UNIVERSITY OF GOTHENBURG

SCHOOL OF BUSINESS, ECONOMICS AND LAW

Master's degree Project in Innovation and Industrial Management

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The Role of Patents in the Automotive Industry

"A Longitudinal Study of the Automotive Industry"

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Gothenburg June 2023
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Abstract

This thesis explores the relationship between R&D, patents, sustainability, and economic growth. We examine innovation in the automotive industry through a quantitative and longitudinal study between 2000 and 2020. We study current theories regarding innovation, sustainability, and patents.

We arrived at some variables that will be analyzed by regression analysis. The results indicate that R&D intensity positively affects both patents and green patents. On the other hand, we do not see any significant results regarding the relationship between patents and economic growth. The results were discussed, and we ultimately concluded by stating the most important managerial takeaways, these being (1) the Importance of understanding changes in patent trends, (2) Investigating regional differences, and (3) prioritizing sustainable development.

Keywords: Innovation, Patents, Automotive industry, Economic performance, R&D, Sustainability

Acknowledgments

We want to start by thanking our supervisor Daniel Ljungberg for his support and guidance through our thesis. We would also like to thank all the students who participated in our seminars and provided us with valuable feedback. Finally, we are grateful to all the Innovations and Industrial Management program students for their friendship and support during the past two years. Your diverse backgrounds and perspectives have enriched our experience at the university. Thank you!

Johan Berlin

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1 Introduction

This chapter provides background information on the topic at hand. The chapter begins with the background section, which places the research problem within the historical and theoretical context of the study. The problem statement follows, which identifies the specific issue that the thesis aims to address. Next, the purpose section outlines the research objectives and potential contributions to the field. Finally, the chapter ends with the delimitation section.

1.1 Background

The automotive industry has been a driver of innovation for over a century, transforming how we travel and shaping the world. From the first electric car built by Sibrandus Stratingh and Christopher Becker in 1835 to the rise of autonomous driving technology, the industry has seen many key milestones that have revolutionized transportation (Bryson, 2004). Today, the industry is estimated to have a three trillion-dollar revenue, making it one of the world's largest and most significant industries (IBISWorld, 2022).

The impact of the automotive industry goes beyond just jobs and goods to consumers; it also directly impacts countries' gross domestic product (GDP). For example, the automotive industry in the United States represents about 3% of the country's total GDP. Moreover, sales and production now occur globally, with China being the largest market for new car registrations in 2021, followed by the United States, Europe, Japan, India, Brazil, and Russia (Statista, 2022).

One critical factor in the success of the automotive industry has been innovation. From engine technology and safety to connectivity and convenience, the industry has always been characterized by its strong focus on innovation and adaptation of new technologies. In recent years, a significant focus of the automotive industry has been on alternative fuel vehicles, primarily electric vehicles (EVs), fuel efficiency, and sustainable manufacturing processes, such as reducing waste and emissions using renewable energy sources.

As interest in electrification in the automotive industry increases, other technologies, such as autonomous vehicles, have become increasingly popular. All major car manufacturers are investing in developing self-driving vehicles through drive-assist and fully automated vehicles to reduce accidents and enhance the driving experience (The Guardian, 2023). Governmental investment is also taking place in this area, further emphasizing the interest in technology.

Patents play a critical role in the automotive industry, allowing companies to protect their inventions and innovations from being copied by competitors. By securing patents, companies can gain a competitive advantage, as they can control the use of their inventions and charge licensing fees (Grzegorczyk & Głowiński, 2020). Patents also encourage innovation by incentivizing companies to invest in research and development (WIPO, 2023a). By providing the rightsholder a monopoly on the subject of the patent, the actual patent is an important part of the innovation landscape. The importance of patents can be traced back to 1474, when the first known patent was granted to an inventor named Filippo Brunelleschi to design a barge that could transport marble along the Arno River in Venice, Italy (European Patent Office, 2022). This marked the beginning of a new era in intellectual property, paving the way for the patent systems in many countries today.

The relationship between patents and economic performance has been a topic of much interest in recent years. Studies have shown a positive relationship between patents and economic growth, with countries with robust patent systems experiencing higher innovation and economic growth (Encaoua, Guellec, & Martinez, 2006). Additionally, research has shown that patents can in general have a significant impact on firm-level performance, with firms that hold patents being more profitable and having a higher market value than those that do not (Hall, Jaffe & Trajtenberg, 2005).

1.2 Problem Discussion

The automotive industry has long been a driver of innovation (IBISWorld, 2022), and patents play a critical role in protecting and incentivizing the development of new technologies (WIPO, 2023a). However, the industry is changing rapidly with the rise of alternative fuel vehicles and autonomous driving technology (The Guardian, 2023). As a result, it is still to be determined how patents and innovation will impact the industry's future growth and success.

This study explores the relationship between patents, innovation, and economic performance in the automotive industry, focusing on the impact of R&D expenditures and green patents (Encaoua, Guellec, & Martinez, 2006). While previous research has suggested a positive association between patents and economic growth in businesses overall (Hall, Jaffe, & Trajtenberg, 2005; Park, 2008), it is still to be determined whether this relationship holds true in the context of the rapidly changing automotive industry. Additionally, competing interests may be at play, such as the need for companies to protect their intellectual property versus the desire for open innovation and collaboration to accelerate progress.

By examining these issues, this study aims to provide insights that can inform decision-making and strategy development in the automotive industry. However, there are also potential limitations and challenges to consider, such as the difficulty of measuring innovation and the fact that patents are just one factor among many that can influence economic performance (Encaoua, Guellec, & Martinez, 2006). Additionally, the study's findings may be influenced by external factors such as government policies and market trends (IBISWorld, 2022). Overall, the study's findings will contribute to a better understanding of the complex relationship between patents, innovation, and economic performance in the automotive industry.

1.3 Purpose, Research Question, and Assumptions

This master's thesis seeks to improve practitioners, decision-makers, and stakeholders' comprehension of the automotive industry. This will be done by examining innovation in the automotive industry. Innovation in our thesis will include R&D activities, sustainable development, patenting, and its effect on economic growth. We argue that innovation is an important driver of economic growth within the industry. Thus, our definition of innovation is important to understand to make the right decisions. These findings will provide a foundation for future decision-makers within the automotive industry in approaching future innovation problems.

The thesis aims to achieve this by offering information on the competitive dynamics of the automotive sector and the parties involved in decision-making within the automotive industry. Ultimately resulting in the following purpose:

Increasing the knowledge about the relationship between patents, innovation, and economic performance in the automotive industry.

This study aims to answer the research question, "*How does R&D investment influence patent filings, and how does this relationship impact innovation, sustainability and economic growth in the automotive industry*?" To answer this research question, two assumptions have been made. The assumptions are made with a background in the discussion above and will be examined and evaluated. The first assumption is that there is a positive correlation between R&D expenditures and patent registrations. This assumption suggests that companies that invest more in research and development are likely to file more patents, which could lead to increased innovation and economic growth. The second assumption is that the most recently filed patents show a growing trend toward green technologies. This assumption suggests that there has been a shift toward environmentally friendly technologies, which could have implications for the future of the automotive industry. Examining the relationships between the variables under investigation will provide evidence for or against these assumptions, ultimately helping to answer the research question.

1.4 Delimitations

Due to the industry's size, complexity, and time constraints, we have made some limitations in this thesis. Firstly, we have limited the car companies to established manufacturers with a long history of patenting and innovation. We have excluded newly established companies as they have a different history in the patent market. Another reason these newer companies have been excluded is that these companies might need more money to invest in R&D activities. The findings of this thesis will be based on activity between 2000-2020. Therefore, we exclude patents and economic activity that may have occurred before and after these years. This selection has been made to exclude any unusual differentiations because of Covid-19. Further, it is essential to remember that some findings in the thesis may not apply to less mature companies that lack brand recognition and credibility. The study should also be viewed from an automotive perspective, meaning the findings and conclusions may not apply to other industries. The automotive sector is a sector characterized by intense potentiation and technological developments. While we believe that the findings might also apply to other sectors, it is important that certain findings may only apply to the automotive industry.

Furthermore, this study only deals with the US patent market. This was chosen because it is a strategically important market to hold patents on and because many large car manufacturers use it. The companies are founded worldwide but have their home markets in the US, Europe, and East Asia. Therefore, this study is limited to one market, the American market, and not several markets where we refer to the domestic patent office of each manufacturer to avoid legal differences between the markets. A shortcoming of this study is thus that some patents held by the companies are not registered in the US but only in their domestic market. Hence, the patent data presented can be interpreted as somewhat misleading, but generally, it represents the manufacturers' patenting activity. The study aims to identify trends in the automotive industry rather than finding exact numbers. Hence, we believe that this data should be regarded as valid.

2 Theoretical Framework

In this chapter, we will explore the theoretical foundations of our study. Specifically, we will examine the role of innovation in driving economic growth and development, as well as the history and evolution of innovation as a concept. We will also delve into the importance of patents and classification systems in promoting and protecting innovation and explore the concept of open innovation.

2.1 A Brief History of Innovation

In 1942, Joseph Schumpeter offered insights into the modern understanding of innovation in business through his seminal work, Capitalism, Socialism, and Democracy. Schumpeter (1942) proposed the idea of creative destruction, wherein new and innovative advancements result in the displacement of established technologies and industries. He suggested that the principal driving force behind economic growth could be attributed to the efforts of entrepreneurs and the creation of innovative ideas. According to Schumpeter (1942), entrepreneurs play a vital role in shaping the economy by utilizing resources and labor to bring new business ideas and products. He also argued for government support for innovation by providing economic incentives and establishing strong property protection rights to create a secure environment for entrepreneurs and innovators to flourish.

The ideas of Schumpeter could be considered radical for the time, but one could identify some early suggestions for the modern innovation landscape. The idea of creative destruction is commonplace for pretensions, and government-funded innovation systems can be found in most modern economies. Crafts and Mills (2017) studied economic development in Britain after the industrial revolution and found a clear indication that the innovation of the late 18th and early 19th century was a driver not only for the increase in GDP during that period but also laid the foundation for the current economic situation not only in Britain but also the global economy. Concluding that innovation has been and still is a driver for the global economy (Crafts & Mills, 2017)

2.2 Innovation

Innovation has become increasingly prevalent and is an integrated part of the business landscape (Khan, 2018). Both Goffin and Mitchell (2017) and Jaumotte and Pain (2005) explain innovation as the successful development and application of new knowledge.

However, as the term gets more and more attention from practitioners, policymakers, and other stakeholders, its meaning has become diffused. Khan (2018) argues that certain misconceptions about innovation in business make the term challenging to grasp. An initial argument is that innovation solely refers to the radical part of innovation. This is something that Khan (2018) argues undermines the importance of the word innovation, it is not done in a quick and dramatic sense, but rather in a calculated and continuous motion.

Innovation can take many forms, including product, process, market, and organizational innovation. Like Khan's (2018) explanation of innovation as a continuous process, Goffin and Mitchell (2017) emphasize the need for companies to approach innovation in a systematic and integrated way rather than a one-off event. They argue that innovation must be managed and requires a clear understanding of a company's objectives further to develop a strategy in line with these objectives and implement that strategy in the organization. Innovation plays a crucial role in the success and sustainability of businesses (Chesbrough, 2003). According to Chesbrough (2003), innovation allows firms to differentiate themselves, stay ahead of competitors, and remain relevant in a constantly changing market. The role of innovation in business has been explored by various authors, including Chesbrough (2003) and Goffin and Mitchell (2017). Goffin and Mitchell (2017) elaborate on the importance of innovation, stating that it helps businesses to create new products and services, improve efficiency and productivity, and drive growth and revenue.

2.3 Innovation as an Economic Driver

Innovation is widely regarded as a key driver of economic growth, as it enhances competitiveness by fostering the development of new services, methods, models, and products. Rosenberg (2004) argues that while economic growth can be achieved through increased inputs, such as capital or labor, it is more likely to be driven by finding new and more efficient ways of utilizing the same inputs. Nobel Prize in Economics laureate Robert Solow (1987) argues that only 15% of economic growth is generated by an increase in inputs, with the remaining 85% derived from other sources, likely to be innovation. Given the uncertain nature of this 85% growth, there has been increased interest in the study and promotion of innovation, as opposed to traditional business exploitation. Maradana et al. (2017) echo the notion that technological progress drives economic growth. However, the extent and magnitude of this impact remain to be further studied.

A factor that needs to be considered is the reciprocal relationship between innovation and economic growth, meaning that each of the factors affects the other, creating new methods and products will result in economic growth, the same way that increased capital in organizations opens the possibility of investments in innovative ideas (Maradana et al., 2017). The study by Maradana et al. (2017) provides evidence for both scenarios. In some cases, they can identify an increase in innovativeness as the GDP increases in countries. It indicates that there is a positive relationship between economic growth and innovation. However, some countries in the study seem to be hindered by a lack of innovation, but as the country's innovation spending increases, so does the GDP. The dynamic relationship between them is both complex and important regarding growth.

Hasan and Tucci (2008) also conclude that innovation positively affects economic growth. They further elaborate on the previously mentioned studies and point out that successful and unsuccessful innovation drives growth. They argue that even if a particular investment does not result in the initial desired results, such as a new product, it will increase the collective knowledge in a particular field and thus spur new ideas for further innovation. These innovation spillovers are more challenging to translate into economic growth than successful innovation. Hasan and Tucci (2008) argue that the risk of failure should not be a deterrent for organizations but rather a reminder of the importance of having internal systems for collecting the mentioned spillover.

However, the term innovation is a concept that has been introduced previously in terms of business, but with the rise of new technological advancements from late 1990, the term has gained increased attention from practitioners and stakeholders (Manyika & Roxburgh, 2011). The roll-out and adaptation of innovations such as the internet, automation, and Artificial Intelligence (AI) have increased the rate of innovation over the last decades and made new business areas possible. Manyika and Roxburgh (2011) argue that pre-internet age innovation was essential for economic growth. However, the information-sharing systems made possible by the internet have drastically increased the innovation rate and thus increased economic growth.

2.4 Patents

Before patents existed, individuals were given exclusive rights to their innovations and discoveries. The Republic of Venice established the first known patent system in the 14th century (European Patent Office, 2022). The first U.S. patent was granted to Samuel Hopkins in 1790 for making potash (United States Patent and Trademark Office, USPTO, 2022). Fast forward, the patent system has evolved significantly with specialized patent offices with extensive laws and regulations governing the patent process (USPTO, 2022). Patents play a significant role in innovation, they give the inventors the exclusive right to make, sell, use, and import their inventions for a limited time in exchange for publicly disclosing the details of their innovations (Harding, 2016). This means that others can learn and build upon the innovations. In addition, it encourages innovation and technological advancement by incentivizing inventors to share their ideas and creations. To be granted a patent, the inventor must show that the invention is novel, practical, and non-obvious (Goffin & Mitchell, 2017).

USPTO (2023) recognizes three types of patents that companies can leverage in their patenting strategy. First, utility Patents are meant for new and practical inventions such as machines, processes, products, and certain substances. On the other hand, design patents cover original and visually appealing designs or shapes of an object. Lastly, Plant Patents cover new and unique varieties of plants that have been propagated without seeds. To be granted a patent, it is important to note that each type has specific requirements and criteria that must be met according to the USPTO (2023).

Phelps (2015) argues in favor of patenting and claims it is an important driver of innovation. In addition, Phelps (2015) points to the importance of economic security for inventors. The patenting systems provide such safety for inventors, and Phelps (2015) argues that a rigid patent system fosters and promotes innovation and R&D spending.

2.4.1 Patent Strategy

A patent strategy refers to companies' methods to leverage and protect their intellectual property rights. Since a company's intellectual property can and should be used as a competitive tool, companies must develop and strategize how to use these patents. (Grzegorczyk & Głowiński, 2020)

The impact of strategic patenting on firms' patent portfolios has been examined in previous research such as Blind et al. (2008). This study found that firms' strategic decisions regarding the allocation of patent applications across different technological areas and the number of patents filed in each area significantly shape the structure of their patent portfolios. The size and diversity of the patent portfolio, the degree of technological diversification of the business, and the level of competition in the industry influence firms' strategic patenting decisions.

Additionally, Blind et al. (2008) found that defensive patenting, which aims to protect a firm's technological base and markets, received more citations than blocking and exchange motives. However, companies using patents to block offensive competitors receive more opposition to their portfolios, while those using patents for defensive purposes have no significant relationship with opposition indicators. This research provides insights into how firms can strategically manage their patent portfolios to achieve innovation goals. It also emphasizes the importance of patent portfolio characteristics in innovation management and policy issues related to strategic patenting.

The defensive patenting strategy protects a company's assets, including technology or methods, from potential infringement by competitors. According to Rice (2015), the defensive patenting strategy is characterized by a more conservative approach than its counterpart, the offensive patenting strategy. The primary purpose of this strategy is to secure a company's patents for their use and to reduce the risk of being sued by competitors. Grzegorczyk and Głowiński (2020) assert that the defensive patenting strategy is especially useful in industries characterized by high levels of innovation, such as the pharmaceutical and technology sectors. Additionally, the defensive patenting strategy can also be extended to the context of acquisitions, where companies aim to fortify their position in a potential merger through a well-developed patent portfolio. (Rice, 2015).

On the other hand, the offensive patent strategy refers to a proactive approach toward competition in intellectual property. (Grzegorczyk & Głowiński 2020). This strategy aims to disrupt competitors' innovation process by acquiring exclusive rights to an invention and using it to engage them in legal disputes. In some cases, the acquired patent may even shut down a competitor's process completely. Therefore, the offensive patent strategy can be seen as a form of attack on competitors in the intellectual property arena and is aimed at giving an advantage over the competition (Grzegorczyk & Głowiński, 2020).

2.4.2 Technical Classification of Patents

In the ocean of patents, a system was created in 1971 called the Strasbourg Agreement (WIPO, 2023a) for individuals and companies to navigate through different types of patents. In this system, patents are categorized and organized following different sections and groups, forming a so-called International Patent Classification (IPC) code. The system follows a hierarchical order with language-neutral symbols depending on what technical area they apply to (Adams, 2001). The main categorization of this system is section, class, subclass, and group, see Figure 1 for a more detailed structure.

Section	Explanation
A	Human Necessities
B	Performing Operations, Transporting
C	Chemistry, Metallurgy
D	Textiles, Paper
E	Fixed Constructions
F	Mechanical Engineering, Lightning, Heating, Weapons
G	Physics
H	Electricity

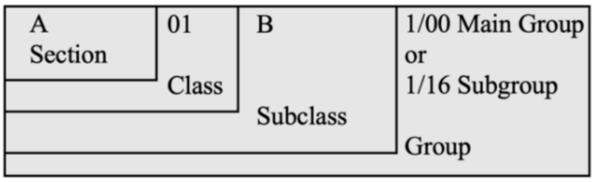


Figure 1: IPC Code Explanation, WIPO (2023b)

Feng et al. (2020) explored potential technological convergence relationships in their study of electric vehicles. Technological convergence is a term for the merging and overlapping of technologies. For example, intelligent vehicles that combine mechanical and communication technology. They found good relationships between patents and, more specifically, IPC codes. They found eight patent codes with strong relationships, see Figure 2. Feng et al. (2020) found that the first five relationships had an evident increase in convergence from 2015-2017. Thus, they further explored these relationships in their study. These five convergence relations cover four subdomains of battery, motor, power electronics, and charging, which are treated as the core technology subdomains in EV innovation, according to Rajashekara (2013) and Un-Noor et al. (2017). For example, B60K-B60L indicates the convergence of "dashboards or the mounting of one or more propulsion units and related devices" and "the propulsion, operation monitoring or electric safety in electric Vehicles". The relationship between these two IPC codes has recently drawn greater attention from inventors.

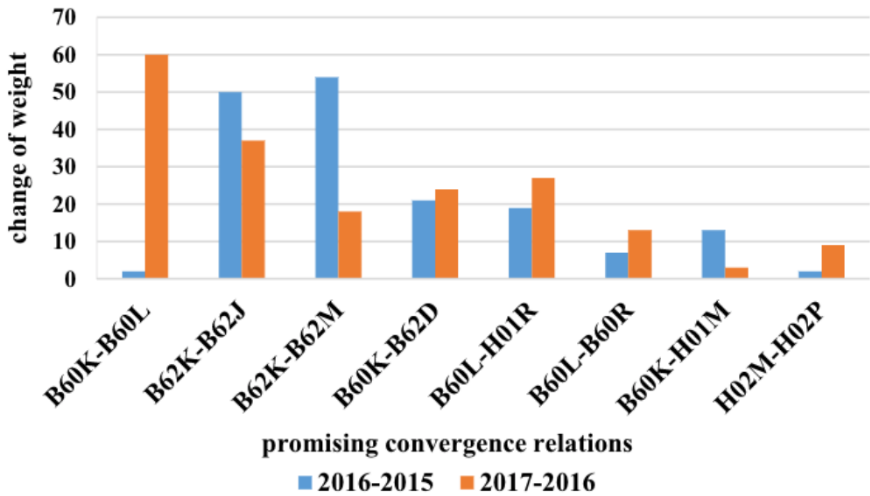


Figure 2: Patents with strong relationship, Feng et al. (2020)

2.4.3 Sustainable Classification

In a recent empirical study conducted by Agnelli, Costa, and Dussaux (2023), it was found that firms that had invested more in clean and grey technologies (see Appendix A for the definition of green, grey, and dirty technologies) in the past benefited from an increase in fuel prices, as it boosted their market share, while firms that had focused on dirty technologies suffered a decline in market share. Aghion et al. (2017) similarly argue that transitioning to a low-carbon economy relies on innovation. The economic benefits of investing in green innovation and the resulting incentives for firms to innovate need to be better understood. In their study, Aghion et al. (2017) empirically evaluate the relationship between environmental policies and innovation, finding that environmental regulations can spur innovation in green technologies. However, they also note that the design of such policies is crucial for maximizing their effectiveness, as poorly designed policies may hinder innovation.

Returning to the study by Agnelli, Costa, and Dussaux (2023), the authors collected data on passenger car market shares and patents for the major car manufacturers across eight countries from 2005-2021. They investigated the effects of different types of innovation. They followed Aghion et al. (2016) definition of technologies as clean, grey, and dirty and various time lags (0 to 20 years) between innovation and economic returns. They found that an increase in fuel prices boosts the market share of firms that have invested more in clean and grey technologies in the past while harming the market share of firms that have focused more on dirty technologies. This suggests that consumers respond to fuel price increases by opting for fuel-efficient or electric/hybrid vehicles. Furthermore, the positive and negative effects on firms' economic performance occur over different time horizons depending on the type of technology, with grey innovation providing twice the economic benefit of clean technology under increasing fuel prices. Agnelli, Costa, and Dussaux (2023) conclude that these differences are likely due to the lengthy process between innovation and commercialization, the varying factors determining purchase decisions, and the salience of information regarding consumer fuel prices.

The study by Agnelli, Costa, and Dussaux (2023) also highlights the significant role of public policies in promoting green innovation. Fuel taxes explain 75% to 81% of the estimated effect of fuel prices on market share for various levels of past green innovation. This finding is consistent with the results of Aghion et al. (2017), who emphasize the importance of well-designed environmental policies in promoting innovation. Governments are advised to maintain strong price signals over time to encourage firms to innovate in cleaner technologies, as it takes several years for them to reap the benefits of such investments. Additionally, governments should incorporate the positive effect of fuel price salience on adopting cleaner cars and green innovation when communicating policies affecting fuel prices and provide information on well-targeted bonus-malus systems that help credit-constrained households purchase cleaner cars.

2.5 Patents, R&D Expenditures, and Economic Performance

We have explored and concluded that innovation positively affects a firm's economic performance. However, a further deep dive into the Research and development expenditures can further help explain the concept. Das (2020) argues that the basis for economic growth is creating knowledge from R&D activities. It results in new goods and services that serve as further innovation intermediaries. Furthermore, these innovations must be protected to ensure an economic benefit for the company, hence the need for patenting. Patented products serve to maximize economic growth and create capital for more R&D investments, thus, the relationship between patents, R&D and economic growth – in theory, can be in a perpetual state of growth. Therefore, practitioners and firms must understand this relationship to stay competitive in their respective markets.

It is not very smart to claim that it is as simple as patenting always has a net positive effect on a firm's performance, meaning that the more a firm invest in R&D activities, the better their economic performance will be (Das, 2020). Altuzarra (2019) describes the bilateral relationship through the fact that patenting only sometimes translates into economic growth, as these patents are both time and resource-intensive activities. However, on the other hand, there is a need for legal protection as an incentive for innovators to ensure they have some economic security (Das, 2020). Therefore, it is argued that the number of patents filed does not reflect a firm's economic performance. The important factor is not the number of patents but rather the quality (Das, 2020).

Kim (2018) further elaborates on the relationship between economic output and R&D activities. The author argues that there are limitations when investing in R&D and companies cannot expect an infinite return on their investment. Kim (2018) argues that the output of R&D activities behaves like a u-shaped u curve. Initial R&D activities result in a relatively high return, while the later ones decrease and finally generate a negative result. On the other hand, Madsen (2007) presents in his report that this relationship is not necessarily true. Madsen

(2007) argues that this u-curve relationship only applies to certain countries and periods. However, Faff et al. (2013) argue that the diminishing returns linked to R&D activities are instead linked to the management's view of innovation. In other words, this u-curve can be avoided by developing a rigid innovation system within the firm that has a holistic and well-thought-out innovation process.

3 Methodology

In this chapter, we will discuss how we conducted our study. We will describe our research approach and design and further explain our variables for regression. We will also justify the choice of variables and the limitations of our study.

3.1 Research Strategy

We have chosen to employ a quantitative research strategy in this study, which involves collecting and analyzing numerical data using statistical methods (Bryman & Bell, 2011). This approach is particularly suitable for testing hypotheses and, in our case assumptions. To identify patterns and relationships in the data and make objective conclusions based on the analysis (Creswell, 2009).

Our decision to use a quantitative approach is based on several reasons, including the fact that we are interested in analyzing the actual relationship between patenting activity and economic outcomes in the automotive industry rather than relying on the subjective views of experts. While a qualitative study could have been conducted by interviewing experts, a quantitative study allows us to examine numerical data such as the number of patents filed, the revenue generated by companies, and the number of employees, providing a more objective view of the relationship between these variables. Additionally, we collected our data from secondary sources such as the USPTO and annual reports, which provide reliable and valid data for quantitative analysis. Our decision to use a quantitative approach is driven by the need to obtain reliable and objective insights into the relationship between patenting activity and economic outcomes in the automotive industry.

Moreover, regression analysis and other statistical techniques, such as descriptive statistics, are beneficial, suitable, and necessary for our research. By employing these methods, we can identify and measure the strength and direction of the relationship between patenting activity and economic outcomes in the automotive industry and control for potential confounding variables that may affect the results.

Regression analysis is a statistical method that measures the relationship between two or more variables and helps identify and quantify the factors influencing the outcome variable. This analysis enables us to determine the extent to which changes in one variable are associated with changes in another. For example, regression analysis allows us to identify the factors contributing to the relationship between patents and economic growth.

We will also use Microsoft Excel to visually represent the relationship between patents and economic growth over the studied years. By creating line graphs and bar charts, we can observe any trends and patterns in the data and better understand the nature of the relationship between the variables. These graphs will complement the regression analysis and provide additional insight into the relationship between patents and economic growth.

For this thesis, we have chosen the deductive research method, which involves testing a theory or hypothesis through data collection and observation. This approach starts with a specific theory or hypothesis and uses it to make observations and draw broader conclusions. Deductive research differs from inductive research, which involves gathering and examining observations or data to establish a theory or explanation (Bryman & Bell, 2015). The research started with a thorough review of existing literature and relevant theories on the research topic. The main data source was secondary data from the USPTO database. The data were collected through a systematic search of patents and patent applications.

3.2 Research Design

We chose a longitudinal research design for this study, which allows for the collection and analysis of data over a period (Bryman & Bell, 2007; Salkind, 2013). We collected patent data and economic performance data from companies in the automotive industry from 2000 to 2020. This design is suitable for examining changes in patenting activity and economic outcomes over time, which will enhance our understanding of how to promote innovation and economic growth through the patent system (Collings & Coward, 2014).

3.3 Data Collection

The data collected for this research consists of secondary data from the publicly available database USPTO. Using secondary data has several advantages for this research. First, it allows for a longitudinal analysis of 20 years, enabling us to analyze trends and changes over time while reducing the potential risk for biased data collection, as the data has already been collected. Additionally, using secondary data saves time and resources, enabling us to focus on analyzing the data (Bryman & Bell, 2011). However, using only secondary data in qualitative research may limit the depth and richness of the data and hinder the researcher's ability to verify

the accuracy and completeness of the data, as pointed out by Bryman and Bell (2011). More about disadvantages and limitations are explained in XXX.
OEMs play a crucial role in the automotive industry as they are responsible for designing and manufacturing key components of vehicles. They are also major employers and contributors to the economy. We aim to provide valuable insights into their innovation strategies and competitiveness by studying their patent activity and performance. Our focus on only OEMs allows us to make meaningful comparisons between similar types of manufacturers over the selected period of 2000-2020. This approach provides a more focused and comprehensive analysis of the automotive industry. It allows us to identify trends and patterns in patent activity and economic performance unique to OEMs.

The study focuses on major car manufacturers with a long-standing history of producing classic gasoline-powered cars. Specifically, we included BMW, Ford, GM, Honda, Nissan, Toyota, and Volkswagen, which are considered significant players in the global automotive industry. These companies were selected based on their stable organizational structure over the studied period, which enabled us to make meaningful comparisons of R&D expenditures, gross profits, and patent data over time. To maintain consistency in our analysis, we excluded manufacturers such as Tesla, which exclusively produces electric vehicles and has a relatively short history in the industry. We also excluded Daimler-Mercedes due to their complex organizational structure over time, which makes it difficult to compare data, particularly regarding patent filings. Finally, other OEMs such as Hyundai and Renault were excluded from the study due to a lack of available data or a low number of filed patents in the US market.

We used the USPTO database to collect the patent data and searched for patents filed by companies in our sample. However, as many companies have multiple registered names and variations in their name spelling, we needed to carefully sort and select a few name variations for each company to ensure a comprehensive search. We selected the companies based on the industry’s most used and recognizable names. This ensured that the data we collected accurately represented each company's patent portfolio.

3.3.1 Dependent Variables

The dependent variable for this regression will be the number of patents applied for by a firm in a specific year. We want to examine the relationship between R&D intensity and patenting to identify trends and draw conclusions about the importance of patents in the manufacturer's business. We argue that patents can be a measurement of innovation. However, we realize that all patents do not result in “innovation” in our sense, so the term innovation should be considered somewhat loose for this thesis. For the first regression, we will look at all patents equally, not making any differences based on the Patent code. In our second regression, however, we will divide the patents based on their sustainability, see Table 1.

Table 1: Second Regression Classification

Regression	Patents
1	All patents
2	Patents classified as “green patents”

These dependent variables were chosen to measure the firm’s innovation level. We explored the possibility of making a quota for the patents, trying out a variable as Patent intensity, where the number of patents for a certain year was divided by the firm size. However, this method was ultimately disregarded as we instead accounted for firm size as a control variable. We ended up with total patents as the dependent variable as we did not want too many quotas in our regression, this would result in the outcome of the regression being too hard to interpret, as all variables would be affected by each other, ultimately resulting in too much fluctuation for any accurate analysis to be made.

Importantly for our report, the patent data we have used is delayed by two years. This means that the number of patents applied for includes those applied for two years later. If we examine the year 2002, these patents are compared with the financial and enterprise data from two years earlier, i.e., the year 2000. This is done because innovation projects rarely occur during a business year. Some take less time, some take longer because we have decided that two years gives the most accurate picture. We have looked for similar studies to take inspiration from them without success. Therefore, we decided that two years was a reasonable measure for our study.

3.3.2 Independent Variables

The primary secondary variable we will look at is what we call research intensity. We developed this measure by dividing a manufacturer's R&D expenses (millions of USD) by the number of employees (thousands) for a given year. This gives an idea of how much is invested in research and development per employee and can be a useful measurement for evaluating a company's research and development performance and efficiency. This was done to standardize the R&D expenses with the manufacturer's size to give a fairer picture between the companies. Another way is to divide by sales volume, which does not consider the size of the company or the number of R&D employees, which could result in less accurate results. Thus, the method of employees was ultimately chosen.

3.3.3 Control Variables

Region

The first control variable or covariate in the regression is used to capture the differences and the effect on where the manufacturer is based. We expect some regional differences between the firms, so this variable will help us further explore these differences and identify regional trends. We have divided our dataset into three categories, Asia and EU, with the third region US as the reference region, see Table 2. US was selected as the reference and we derive our patent data from the USPTO.

Table 2: Manufacturers Divided into Regions

Manufacturer	Region
BMW	EU (1)
Ford	US (0)
GM	US (0)
Honda	Asia (2)
Nissan	Asia (2)
Toyota	Asia (2)
Volkswagen	EU (1)

Employees

The second covariate is employees, i.e., the company's total employees. We recognize that a larger company, in terms of employees, has more manpower to dedicate to innovation and patenting. In a regression analysis, it is important to include firm size as a covariate to account for its potential influence on the dependent variable (in this case, patent output). Company size can impact a company's R&D capacity. Larger companies may have more resources to invest in R&D, and therefore, may have more patents than smaller companies. Hence, we will include this variable to see if the relationship between patents and innovation is related to company size.

EBIT

Our analyses will use the control variable EBIT (earnings before interest and taxes) to control economic performance. EBIT measures a manufacturer's profitability, which is probably correlated with R&D spending and patent production. Therefore, the effect of profitability on the link between R&D spending and patent output can be considered by using EBIT as a control variable. Furthermore, we assume that a higher EBIT will result in more capital being made accessible and available for investments in R&D activities, thus making it an interesting control variable to consider.

Period

The last variable we have chosen to control is the time aspect. We want to control the fact that firms seek more patents over time, an assumption we were able to establish during the data collection. Therefore, we have divided the years into four periods. We recognize that the variation between two years is insignificant, so to keep the variables down, the following grouping was made, see Table 3.

Table 3: Years divided into four periods

Period	Years
0	2000-2005
1	2006-2010
2	2011-2015
3	2016-2020

This variable is interesting in both regressions, especially in our second regression linked to sustainable patents. Where we can test whether green patents have become more popular in connection with the technological shift in the automotive industry.

3.4 Data Analysis

We used a systematic approach to examine the numerical data collected for our quantitative research, aiming to identify patterns and relationships between variables. As emphasized by Bryman and Bell (2011), this process involved reducing the collected data to a manageable form and identifying patterns within it. To achieve this, we used statistical analysis techniques, specifically regression analysis, in the software Stata. Regression analysis helped us quantify the relationships between patent data and economic performance key figures, which was crucial in our confirmatory approach to testing our exploratory assumptions. While Yin (2014) stresses the importance of a priori analysis plans, our study was exploratory, making it more difficult to define specific assumptions upfront. Nonetheless, we ensured that the data was collected in an amenable way to the chosen analysis techniques and reduced the risk of data analysis errors.

Our rigorous and structured approach to data analysis using Stata and regression analysis helped ensure the validity and reliability of our findings.

In addition to the regression analysis, we also utilized Excel to analyze trends in IPC codes. Initially, we selected the ten most frequently filed patent groups between 2000 and 2020, which we sorted down to subclass. This was sufficient as it allowed us to focus our analysis on the most relevant patent groups for the automotive industry during this period. We then assessed which of these patent groups were classified as green, grey, or dirty based on Agnelli, Costa, and Dussaux's (2023) classification. This enabled us to distinguish between environmentally friendly technologies and those with a negative environmental impact. To further explore the relationship between patenting activity and green technologies, we compared the number of green and dirty patents filed between 2000 and 2020. This provided insight into the level of investment in environmentally friendly technologies versus those with a potentially negative environmental impact. We then examined the distribution of green patents by company and employment history at these companies. By analyzing green patents per employer, we could identify which companies were the most active in developing environmentally friendly technologies. Finally, after conducting these preliminary analyses, we conducted the regression analysis to test our assumption regarding the positive trend toward green technologies.

3.4.1 Regression Analysis

Regression analysis is a statistical technique used to examine the relationship between two or more variables. Our study used regression analysis to investigate the relationship between patent filings and economic performance. Specifically, we used multiple regression analysis, which allows us to analyze the relationship between several independent variables and one dependent variable. We used Stata software, a statistical program commonly used in quantitative research to perform the regression analysis. We put our collected data into Stata and ran the Ordinary Least Squares (OLS) regression analysis. The OLS regression model estimates the relationship between a dependent variable and one or more independent variables by minimizing the sum of squared residuals. The analysis output provides information on the strength and direction of the relationships between the variables and statistical significance levels.

We also included control variables in our analysis to account for other factors that could affect the relationship between patent filings and economic performance. These control variables include Region, Employees, EBIT and Period. We can better isolate the relationship between patent filings and economic performance by controlling these variables. Like Bryman & Bell (2011) and Yin (2014) suggest, regression analysis is an important technique in quantitative research that helps us understand the relationships between variables and make informed predictions. With the use of Stata software and OLS regression, we conducted a rigorous analysis that considers the complexities of the data and provides reliable results.

3.5 Limitations

One of the limitations of our study is the potential for incomplete and inaccurate data. Specifically, we encountered issues with companies filing patents under different names, which led us to exclude some patents from our analysis. Additionally, some of the data we collected did not include IPC codes, which we had to delete from the dataset. These limitations may have impacted on the accuracy and completeness of our findings. Furthermore, our sample size was limited to seven car manufacturers and a 20-year period, which is a limitation. However, this sample size is sufficient for our objectives, especially when considering our study's specific context and focus. Another potential limitation is the assumptions made during the regression analysis, as suggested by Bryan and Bell (2011). While we tried to ensure the assumptions of normality, linearity, and homoscedasticity were met, there may be other factors that should have been accounted for in our analysis. This may have impacted on the reliability of our results. Finally, as Yin (2014) suggests, the generalizability of our findings may be limited due to the specific context of our study. Our results may not be applicable to other industries or geographic regions, and other factors not accounted for in our study may significantly impact the relationship between patent filings and economic performance.

4 Results

This chapter will present the results of our study, which aims to examine the two assumptions. The first assumption will explore the relationship between the number of patents and economic performance, while the second assumption will investigate the trends in IPC codes. We will utilize quantitative methods and data analysis to explore these assumptions and examine the extent to which these are supported.

4.1 R&D and Patents

The purpose of this study is to increase the knowledge about the relationship between patents, R&D intensity, and economic performance in the automotive industry. Therefore, the first assumption that will be examined is if there is a positive association between R&D intensity and patent registrations.

4.2 Descriptive Statistics

To conduct the regression, we first need to understand and analyze the data used for the regression. The dependent variable in the regression will be the amount patents filed for by the different manufacturers. To further illustrate the relationship between the manufacturers, we have presented the data in the table above as a graph, see Figure 3.

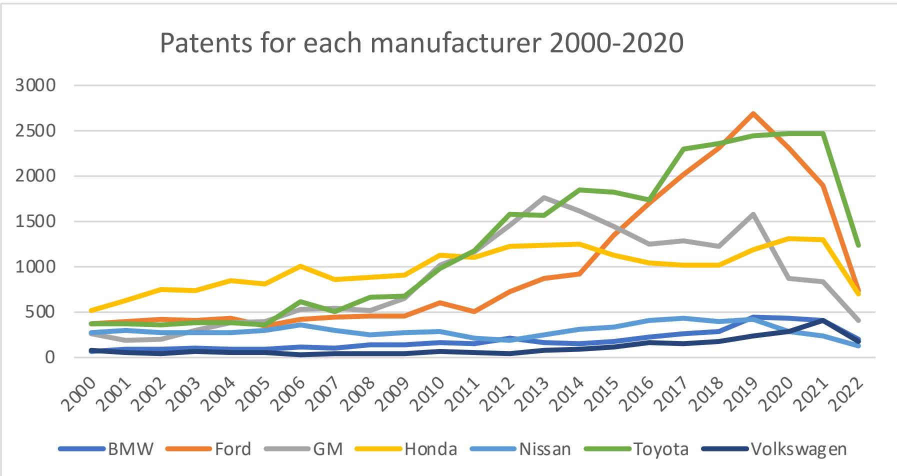


Figure 3: Patents applied for each manufacturer 2000-2020

We notice that the manufacturers were relatively close and grew in unison until the year 2010, while we see that some manufacturers grow faster than others. BMW, Nissan, and Volkswagen have had relatively slow growth compared to the others. Ford and Toyota have had the most filed patents over the period, indicating that these manufacturers have heavily invested in patenting and R&D. However, this has been decreasing since 2019, a trend that's true for most manufacturers. Ford has the largest variation, with a standard deviation of 1555, this is most likely due to the rise between 2014-2019 and the fall between 2019-2022. This thesis will not further investigate this, but our theory is that it is correlated with the Covid-19 virus that began in 2019.

To prepare for the regression, we can further look at the main independent variable of R&D intensity. This quota has been made by dividing the R&D expenses for the year by the total employees of the firm. This has been done to normalize the firms and make them more comparable to each other, see Figure 4.

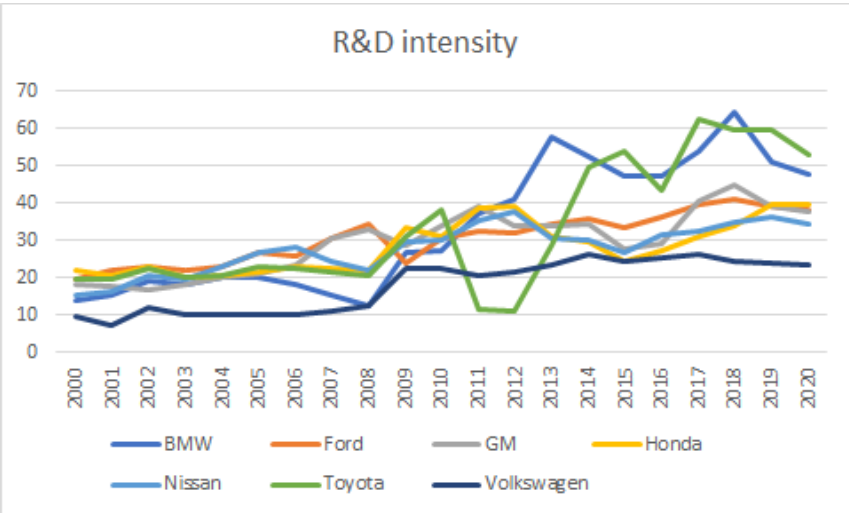


Figure 4: R&D Intensity 2000-2020

We notice some fluctuations for all manufacturers of the period, indicating that R&D is not a stable variable. However, after the financial crisis of 2008, most manufacturers see a strong increase in R&D intensity. It´s important to remember that this variable is affected by both R&D expenses and number of employees. Still, we argue that with the size of these firms, the major differences between the manufacturers can be derived primarily from differences in R&D expenses. BMW and Toyota have been among the highest in R&D intensity, while Volkswagen has been among the lowest. Overall, we can notice a slight increase in R&D intensity over the period, but this varies in the degree of the different manufacturers. A point of interest is the decline for all manufacturers since 2019, which as mentioned earlier may be a consequence of the disruptions caused by the COVID-19 pandemic. Before the regression, we present a summary of the descriptive statistics for the variables in the regression to come, see Table 5.

Table 4: Summary of Descriptive Variables

Variable	Obs	Mean	Std, dev,	Min	Max
Patents	147	1230,8	1386,4	26	6336
Green Patents	147	172,3	261,6	0	1251
R&D Intensity	147	28,8	11,8	7,1	64,6
Employees	147	243,4	129,2	96	671
EBIT	147	5142,4	7580,5	-38732	21961

We can see that the variables patents and green patents have a very large spread, with a standard deviation of 1386 and 262, respectively. An interesting detail is that we have a 0 value as the minimum value for green patents, which means that during 2000-2020, at least one company applied for zero "green" patents. Comparing this with the maximum value of 1251, we believe that interest in green patents has increased over time.

R&D intensity, on the other hand, has a slight variation between observations. If we look back to Figure 4 (R&D intensity 2000-2020), we can see this visually, the companies have had a positive trend, but compared to the patents, these have grown at a more even rate across all manufacturers. Employees are a relatively stable variable but are affected by extremes. In our case, Volkswagen has significantly more employees than the others, which contributes to the standard deviation. We also see great variation in the EBIT variable. This variable is strongly affected by externalities to the companies in a clear way. The large negative results reflect General Motors, which had great difficulties with the financial crash around 2008. Finally, we present a correlation matrix in Table 6 to give the reader a better understanding of how the variables are associated with each other.

Table 5: Correlation Matrix

	Year	Patents	Green patents	R&D Intensity	Employees	EBIT
Year	1					
Patents	0,5376	1				
Green patents	0,5638	0,8753	1			
R&D Intensity	0,7079	0,5594	0,5994	1		
Employees	0,0941	-0,0090	0,0508	-0,1868	1	
Ebit	0,3202	0,3145	0,3400	0,2516	0,2466	1

We notice that most of the variables are positively correlated. Most prevalent is the relationship between R&D intensity and year, as well as Patents and Green patents. This gives us an indication that R&D has been increasing over the years, which would be expected in an industry such as the automotive. In addition, the relationship between Patents and green patents was also expected as the "green" patents are included in the broader variable of patents. Since we have a high correlation between our variables, we need to consider that when we interpret the regression results. A high degree of correlation can create more unreliable coefficients in the regression. Hence, we shouldn't focus too much on the exact values of the regression but rather on the overarching trends we can notice from the results.

4.3 Regression 1

We will conduct a linear regression analysis to address the first assumption and investigate the potential positive correlation between the number of patent applications and R&D expenditures. We will use region, number of employees, EBIT, and year as covariates to control the regression. This linear regression will be a foundation for the first of our two assumptions, see Table 6.

Table 6: Linnear Regression of Patents

Variables	**Patents (1)**
R&D Intensity	26.66***
EBIT	0.0415***
Employees	0.473
Period	
1. 2006-2010	290.2
2. 2011-2015	695.8***
3. 2016-2020	1.118***
Region	
1. Region EU	-1.634***
2. Region Asia	-460.4**
Constant	299.0
Observations	147
R-squared	0.575
*** p<0.01, ** p<0.05, * p<0.1	

Firstly, we can analyze the R-squared value in the output (Regression analysis of the automotive industry) presented above. A value of 0,575 indicated that about 58% of the variance in the number of patents filed could be attributed to the different independent variables presented. However, this result indicates that about 42% must be attributed to other factors, concluding that our regression can't fully explain the whole picture. The coefficient for R&D intensity is 26,66, with a p-value of 0, which indicates statistical significance, meaning that a 1 unit increase in R&D intensity results in an increase in patents by 26. Since R&D intensity is a quota of R&D expenses and employees, it can be challenging to translate this into real terms. Still, it can be interpreted as for every increase of 1 million USD per 1000 employees, the firm will get 26 more patents. Further, we can see that the control variable "Employees" has a positive coefficient of 0.473. Still, a non-significant p-value indicates a weak correlation between the variables, meaning that firm size can be considered trivial for patent registration. On the other hand, we can see that the economic performance covariate of "EBIT" has a significant positive impact. The coefficient indicates an increase in EBIT of 0.0415 million USD results in an increase in patents, which interferes as the better economic performance, the more patents that are being filed for. This could result from more capital being freed up for R&D activities. Lastly, we can see that period, or our time variable, has influenced patenting. The coefficient increases in line with the periods. As the periods are divided chronologically from 2000 to 2020, we can conclude that the number of patents has increased since the turn of the millennium. This gets further emphasized considering the low p-values in periods 2 and 3.

Table 7: Region Effect on R&D Intensity

Variables	Patents (1)
R&D Intensity	118.5***
1. Region EU	1.889***
2. Region Asia	1.157*
Region effect on R&D Intensity	
1. Region EU	-120.8***
2. Region Asia	-53.08**
EBIT	0.0411***
Employees	0.436
Period	
1. 2006-2010	-4.619
2. 2011-2015	351.3
3. 2016-2020	519.9*
Constant	-2.165***
Observations	147
R-squared	0.692
*** p<0.01, ** p<0.05, * p<0.1	

To further analyze the regression, we have conducted an additional regression (see Table 7 above) examining the relationship between region and R&D intensity. This regression shows that the US has a coefficient of 118.4. If we further look at the coefficients for the EU and Asia, we see that they relate to the US with coefficients of -120.8 and -53 respectively. Figure 5 below illustrates predictive margins.

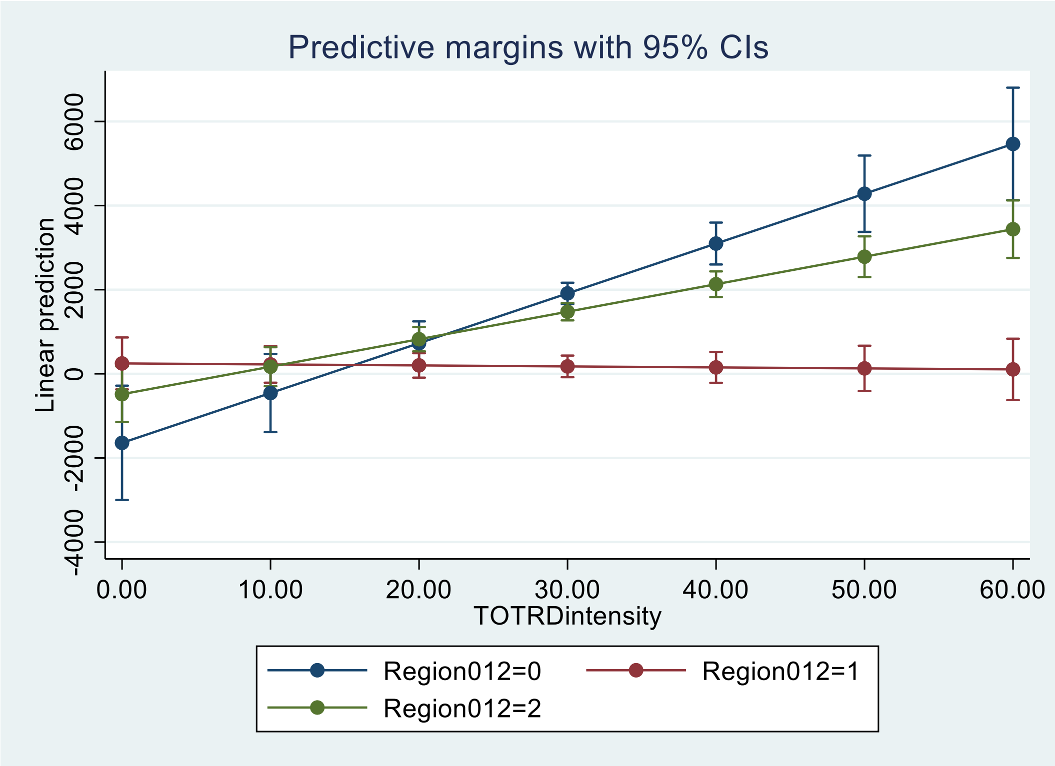
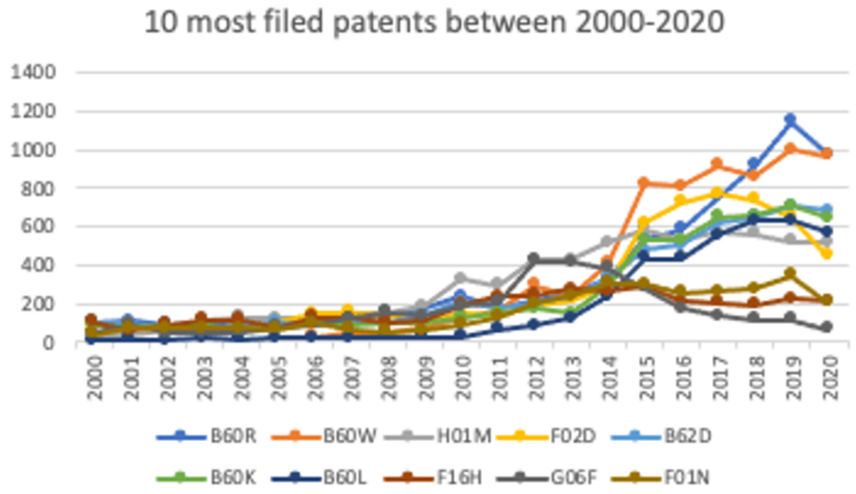


Figure 5: Illustration of Predictive margins

The illustration is somewhat misleading as it is highly unlikely that a company would have 0 in R&D intensity, but it still provides important insights into how the regions differ. The region that stands out is the EU, which has a slightly negative coefficient. This can be interpreted as the EU being less efficient than the other regions. The US has the highest coefficient, but Asia also has a positive coefficient. This can be interpreted as the US is the best region for converting R&D intensity into patents, followed by Asia and the EU in that order. However, given the few observations in this dataset, it implies a high degree of uncertainty.

4.4 Green Patents

The second assumption of this study that will be examined to achieve the purpose of this study is that the most filed patents in recent years show a growing trend toward green technologies. To analyze patents filed within the industry, an overview of the ten most common patents filed from 2000-2020 is presented in Figure 6. The patents were selected by ranking all those filed patents in the industry, from most to least filed.



IPC Code	Sum of patents
B60R	7242
B60W	6796
H01M	6384
G06F	6098
F02D	5936
B62D	5721
B60K	5453
B60L	3942
F16H	3543
F01N	3248

Figure 6: 10 most filled patents between 2000-2020

To further process the data and look at the sustainability aspect of patents filed, one must first determine what makes a patent sustainable. As explained in the theoretical framework, the patents are divided into green, grey, and dirty, following Agnelli, Costa, and Dussaux's (2023) definition. By selecting the ten most filed IPC codes, we can capture the areas of innovation/R&D that are most influential within the automotive industry. When looking at the top ten most filed IPC codes, four patents are recognized as green, one as dirty, and five as neutral, as these patents don't directly affect the vehicle's sustainability. Neutral patents can for example be related to safety measurements and interior design and thus have a neglectable impact on the sustainability of the car. The complete classification of green, dirty, and neutral patents among the top 10 most filed patents is found in Figure 7.

B60W	B60R	H01M	F02D	B62D	G06F	B60K	B60L	F01N	F16H
Green	Neutral	Green	Dirty	Neutral	Neutral	Green	Green	Neutral	Neutral

Figure 7: 10 most filled patents between 2000-2020 categorized into Green, Neutral and Dirty

Of the ten most filed patents between 2000-2020, four are green, while only one is dirty. These four green patents are B60W (control systems for EVs), H01M (conversion of chemical energy into electrical energy), B60K (mounting of electrical propulsion units), and B60L (propulsion of electrically-propelled vehicles). Figure 8 compares the green patents to the neutral and dirty patents from 2000-2020.

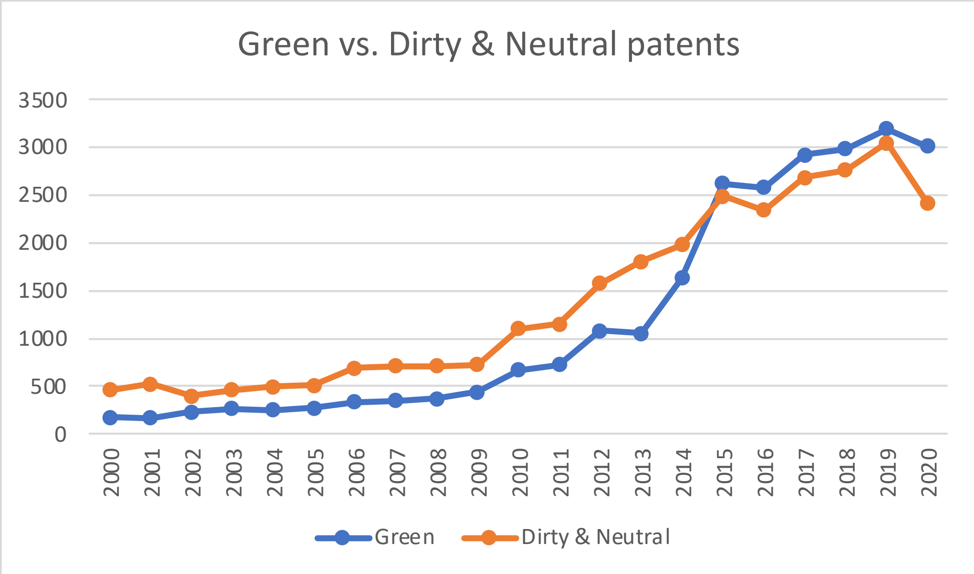


Figure 8: Total number of Green vs. Dirty and Neutral Patents, 2000-2020

Until 2014, the relationship between these two groups of patents stayed relatively the same. However, in 2015 green patents surpassed the group of dirty and neutral patents in the number of patents and have since stayed ahead. Moreover, a drastic increase in these green patents occurred between 2013 and 2015. Figure 9 shows compiled data on these green patents among the seven studied car manufacturers.

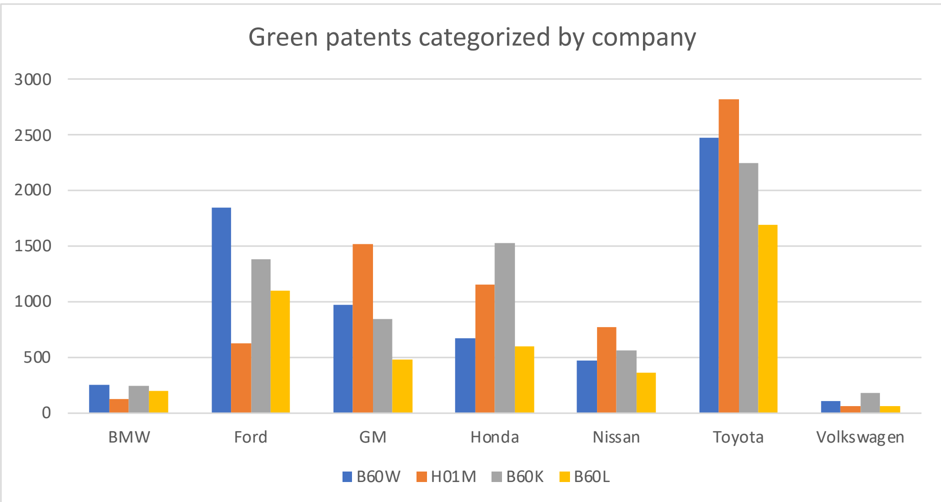


Figure 9: Green Patents 2000-2020 Categorized by Company

Toyota holds almost twice as many of these green patents as Ford, which holds the second most. On the other hand, it is notable that Volkswagen, which has the most employees, does not hold many green patents among the ten most filed in the industry. However, to better understand the differences among the companies, employment history will be considered. Figure 10 shows the employment history over the years 2010-2020.

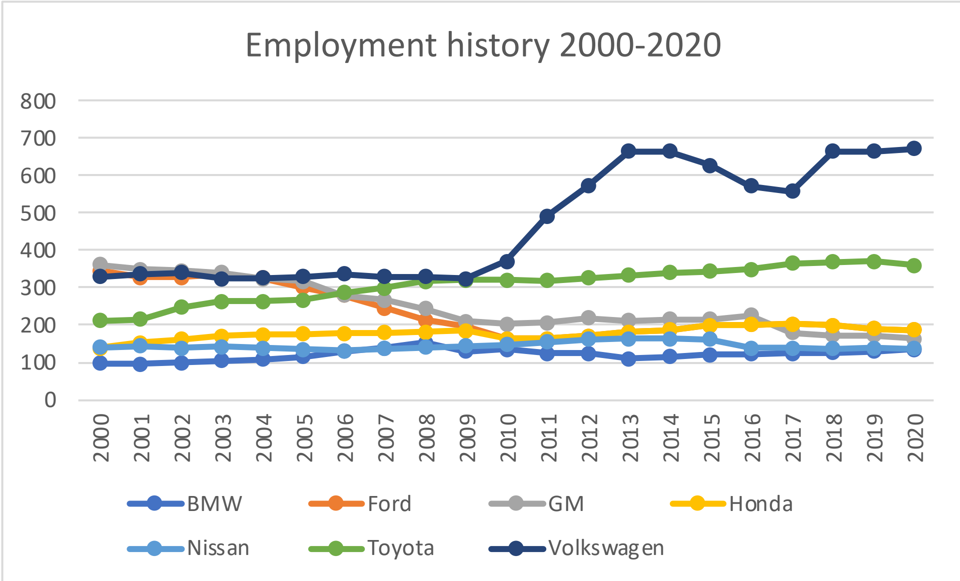


Figure 10: Employment History Among the Seven Studied Car Manufacturers 2000-2020

The data shows that the employment history has been stable since 2000, except for Volkswagen and Ford. From 2000 to 2010, Volkswagen had a stable workforce, but from 2010 to 2020 increased its workforce by almost 300 thousand employees, and Ford shrunk their workforce with the most significant change from 2005 to 2010. To consider the size of the company's total patents per employer is calculated and presented in Figure 11.

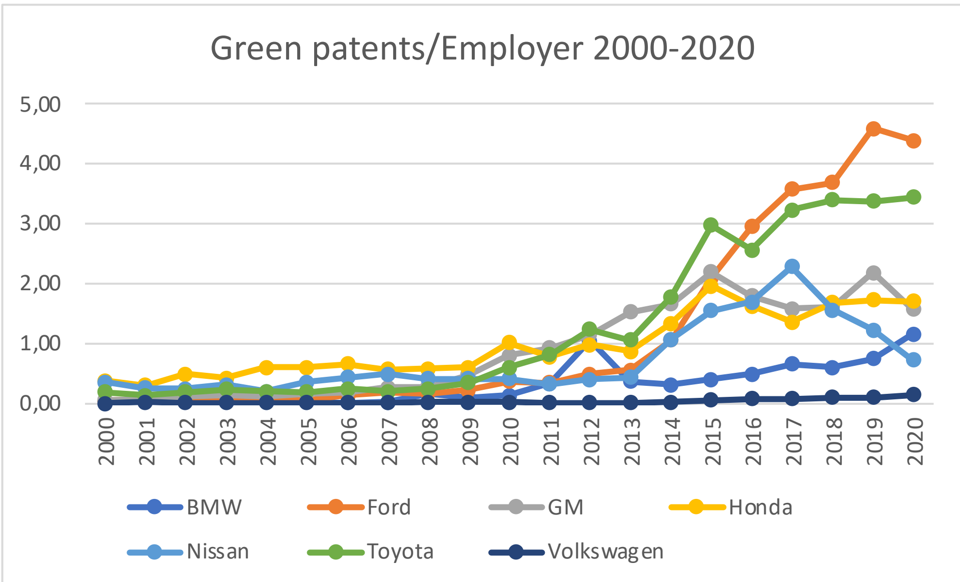


Figure 11: Green Patents Divided by Employees 2000-2020

The data shows that Ford has filed most green patents per employer when considering the company's size. Furthermore, Toyota files second to most green patents per employee. These two companies stand out when looking at this data. The companies Honda, GM, BMW, and Nissan have all had between 0,75 and 2 green patents per employer during the last ten years. If we look closer at the previous five years, there is a decline in green patent filings for Nissan, Honda, and GM. BMW has not been at the top looking at this data, but an increase in green patenting has happened in the last 5-6 years. However, what stands out in this data is that Volkswagen is completely last and has been during the whole period from 2000-2020.

4.5 Regression 2

Looking at the regression (see Table 8), we can identify a positive and significant relationship between the number of green patents and R&D intensity. An increase in R&D intensity results in approximately eight new green patents on a global scale. As the regression for total patents suggested, more R&D intensity increases patents, so an increase in sustainable patents would also be expected.

Table 8: Relation Between Number of Green Patents and R&D Intensity

Variables	**Green Patents (1)**
R&D Intensity	8.278***
EBIT	0.00552**
Employees	0.296**
1. Period	-3.447
2. Period	18.32
3. Period	177.5***
Region EU	-184.8***
Region Asia	22.49
Constant	-168.7***
Observations	147
R-squared	0.564
*** p<0.01, ** p<0.05, * p<0.1	

Both firm size and economic performance have a positive and significant coefficient, indicating that larger firms with positive economic performance seem to invest more in sustainable patents. This can result from having the capital available and the need to stay competitive in the market. In addition, the automotive industry is in a transition period characterized by the technological race to create more environmentally friendly ways of transportation. The time variable *Period* also provides insights into the changes in attitude towards green patents. Again, we see a Positive trend since 2006, with the largest positive and statistically significant coefficient between 2016-2020, indicating an increased interest and filings in the later years, see Table 9.

Table 9: Relation Between Number of Green Patents and R&D Intensity 2

Variables	**Green Patents**
R&D Intensity	16.28***
1.Region EU	294.0**
2.Region Asia	-47.24
Region effect on R&D Intensity	0
1.Region EU	-16.83***
2.Region Asia	2.238
EBIT	0.00563***
Employees	0.109
1.Period 2006-2010	-40.90
2.Period 2011-2015	-2.517
3.Period 2016-2020	114.6**
Constant	-336.0***
Observations	147
R-squared	0.720
*** p<0.01, ** p<0.05, * p<0.1	

Compared to the regression for all patents, we see a similar result. The EU has a very coefficient net which indicates that there is no correlation. However, we see that Asia is the region with the highest coefficient, suggesting that this region is the most efficient way to convert R&D into sustainable patents, closely followed by the US.

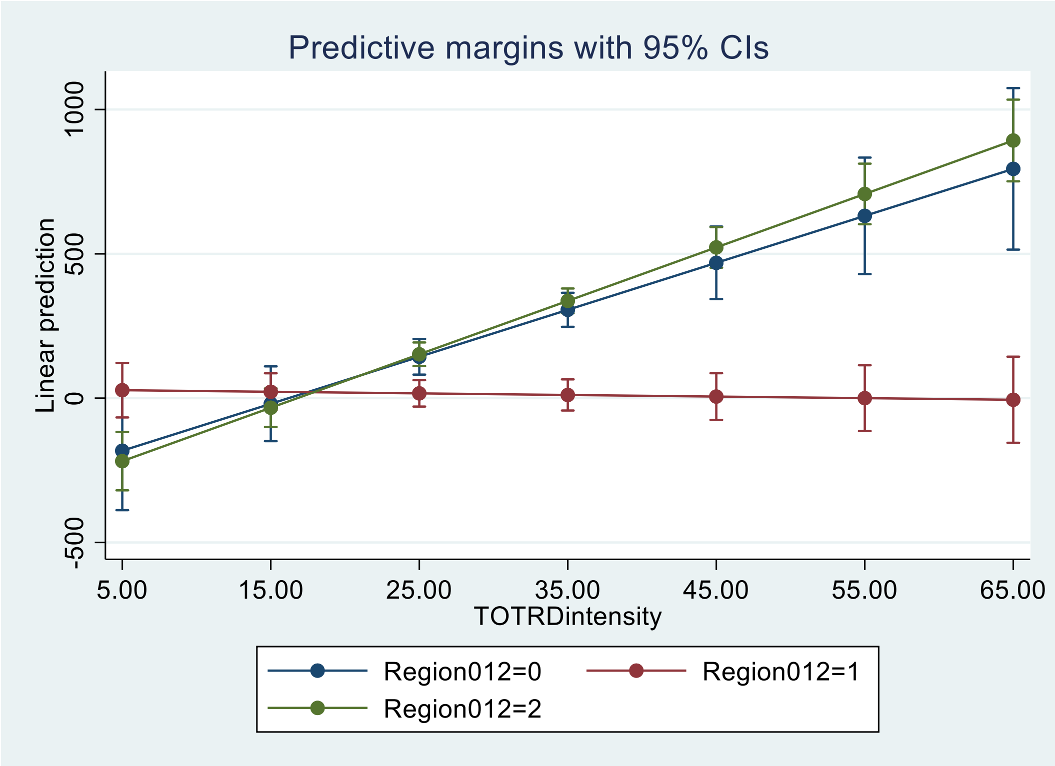


Figure 12: Predictive Margins

In summary, we can identify that both the regression for patents and sustainable patents provide statistically significant insights into the relation between Patents and R&D intensity. Our regressions show that R&D intensity and economic performance positively impact the number of patents. This can be explained by the fact that these variables are interconnected. Space for R&D activities is based on sound economic health. This can be because manufacturers can allocate their profits to innovation and development.

4.6 Economic Performance, Regression 3

Ultimately, these manufacturers aim to turn their innovation activities into economic performance. Therefore, we want to conclude the results chapter by looking at the relationship between the amount of patent filings and yearly revenue, to see whether the patent filings result in any economic growth for the firms. Looking at the annual revenue in Figure 13 for each firm, we see some familiar patterns.

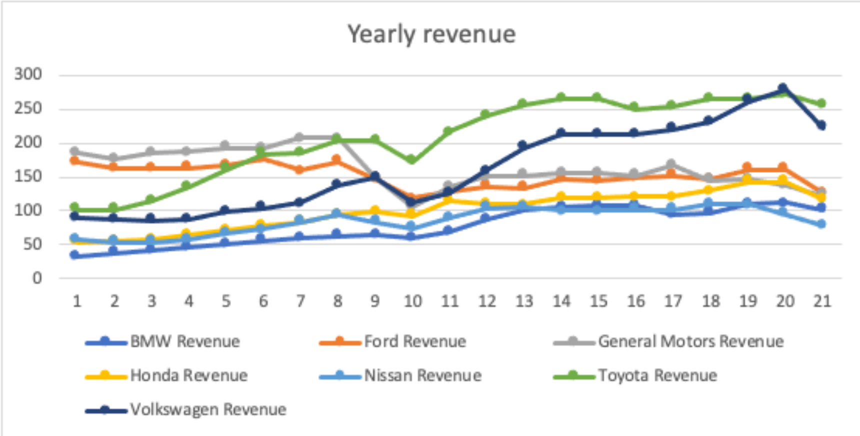


Figure 13: Yearly Revenue for each Manufacturer

Like the other descriptive graphs, we see a dip around 2008, which was expected. However, we see a difference in how well the boom has recovered since 2008. Toyota and Volkswagen look like the winners as they have managed to recover and achieve higher revenues. This contrasts with General Motors and Ford, who lost their revenue as both had the highest revenue. To further investigate the relationship between Patents and Revenue we can look at the regression in Table 10 below.

Table 10: Regression

Variables	**Revenue**
Patents	0.003
Green patents	0.031*
R&D Intensity	1.108***
1.Region EU	-45.8***
2.Region Asia	17.79***
Employees	0.367***
EBIT	0.0008**
1.Period 2006-2010	16.21***
2.Period 2011-2015	9,519
3.Period 2016-2020	0.359
Constant	-336.0***
Observations	147

Patents seem to have a positive association with revenue. However, it is hard to confirm as we see a lack of statistical significance in our regression. Green patents on the hand display a positive and significant result, indicating that green patent filings might be more beneficial for the firms in terms of increasing revenue. Further, we notice a positive correlation with R&D intensity, indicating that a firm can expect a higher revenue as they increase their R&D intensity. To further analyze the relationship between Patents and green patents we conducted like before a regression that takes regional differences into consideration.

Table 11: Regression

Variables	Revenue
Patents	0.0018
1.Region EU	-77.28***
2.Region Asia	-51.96***
Region effect on Patents	
1.Region EU	0.053**
2.Region Asia	0.02***
Green Patents	0.0138
Region effect on green patents	
1.Region EU	0.181
2.Region Asia	0.0017
R&D Intensity	0.136
Employees	0.317***
EBIT	0.00084*
1.Period 2006-2010	18.99***
2.Period 2011-2015	16.81***
3.Period 2016-2020	7.102
Observations	147

We can see that in terms of patents, region EU has the highest positive coefficient of all regions, indicating that the effects of patents seem to have the most impact in the EU region. One could therefore argue that companies based in the EU should put more emphasis on patenting compared to manufacturers in US and Asia, however, this is as mentioned earlier somewhat of a simplification as other factors play a factor as well. But as a result of the statical significance displayed the results should be taken into consideration. For the green patents, it is hard to come to a concluding answer weather we see some regional differences, due to the lack of statical significance. It looks like the region EU is the frontrunner for green patents as well, but it is hard to say something definitive. To further clarify the relationship between Patents and

Revenue, we can illustrate this through a scatterplot with a predicted value, see Figure 14 below.

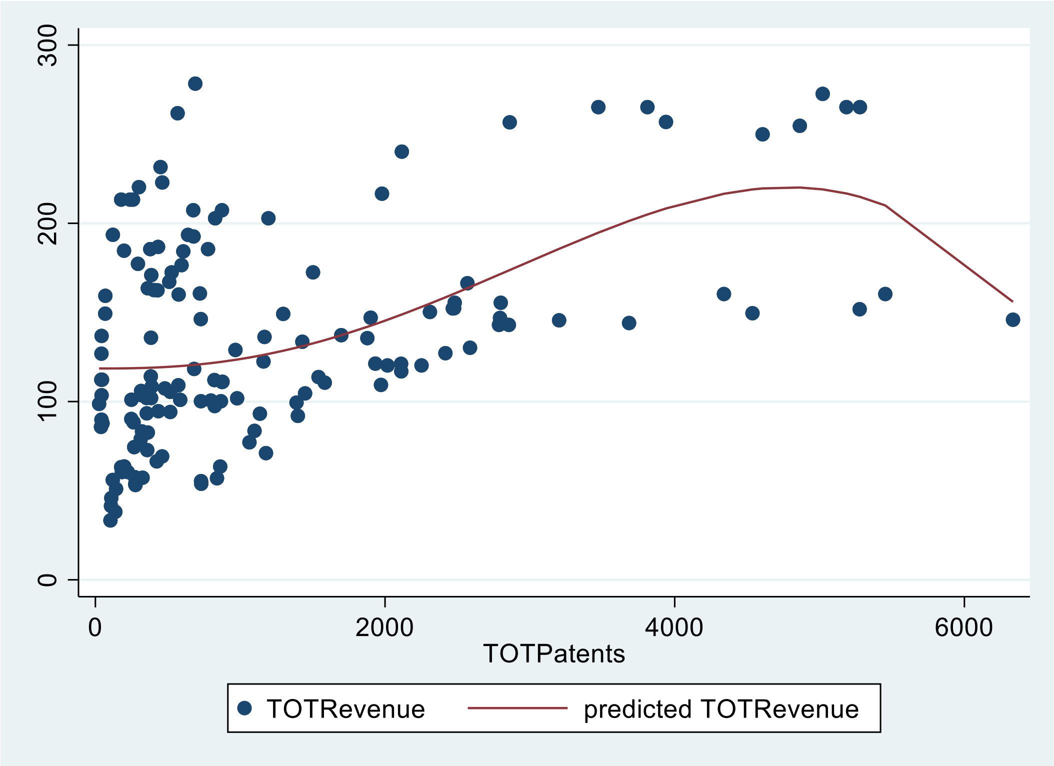


Figure 14: Scatterplot with a Predicted Value

An initial observation is that there is a big difference between how effective companies are at exploiting their patents. For example, we assume that patents provide an economic increase. In that case, the observations with patents between 0-1000 searches are not in a cluster but spread out on the X-axis, reflecting revenue. This means that some companies get more revenue from the same number of patents applied for. This can be explained by what type of patents these are, but it still points out a difference between the observations. Something that will be further discussed in the next chapter.

We see an initial positive trend when further analyzing the scatterplot of yearly revenue and patents. However, we notice a decreasing increase of around 4000 patents. This means that there is effectively a limit to how many patents a company should apply for before the efficiency per patent starts to decline. As we do not have enough observations where a company has applied for 4000 or more patents, it is difficult to say exactly when this decline starts, but we can see that the increasing trend when patent applications are lower decreases when companies apply for more patents. It is important to remember that this is just a prediction based on patent applications, not a prediction of innovation activities overall. When looking at revenue and R&D intensity, we see a slight positive trend as the R&D intensity increases, see Figure 15 below.

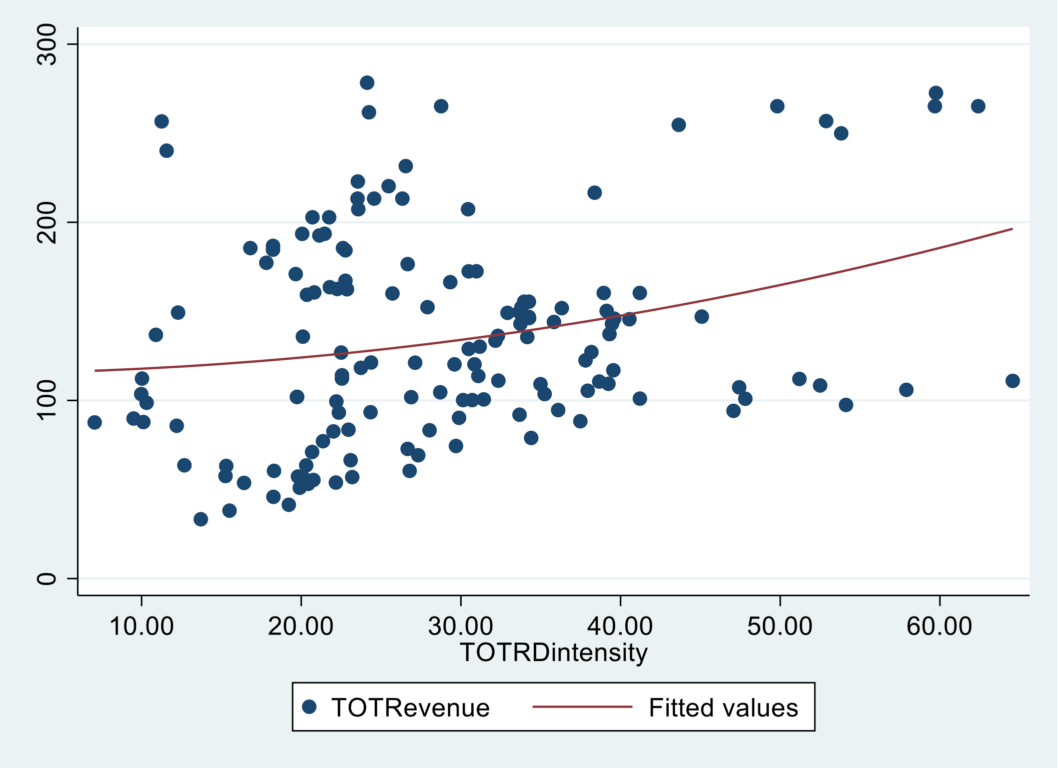


Figure 15: Scatterplot over Revenue and R&D Intensity

However, this suffers from the same lack of observations as for the patent and revenue scatterplot so the exact numbers should be considered with some hesitation. But we can say that these plots provide insight into the relationship between R&D intensity, patents, and Revenue. Based on the results, there seems to be a limit to the effectiveness of patents but not with R&D intensity. We realize that there must be a limit to the R&D intensity in reality as well, but it points out that patenting might not be the most effective way of conducting innovation activities, and companies might consider alternative avenues.

5 Discussion

In this chapter, we will discuss the inputs from the regressions and the graphs to conclude the impact of patents on innovation. Next, we will compare this with ideas from our literature review. Then we will discuss the managerial implications and how our findings can be used in practice. Finally, the chapter concludes with suggestions for future research and how our report can be complemented to provide decision-makers with more profound information on the subject.

5.1 R&D Intensity and Patents

As mentioned in our thesis, the automotive industry is undergoing major changes. Therefore, industry professionals and stakeholders need deeper insight into how innovation relates to R&D intensity and patenting. Our study has demonstrated a relationship between R&D intensity and patenting, which at first glance, should indicate that companies should prioritize high R&D intensity to maintain their position in the market. Crafts and Mills (2017) pointed out the historical evidence that innovation has been an economic driver since the industrial revolution, something that we see no indication of changing. However, the manufacturers cannot get too comfortable. As Khan (2018) and Goffin and Mitchell (2017) mention, in such a changing environment as the automotive industry, firms need to emphasize the "why" and "what" in their innovation activities. We have in our analysis of the patent landscape identified that there has been a change in trend in what type of patents the manufacturers file for. A potential risk that we see is that the innovation departments for the manufacturers miss these trends and stick to what has worked before, something that might not be true in such a volatile and shifting industry.

We have seen an increase over the periods examined in our report and proven with statistical significance in the regression of both patents and green patents. However, it is whether this increase in patents has come to fruition regarding real components. But this may be less interesting to examine in terms of our research question. So instead, we look at how patents can contribute to innovation and economic performance in the industry. Hasan and Tucci (2008) argued in favor of having an explorative mindset when approaching innovation. A certain patent filing might not result in a new component or an "invention," but it might yield a deeper understanding of the subject area and ultimately result in an even better "invention" further down the road. We believe this mindset is critical in an industry such as the automotive industry.

R&D intensity has increased over the period we have analyzed, indicating that the industry overall is investing more in innovation, which is a smart move. However, one thing we take caution against is setting a goal that every patent should culminate in a direct improvement of the car. Instead, we argue that each patent application and R&D project should be seen as an extension of the company's collective knowledge on a particular topic. A good example is the green patents which have seen an increase since 2010. This was a relatively unexplored area compared to more traditional internal combustion engine cars, so it was probably difficult for manufacturers to know exactly which components would be useful. As mentioned earlier, we don't know which of these patents became a reality, but we are confident that the knowledge and lessons learned have made manufacturers more efficient in their journey towards more sustainable cars.

5.2 Innovation and Economic Growth

In the literature review, we see differing views on the role and effectiveness of R&D in generating economic growth. Both Kim (2018) and Matsen (2007) recognize the importance of R&D and its usefulness when it comes to staying competitive towards the competition. However, their opinion differs as to whether there are diminishing returns or not. In our regression, we have seen a positive correlation between patents and economic growth – revenue in our case, but it displays characteristics of being slightly diminishing as the number of patents increases. This would support the theory that Kim (2018) presented and conclude that there is a negative bell curve relationship between the variables. On the other hand, when looking at R&D intensity and its effect on revenue, we see a positive trend, indicating that as R&D intensity increases, so does the yearly revenue. This graph supports Matsen's (2007) claim that the theory of a bell curve is flawed and only applies when certain conditions are met.

Our data provide proof for both theories, which makes it difficult to conclude in a definitive answer. However, we as authors lean towards agreeing with the theory presented by Faff et al. (2011) and that the diminishing returns displayed result from firm internalities. Firms with a developed innovation structure might see different diminishing returns, as they are better at avoiding R&D spillovers, i.e. outcome of R&D activities which is not utilized. Therefore, one conclusion could be that the important question is not "How much should we invest in innovation?" but instead, "How much capacity do we have as an organization to invest in innovation."

5.3 Region Differences

Another interesting insight into our regressions is the issue and the differences we see between regions. The US and Asia have positive trend lines, indicating that these regions are good at converting their R&D intensity into patents. The EU, on the other hand, according to our regressions, is behind the other regions, and we want to investigate further what this may be due to. The simplest explanation may of course be that our sample size is relatively small and the data we have used happens to be a "bad" sample of the EU as a region. But since we see such a clear difference, we believe that something else may be behind the results. Looking at the number of patents filed in the US, we see that the European manufacturers file for substantially fewer patents than those based in the US or Asia. The reasoning behind this is hard to determine without discussing it with the manufacturers, but this can be the reason behind the comparatively negative results for EU as a region. When collecting data for the regression, we noticed that the EU-based manufacturers had most of their patents filed for at the EU alternative to the USPTO, the European Patent Office (EPO). Purely based on the results of our thesis, it is fair to say that the EU is less effective compared to the US and Asia, which might be true to some extent, but we think at it is not as extreme as the data suggests. Volkswagen has been a leader in terms of revenue since the crash of 2008, and if EU as a region would have been as bad as the data suggest, we doubt that Volkswagen, as an EU-based manufacturer, would be able to compete at the level it does. On the other hand, BMW has been struggling with its revenue and ranks as one of the lowest revenues in our dataset, which might suggest some truth to the result of EU not being as effective when it comes to R&D intensity. Ultimately, we recognize that it is difficult to get a definitive answer for the reason for the results without talking to the manufacturers. But we believe our regression doesn´t reflect the whole story and should therefore be viewed cautiously.

Another interesting point is that the EU seems to be a frontrunner in economic performance. Our regression tells us that US and Asia are more efficient in converting R&D intensity into patents. However, when looking at converting patents into economic growth – revenue in our case, US and Asia seem to be behind the EU. This presents an interesting relationship between R&D intensity, Patents, and economic performance. Indicating that there might be some regional differences and some regions may be better at certain aspects of the whole innovation process.

5.4 The Importance of Sustainability

This study also investigated the trends in the automotive industry's green patents filed from 2000-2020. Our findings indicate that there is a growing trend toward green technologies, which support the importance of sustainability, innovation for economic performance, growth, and development,

Several researchers have recently discussed the significance of green technologies and sustainable practices. For instance, Aghion et al. (2017) argue that transitioning to a low-carbon economy relies on innovation and that investing in green innovation can bring economic benefits and incentives for firms to innovate. However, these benefits are not well understood.

Goffin and Mitchell (2017) and Phelps (2015) discussed the role of innovation and sustainability in driving economic growth and development. They suggested that companies that invest in R&D and sustainability practices are more likely to achieve long-term success and competitive advantage. Similarly, Feng et al. (2020) emphasized the importance of sustainable practices for reducing environmental impact and promoting green development.

In our thesis, we used Agnelli, Costa, and Dussaux's (2023) framework to categorize patents into green, grey, and dirty patents. The framework helped to identify the patents related to sustainability practices and technologies in the automotive industry. Furthermore, using this framework enhances the accuracy of the analysis and provides a clear picture of the trend toward green technologies in the industry.

Moreover, we found a positive relationship between R&D intensity and the number of green patents filed. This finding is consistent with the literature, which suggests that R&D investment is a critical driver of innovation and sustainability practices in various industries (Aghion et al., 2016; Aghion et al., 2017).

Feng et al. (2020) investigated relationships between IPC codes and found interesting convergences. Even though we did not investigate relationships between IPC codes, our result showed an increased trend in green technologies. Feng et al. (2020) found specifically B60K and B60L to converge strongly with other technologies. In our study, these two patent groups are today among the ten most filed patent groups. Based on this, these patent groups not only have a strong convergence to other patent groups but are also within the ten most filed patents groups during the studied period 2000-2020. Rajashekara (2013) and Un-Noor et al. (2017) explained that these patent groups are strongly connected to the innovation of EVs and are drivers of innovation for green technologies. Therefore, it correlates with our results which show a growing trend in green technologies and are positive in terms of sustainability and a transition to a low-carbon economy.

5.5 Discussion of the Correlation Matrix

To conclude the discussion, we think it is important to acknowledge the correlation matrix presented in the results section. We found a high degree of correlation in some of the variables. The correlation between patents and green patents can be easily explained, as the green patents are included within the patent variable. However, some other troubling correlations can be the correlation between both patents and green patents with R&D intensity, since this is our main independent variable. Since they display a high degree of correlation, the results of regression might indicate an overconfident relationship, meaning that the displayed coefficients might not be as high in reality, but rather a result of 2 variables being correlated by chance. We think however that that is not the case in terms of our thesis, as we assume that R&D intensity will affect the number of patents being filed for.

Another correlation that we think it is important to address is the relationship with time. Over our periods we see an increase in patent filings. Therefore, it is important to remember that some variables are not as important as the regressions display, but rather just a result of manufacturers increase in patent filings over time.

As summery, we recognize the problem of having a high degree of correlation in data when conducting a regression and if the thesis were to be done again, we would try to address this high degree of correlation by conducting more regression were some variables would be tested by being excluded. This is to better understand how a certain variable affects the regression.

6 Conclusion

The concluding chapter of this study will provide a comprehensive summary of our discussion and key findings from our research. In addition, the chapter will highlight our contributions to the studied field. Managerial implications will be presented, including recommendations for managers in the automotive industry. Furthermore, we will propose avenues for future research.

6.1 Managerial Implications

Based on our discussion, our study suggests that companies in the automotive industry should prioritize strategic innovation instead of only focusing on increasing R&D intensity. For managers, it is important to understand changes in patent trends and identify the "why" and "what" of their innovation efforts. It is therefore important to align innovation activities with the rising needs of the market to stay ahead of the competition.

It is important to encourage an explorative mindset, learning within the organization, and understanding that every patent or R&D project will not result in immediate improvements or tangible results. But instead, view patents and R&D projects as valuable opportunities to reach increased knowledge and gain insights that can contribute to breakthroughs in the future.

Managers should view patents and R&D projects as an extension of the company's collective knowledge and encourage cross-functional collaborations to maximize the effect of R&D activities. This will contribute to the organization taking the learning of previous projects to drive continuous improvements and efficiency.

Even though our study has shown that increased R&D intensity can positively affect revenue, it is important to consider the organization's ability to invest in R&D. Managers should evaluate how they choose to structure their innovation and internal capacity to avoid diminishing returns and utilize R&D investment effectively. Furthermore, to ensure sustainable growth in the company, one should strive for a balance between investments in innovation and the capacity within the organization.

The study has shown differences between regions in patent trends, where the EU is behind US and Asia. Therefore, managers within their respective regions should at least investigate the reasons behind these differences to better identify strategies to enhance innovation effectiveness. One potential direction could be collaborating with research institutions, technology clusters, or industry associations to facilitate knowledge exchange to foster innovation. Furthermore, we recommend that managers evaluate their innovative supply chain since we notice regional differences. Some regions are more efficient in producing patents, and others are more effective at turning these patents into economic performance.

The importance of sustainability in the automotive is clear, and our study has not shown otherwise. Therefore, managers should prioritize sustainable practices and continue to invest in green technologies. In the long run, this can lead to competitive advantages and long-term success and lower the company's environmental impact. In addition, sustainability should, if not already, be integrated as a core element in the company’s central innovation strategy and product development process.

The automotive industry is evolving rapidly, and managers should continuously monitor trends in the market, technological advancements, and regulatory changes. In these changing environments, managers should regularly update and adapt the company’s innovation strategy. It is of great importance to respond effectively to emerging opportunities and challenges.

By considering these managerial implications, managers in the automotive industry can better navigate the complex landscape of innovation, patents, and sustainability to drive long-term success and be part of a more sustainable future.

6.2 Future Research

A possible avenue for future research is to conduct a comparative analysis of innovation strategies between companies with high and low R&D intensity and companies with patenting activity. These may include case studies or interviews with company managers and R&D personnel from various industries to learn how to prioritize and approach innovation and how it relates to patenting activity and R&D investment. The study provides insight into how companies can better allocate resources to innovation and patenting and shed light on broad innovation trends across industries.

Another potential area for future research is examining how government policies and regulations affect firms' innovation and patenting activities. This may include analyzing data on patent filing and R&D investment in countries with different political systems and conducting interviews with government officials and industry representatives to better understand the impact of specific policies on innovation outcomes. By better understanding the role of politics in shaping innovation and patenting, this study can help inform policy decisions to promote innovation and growth in many areas.

Furthermore, we would like to see the report extended by a study more focused on the conversion from patent to invention. It is difficult to measure innovation and to find a fair measurement tool. We have mentioned that patent applications can be used as a measure of innovation, but at the same time we are aware that it only gives part of the picture. Therefore, we suggest further research on how many of the patents applied for actually become components or methods used in the physical products. This would provide deeper knowledge on the subject and be used to identify factors that determine how good a manufacturer is at using the patents they have been granted.

One limitation of the study is that it only analyzed the patents filed in the automotive industry. Future studies can extend this analysis to other industries and examine the trend toward sustainability practices across industries. Additionally, the study did not analyze the quality of the patents filed. Future studies can use more advanced methods to evaluate the quality of the patents filed and identify the most innovative patents related to sustainability practices.

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Appendices

Appendix A

Clean Patents	
	IPC codes
Electric vehicles:	
Electric propulsion with power supplied within the vehicle	B60L 11
Electric devices on electrically propelled vehicles for safety purposes; monitoring operating variables, e.g., speed, deceleration, power consumption	B60L 3
Methods, circuits, or devices for controlling the traction motor speed of electrically propelled vehicles	B60L 15
Arrangement or mounting of electrical propulsion units	B60K 1
Conjoint control of vehicle subunits of different type or different function/including control of electric propulsion units, e.g., motors or generators/including control of energy storage means/for electrical energy, e.g., batteries or capacitors	B60W 10/08, 24, 26
Hybrid vehicles:	
Arrangement or mounting of plural diverse prime movers for mutual or common propulsion, e.g., hybrid propulsion systems comprising electric motors and internal combustion engines	B60K 6
Control systems specially adapted for hybrid vehicles, i.e., vehicles having two or more prime movers of more than one type, e.g., electrical and internal combustion motors, all used for propulsion of the vehicle	B60W 20
Regenerative braking:	
Dynamic electric regenerative braking	B60L 7/1
Braking by supplying regenerated power to the prime mover of vehicles comprising engine-driven generators	B60L 7/20
Hydrogen vehicles/fuel cells:	
Conjoint control of vehicle subunits of different type or different function; including control of fuel cells	B60W 10/28
Electric propulsion with power supplied within the vehicle using power supplied from primary cells, secondary cells, or fuel cells	B60L 11/18
Fuel cells; manufacture thereof	H01M 8
Grey Patents	
Fuel efficiency of internal combustion engines:	
Fuel injection apparatus	F02M39-71
Idling devices for carburettors preventing flow of idling fuel	F02M3/02-05
Apparatus for adding secondary air to fuel-air mixture	F02M23
Engine-pertinent apparatus for adding nonfuel substances or small quantities of secondary fuel to combustion-air, main fuel, or fuel-air mixture	F02M25
Electrical control of supply of combustible mixture or its constituents	F02D41
Methods of operating engines involving adding nonfuel substances or antiknock agents to combustion air, fuel, or fuel-air mixtures of engines, the substances including non-airborne oxygen	F02B47/06
Dirty Patents	
Internal combustion engine:	
Internal combustion piston engines; combustion engines in general	F02B
Controlling combustion engines	F02D
Cylinders, pistons, or casings for combustion engines; arrangement of sealings in combustion engines	F02F
Supplying combustion engines with combustible mixtures or constituents thereof	F02M
Starting of combustion engines	F02N
Ignition (other than compression ignition) for internal combustion engines	F02P

Source: (Aghion et al., 2016[2]).