Green patents overall), (H1b) ln (Green patents filed), (H1c) ln (Green patents acquired), (H1d) ln (Green patents acquired) * ln (Green patents filed), (H2a) ln (Green patents overall) * ln (Total patents overall), (H2b) ln (Green patents filed) * ln (Total patents filed), (H2c) ln (Green patents acquired) * ln(Total patents acquired), (H3) ln (Green patents acquired) * Top patents filed

Table A8. Descriptive statistics for subset n > 4, without log transformations

Variable	N	Mean	Std. Dev.	Min	Max
ROE change	1789	-0.421	13.527	-133.446	126.342
Green patents overall	1789	1.699	4.869	0	84
Green patents filed	1789	0.753	2.894	0	77
Green patents acquired	1789	0.945	3.051	0	60
Green citations overall	1789	39.189	201.901	0	5,623
Green citations filed	1789	18.974	126.783	0	3,491
Green citations acquired	1789	20.215	133.637	0	4,642
Total patents overall	1789	463.559	1,083.036	0	14,690
Total patents filed	1789	410.885	972.834	0	11,516
Total patents acquired	1789	52.843	267.177	0	7,409
Firm leverage	1789	15.123	13.009	0	82.322
Company age	1789	52.414	34.309	0	166
Sales (x 1,000)	1789	7,338,376	25,031,692	1,792.421	3.731e+08
ROE	1789	17.986	15.388	0.032	201.999
Top 30 filed patents	1789	0.082	0.274	0	1
Top 30 filed citations	1789	0.079	0.270	0	1

Table A9. Chi square test results for median size robustness check

	Patents								
	(H1a)	(H1b)	(H1c)	(H1d)	(H2a)	(H2b)	(H2c)	(H3) Top	(H3) non-Top
> median size	1.310**	0.496	1.957**	0.525	0.109	-0.402	-0.257	1.757	2.676*
	(0.641)	(0.652)	(0.785)	(0.813)	(0.349)	(0.544)	(0.326)	(1.058)	(1.458)
< median size	1.601*	0.079	2.660*	1.171	0.438	0.662	1.603	1.333	2.786*
	(0.967)	(0.834)	(1.378)	(1.757)	(0.653)	(0.801)	(1.095)	(2.137)	(1.454)
Prob > $\chi 2$	0.741	0.814	0.649	0.867	0.132	0.100	0.092	0.052	0.438

	Citations								
	(H1a)	(H1b)	(H1c)	(H1d)	(H2a)	(H2b)	(H2c)	(H3) Top	(H3) non-Top
> median size	0.378	0.153	0.648**	0.047	0.134	-0.033	-0.042	2.422*	1.801*
	(0.234)	(0.242)	(0.648)	(0.101)	(0.114)	(0.163)	(0.144)	(1.424)	(1.045)
< median size	0.173	-0.081	0.407	0.132	0.049	0.227	0.366	2.038	2.070*
	(0.347)	(0.335)	(0.459)	(0.174)	(0.208)	(0.277)	(0.363)	(1.323)	(1.070)
Prob > $\chi 2$	0.612	0.705	0.585	0.644	0.614	0.195	0.594	0.743	0.501

Appendix B – Formulas

B1. Jaro Similarity formula (Sorel, 2022)

The Jaro Similarity sim_j of two given strings s_1 and s_2 is:

$$sim_j = \begin{cases} 0 & if\ m = 0 \\ \frac{1}{3}\left(\frac{m}{|s_1|}\right) + \frac{1}{3}\left(\frac{m}{|s_2|}\right) + \frac{1}{3}\left(\frac{m-t}{m}\right) & otherwise \end{cases}$$

Where:

- $|s_i|$ is the length of the string s_i
- m is the number of matching characters
- t is the number of transpositions

Jaro-Winkler Similarity

$$sim_w = sim_j + \ell p(1 - sim_j)$$

Where:

- sim_j is the Jaro similarity for strings s_1 and s_2
- ℓ is the length of common prefix at the start of the string up to a maximum of 4 characters
- p is a constant scaling factor

B2. Return On Equity

$$ROE = \frac{Profit}{Shareholder\ equity} = \frac{Profit}{Assets} x \frac{Assets}{Shareholder\ equity} = ROA\ x\ Leverage$$