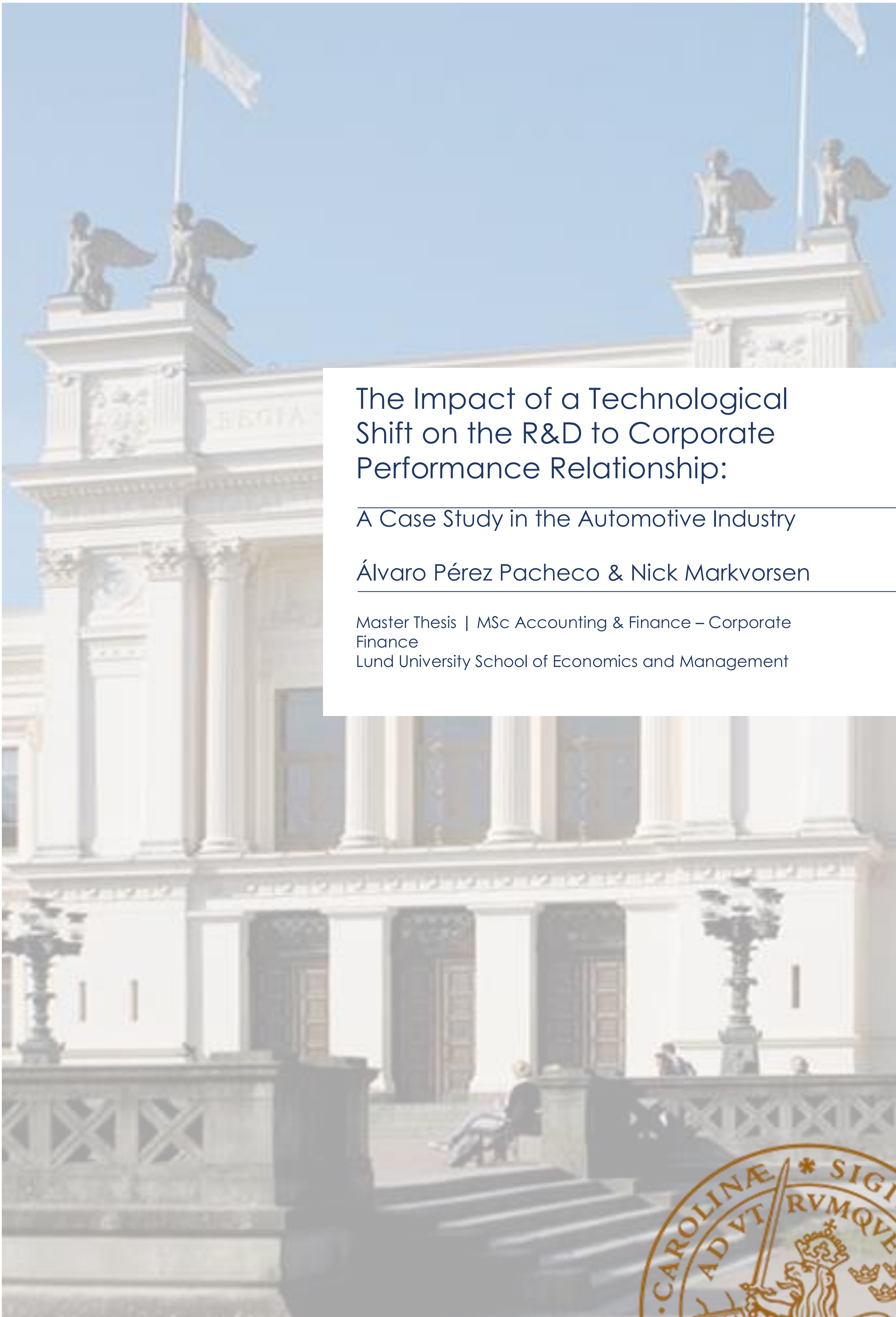

The Impact of a Technological Shift on the R&D to Corporate Performance Relationship:

A Case Study in the Automotive Industry

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ABSTRACT

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Keywords: Technological shift, R&D, research and development, firm performance, R&D on future firm performance, innovation and future profitability

Purpose: This paper aims to determine if the relationship between R&D and future firm performance changes once there is a shift in technology.

Methodology: Econometric inference, Pooled OLS, hypothesis testing.

Empirical foundation: Sample set comprised of companies within the automotive industry between 2001 and 2016.

Conclusion: Positive contribution of R&D on future firm performance, increased relationship after a technological shift.

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LIST OF ABBREVIATIONS:

ADV - Advertising Expenses

BEV- Battery Electric Vehicle

BM - Book-to-Market ratio

CAPEX - Capital Expenditures

EBITDA - Earning Before Interest Tax Depreciation & Amortization

NI - Net Income

NPV - Net Present Value

OECD - Organisation for Economic Cooperation and Development

R&D - Research and Development

Tech. Shift - Technological Shift

1. INTRODUCTION

This chapter will start by giving the reader a background on the research question of this thesis. Furthermore, will it specify the research question and give an insight into this report's academic and professional contributions. Lastly, it will provide the reader with an overview of the structure of the thesis.

1.1. Background

In its 2003 report, the OECD highlights that the competitive environment for global business has changed (OECD Science, Technology and Industry Scoreboard, 2003). This change is driven by globalisation and technological advancements. Specifically, in high tech industries (Kumbhakar et al., 2011), where changing market features such as shorter product lifecycles, increasingly complex manufacturing product designs, fragmented markets, and growing similarity among products led many firms to reshape their competitive strategy and adapt to the new market environments (Pisano and Wheelwright, 1995). In other words, this means that disruption of the previously established competitive dynamics has taken place. Therefore, businesses worldwide utilise innovation as a tool to gain a competitive advantage in the marketplace.

In economic terms, innovation is described as developing and applying "ideas and technologies that improve goods and services or make their production more efficient" (How does innovation lead to growth?, 2017). The keywords in this definition are developing and applying. Companies across all industries invest in research and development (hereinafter R&D) for two main reasons. Firstly to obtain patents to commercialise, which then lets them gain an advantage in the market. Secondly, to enhance production efficiency (Hsu, Chen, Chen and Wang, 2013). Therefore, R&D partly drives competitiveness in today's business environment and is expected to increase firm productivity (Griliches, 1979). To strengthen competitiveness, companies seek to enhance product differentiation through product innovation and enhanced efficiency through process innovation (Link and Siegel, 2007).

Overall, this means that innovation and R&D have gained importance. This is manifested further by the increasing R&D investments companies make.

R&D has shown annual investment increases of approximately 4% per year over the past decade (Brennan, Ernst, Katz and Roth, 2020). One industry that has been highly affected by the increasing focus on R&D in combination with a technological shift is the automotive industry, which invests up to 40% of its EBITDA into R&D (Brennan, Ernst, Katz and Roth, 2020).

This is anchored in the fact that the automotive industry faces significant changes and has to cope with a transformation in customer demand and political regulations (Jannel et al. l, 2013).

Increasing environmental awareness and government incentives have led to the demand among customers shifting away from the previously dominant technology of combustion engines (Fleming, Telang and Singh, n.d.). This has forced the industry to rethink its current drivetrain technology (Jursch, n.d.), which has led to increasing interest in battery electric vehicles (BEV). Furthermore, shared mobility and technological revolutions such as driverless and connected cars (IoT) push the industry to catch up with the current state of information technology. These developments indicate a move away from the mere focus of improving known technologies towards a level plain field within the space of battery electric vehicles and the overall industry. Innovation once again shapes the competitors of the future.

Despite the increased spending on R&D, it is still unclear how R&D investments affect future firm performance. Scholars have been debating the topic for decades but have yet to find a conclusive answer. At this point, most scholars find positive relationships between R&D and future firm performance (Branch, 1974: Morbey, 1988; Long and Ravenscraf, 1994, Sougianni, 1994) for example, Aguiar and Gagnepain, (2017) find that cooperative R&D among European firms significantly increase performance, while others do not find any- or negative relationships. In addition to these inconclusive findings, scholars still argue about the magnitude and if the relationship is linear or non-linear over time for different levels of R&D spending.

This paper delivers a theoretical and contextual review on the current knowledge of the relationship between R&D and future profitability. Through an empirical approach on a determined case study, an understanding of the sign, economic and statistical significance has been framed to address the previous knowledge gap. Technology then has been identified as a factor to strengthen this relationship.

1.2. Research Question

Given the unresolved findings concerning the influence of R&D on future firm performance, it is essential to note that the technology shift within the automotive sector gives the unique opportunity to shed light on what influence technology plays in the R&D to future firm performance discussion, thereby increasing the existing knowledge on the topic. It is, therefore, crucial to further investigate the relationship between R&D and future firm performance to highlight the risk and rewards companies attain by investing in R&D within a highly technologically shifting environment, such as the automotive industry. However, first, it is fundamental to understand the overall relationship between R&D and future firm performance within the automotive industry. Therefore, the first research question is:

Do R&D investments have a positive relationship with future firm performance in the automotive industry?

The second part of the research question includes the shift in the technological environment. Hence, the second research question is:

Has the shifting technological environment positively influenced the effect of R&D on future firm performance in the automotive industry?

Our research question points towards an increase in performance due to the current Green / Technological revolution. The question is then also asking if the change in political and consumer sentiment has forced the automotive industry to reshape its strategy to R&D investments. This change has occurred since consumers increasingly focus on electric and highly software-focused vehicles. Hence, automotive producers are still at the beginning of developing vehicles that can fully replace combustion engines. Our research marks 2011 as a shifting year, which will be further explained in later sections. For now, the motivation for this specific point in time is based on technological changes within the industry and political frameworks worldwide changing the business landscape, forcing automotive manufacturers to focus on sustainability.

1.3. Contribution

To the best of our knowledge, previous studies have merely investigated the impacts of R&D investments on firm performance. Still, none has focused on the implications of a technological shift on the relationship between R&D and future firm performance. This study focuses on exactly this question with the automotive industry as a proxy for a highly technological changing environment. The value created through this research stems from the impact of the technological shift on the R&D to future firm performance. As technology is a force that will impact every industry in the future, we aim to help understand its implications on companies commitment to R&D and the implications for future firm performance. Additionally, the focus on technology helps widen the current state of knowledge, given that the significant technological changes in the market space have not yet been researched concerning R&D and future firm performance. Therefore, this paper brings forward a model, which serves as guidance on predicting the implications of investing in R&D.

Furthermore, the automotive industry is "seen as a crucial part of the world economy…" (Jannel et al. l, 2013). This means that the industry and its performance have significant implications for the overall world economy. Hence, investigating potential changes in the competitive strategy is crucial. Furthermore, investigating whether or not there is a reward for those who commit resources to R&D in a technologically shifting environment like the automotive industry creates value for policy-makers, managers, and shareholders alike, specifically, as a guide for readers of financial statements of R&D intensive companies since it gives indications towards future performance.

1.4. Thesis Structure

The following chapter will be devoted to a theoretical background and literature review that summarises theory around innovation and its competitive impact. Additionally, it highlights the essential findings of R&D spending and firm performance. The chapter starts by evaluating literature from the perspective of economics as to why or why not R&D would impact firm performance, after which it moves to factors affecting the investment in R&D. Lastly, it looks at previous findings on the relationship between R&D and firm performance.

Chapter number three will give an overview of the automotive industry and highlight how it operates. Additionally, the chapter will explain the drivers, challenges and trends.

The fourth chapter of this thesis will explain the empirical background. More specifically, it will start by providing statistical support for the model. Additionally, it will highlight theoretical assumptions which are made when constructing the model.

The fifth chapter will be explaining the sample used to empirically test the research hypothesis. In this chapter, the reader will get be made familiar with the data that will later be used in the analysis.

The sixth chapter will describe the actual execution of the empirical analysis, interpret the statistical results, and provide an additional specification to test the robustness of the main inference.

The final chapter summarises the results and derives the conclusions. Furthermore, it evaluates the depth of the findings and highlights possible limitation of the study. After which, it will give recommendations for additional research.

2. THEORETICAL BACKGROUND

The relationship between R&D and firm performance has been studied extensively over the past decades. Even though multiple scholars have attempted to describe the relationship, still no conclusive answer has been found. This section provides theoretical grounding around this relationship. It begins with an introduction to innovation and its impact on economic growth. Afterwards, it moves to the theory behind the value creation of R&D in terms of performance impact. It also discusses other factors that determine investments in innovation and its strategic implications. Finally, the previous empirical findings on the relationship between R&D and firm performance are reviewed and contrasted to evaluate the research gap.

2.1. Innovation as a value driver

To investigate how R&D affects future firm performance, it is crucial to understand what innovation is and how it affects the companies and the overall economy. As the father of innovation-based economic theory, Schumpeter describes innovation as a critical condition to economic change. In his work from 1934, he defines five types of innovation. 1) new products, 2) new production processes, 3) new materials or resources, 4) new market, 5) new forms of organisations.

Innovation in either of these ways, he argues, leads to further innovation. Based on this, he establishes a theory in which economic change is created through creative destruction. The following quote explains what he means by creative destruction:

> "Creative destruction is the innovation process of industrial mutation, that incessantly revolutionises the economic structure from within, incessantly destroying the old one, incessantly creating the new one."
>
> (Schumpeter, 1942)

Schumpeter underlines that creative destruction leads to a reinvention of economic structures. He points towards innovation as a driver for further evolution since innovative ideas make old ones obsolete. Hence, Schumpeter describes innovation and the following change as a driver of production output and competitive advantage. He notes that those who are aware of discontinuities in the business environment and act on them will benefit. Furthermore, he describes “the disruptive innovation process occurring at irregular intervals” (Ziemnowicz, 2013).

These intervals are also described as waves or cycles in economics. Schwab (2016) argues that in line with Schumpeter’s wave theory, throughout history, revolutions have occurred once new technologies have emerged and shaped how humanity sees the world, thereby leading to changes in economic systems and social structures. Three past industrial revolutions have shaped today’s economic and social structure.

The first industrial revolution with the steam engine at the centre has led to technological development and exponential growth. This growth was achieved through the ability to move economic goods and constant iterations of innovation where new technology replaced the old.

The public availability of electricity caused the second industrial revolution in the late nineteenth century. This revolution facilitated the rise of mass production. Afterwards, the third industrial revolution also called the digital revolution, propelled the mid-twentieth century economy forward through the invention of the computer.

This has led to the age of personal computers and the internet as it is known today. Finally, humanity has now arrived at the fourth industrial revolution, shaped by artificial intelligence, augmented reality, robotics, genome editing, and 3-D printing. **Figure 1** highlights that the distance between these revolutions has decreased. Schumpeter describes this effect by the rapid development of new technologies (Catch the wave. The long cycles of industrial innovation are becoming shorter, 2014).

Robert Solow’s (1956) research further validates Schumpeter’s theory, showing that technology, which is created through innovation, plays a crucial role in production output and continued economic growth. The model he proposed describes how he believes the economy is growing despite undergoing cyclical changes. **Figure 2** displays that real output in the economy fluctuates over time. This fluctuation is referred to as the business cycle. The business cycle is marked by expansions, which are the upwards movements of this line and contractions for the downwards movements. These movements describe how the real level of the output in the economy changes over time. The upwards facing dotted line represents the economy’s growth in terms of GDP.

The question many classical economists have been trying to explain is why the economy constantly grows. Solow explains this by looking at capital accumulation, labour (population) growth and productivity increases. He finds that the growth is mainly explained by technological progress (productivity increases). Solow finds growth is not merely caused by capital since capital has a decreasing return to scale. This means that if capital increases in a fixed labour supply market, the output will not increase continuously as the economy will eventually reach a steady state. If invested capital exceeds an equilibrium point, it will no longer drive economic growth.

Figure 3 illustrates how the Solow growth model works. More specifically, it explains why the economy reaches a steady-state equilibrium, where new capital no longer drives growth. As long as the depreciation line (Required investments) is below the investment line (Saving = actual investments), investments into the economy will increase. Once the investment line crosses with the depreciation line, the market reaches its steady-state equilibrium. Everything before this cross will lead to further growth of the economy fuelled by invested capital. After that point, there will be a decrease in net investments in the economy. Therefore, the economy will always revert to a steady-state. Only once technology enables new business models and products, capital and labour can once again drive growth.

The Solow model shows that technology (productivity increases) plays a vital role in developing the economy. Intuitively, the question arises of how new technology is created and which factor plays a role in this development.

This is being explained by Paul Romers (1990) in his paper endogenous technological change. Romers and Solows beliefs differ substantially on one point. Solow's model anticipates the growth of ideas as exogenous and assumes them to be a public good, which does not relate to capital or labour.

Even though, Romers, just like Solow, sees ideas and thereby the development of new technologies as the driver for growth. He states that researchers who are profit-maximising agents are at the nucleus of the immediate pre-commercial stage of growth. Hence, he describes ideas and the resulting new technologies as non-conventional and not being a public good.

Furthermore, Romer's description labels ideas as a non-rival, potentially excludable good, which means it does not support price-taking competition. He states that; it needs a monopolistic competitive environment because ideas cannot be sold in competitive markets since their marginal cost is zero. The investment in R&D to "research" an idea needs to be funded, which means the investor needs a monopolistic power to recoup the initial investment.

In conclusion, it becomes clear that innovation is a force driving the economy and human life. The result of innovation is the development of new technologies, which enable new business models and thereby create economic growth. However, growth does not come without cost since new ideas are born through human capital or, as Romer's puts it, profit-maximising agents. Therefore, capital needs to be invested to generate ideas. In times of newly forming economic cycles, these investments in ideas are significant since they give the potential for creative disruption and competitive advantages by attracting capital and generating growth through differentiation.

2.2. R&D influence on future firm performance

The previous subchapter stressed how technological change is driven by innovation, and is highly dependent on industrial research, entrepreneurship and academics. In most economies, businesses represent the main driver for innovation (Link and Siegel, 2007). Companies invest heavily in R&D, which potentially generates new sources of revenue. A company's investment in R&D can be seen as an investment into the future. Companies aim to attain intangible assets, which might later convert into increasing cash flows, thereby creating growth opportunities (Chauvin and Hirschey, 1993). Managers will only invest in R&D if the benefits they can attain through their investment are higher than the initial investment cost.

However, if growth opportunities materialise, innovative companies grow more quickly through higher profits (Kleinknecht et al., 1997). Therefore, it seems Schumpeter's argument holds that innovative companies gain an advantageous competitive position in the market. This competitive position is attained in either of the following two ways.

Firstly, through product innovation. Product innovation refers to investing in R&D to commercialise a new product and bring it to the market. Thereby, companies temporarily obtain a monopoly in the market since they can sell products at a price not dominated by competitive price pressure. Additionally, these new products are not available through their competitor's product portfolio, which increases the innovators market power (McDaniel, 2002).

Secondly, the company can increase its cashflows through innovation by saving cost. Innovation in production processes or services can decrease production costs by keeping costs constant when producing more units or lowering the unit cost for the existing products. Therefore, the company can lower prices and undercut competitors to gain more market share. (McDaniel, 2002).

However, many firms do not risk innovating since these growth opportunities are not free of cost, such as spillover effects (Higson, 2001). Furthermore, Asplund & Sandin (1999) and Cozijnsen et al. (2000) find that only one in five started projects is viable, which means that R&D investments face substantial risk. Hence, companies risk investing in long R&D projects without ever generating any benefits.

2.3. The investment in innovation

The investment decision is at the centre of every company. It involves assessing to what degree investments yields a successful outcome. Therefore investment in innovation has to be aligned with their strategy. From a strategic point of view, companies can decide to take several paths to innovation.

Firstly, they can be the innovators who are at the forefront of their respective industry and drive change. Secondly, they can let others innovate and follow the process once they find that innovation gives them a competitive advantage – assuming the innovation process can be replicated. Lastly, they can decide not to innovate and keep operating their business as it is. Thereby, save investments since an innovation-based strategy means committing financial and timely resources. When analysing the market-based forces to competitive strategy Michael Porter’s strategy framework represents a helpful tool.

When using Michael Porter’s generic strategy framework, it becomes clear that innovation plays a vital role in several aspects of these strategies in achieving both differentiation and cost leadership. This is further supported by including Schumpeter’s five characteristics of innovation in combination with those strategies since innovation and these five characteristics directly impact competitive position.

Cost leadership strategies aim at being the lowest cost operators. This typically involves production at a large scale which enables the business to exploit economies of scale. As previously mentioned, is innovation in production processes aiming at achieving precisely this objective. When integrating Schumpeter's five characteristics of innovation, other patterns become evident. Innovation in those characteristics have the possibility to enable company cost reductions.

In differentiation strategies, companies aim at offering products that are unique from the competition. Also, in this case, innovation plays a vital role. Specifically, product innovation is often a way for companies to achieve, for example, superior product quality and differentiate their product from competitors.

However, innovation is not only based on strategy. Multiple external dimensions need to be taken into account when evaluating an investment in the innovative process.

When it comes to the factors that impact innovation, the literature points to size as an essential dimension. An example, therefore, are (Felder et al.,1996), who test the relationship between R&D and other innovation expenditure among small firms. They find that large firms tend to participate more in innovative activities than small ones. However, once small firms decide to innovate, they commit more resources to innovation than large firms in terms of investment in relation to sales. This is further confirmed by (Vossen and Nooteboom, 1996), who add that the commitment of resources amounts to greater productivity once they commit. The relationship between size and innovation seems to be positively correlated, even though no linear relationship was found (Kleinknecht, 2000).

In addition to the size of organisations playing a role in the innovation-decision, financial constraints and human capital need to be considered.

Hall and Lerners (2010) findings suggest that small and innovative firms face a higher cost to finance innovation, which is only partly lowered by the presence of venture capital. For large companies, they find mixed results. However, large firms tend to use internal financing. Their evidence shows that venture capital cannot fully bridge the innovation gap, especially in countries where financial markets for venture capital exits are underdeveloped. This further explains why large and developed firms are commonly the ones driving continuous R&D efforts. Additionally, putting the findings by Felder (1996), Vossen and Nooteboom (1996) in perspective, since this could be an explanation why smaller firms are less likely to invest on a continues basis. But rather take a one off risk, when the reward is big enough.

Overall it can be concluded that innovation plays a vital role in the firm's decision-making process. Company strategic objectives vary, and their decision to invest in R&D is to a high degree dependent on the strategy they choose to pursue. In addition to the internal strategic decisions, size, financial strength and cost of financing affect the level of R&D investments.

However, the decision for innovation is sometimes determined by government, industry, and customer forces. These external forces represent a critical factor that needs to be considered when deciding on an R&D investment.

A critical factor is the environment in which the company operates. Features such as the legal, regulatory, financial and institutional framework of a country impact firm performance (St. Petersburg State University, 2008). From a firm perspective, property rights and their protection by governments play a vital role in the decisions to invest in R&D. If companies cannot assure that a supportive legal framework protects their investments, companies are reluctant to invest (Link and Scott, 2010). Furthermore, some regions offer better environments for companies to conduct R&D (National Bureau of Economic Research, 2002). The reason therefore being that some regions provide better incentives to innovate through grants and have more developed innovation clusters. Additionally, some regions provide better access to a highly skilled labour force, which can drive innovation. Therefore, firms from some regions yield more positive results in terms of innovation output.

To determine how resources are spent, companies must critically assess how many resources they need to designate to the innovation process, among other alternative investments. The decision is commonly referred to as the analysis of innovation intensity within the industry. Klomp and Van Leeuwen (1999) use R&D as an indicator, and to increase comparability among companies, R&D expenditures are divided by total sales. This is referred to as R&D intensity. This indicator is often used in R&D related research since it has the advantage of being easy to measure and obtain. However, Kleinknecht (2000) points to a weakness of this measure. According to him, it does not provide any information on the efficiency by which a company innovates. Another variable often used in R&D related studies to explain innovation intensity is the number of employees working on R&D related topics. However, this measure also faces the same weakness as R&D to sales by not including any efficiency measures.

Furthermore, does it not give any indication towards the quality of the researching employees. The last indicator of innovation intensity is the share of the new products introduced (Mairesse and Mohnen, 2001). However, this variable is better suited to measure the output and, thereby, innovation rather than its intensity since new products are generated due to the innovation process. Finally, the indicator R&D to total assets is considered since the successful R&D projects are capitalised in the form of intangibles (sometimes as patents), so both size and R&D efficiency are tackled.

Klomp and Van Leeuwen (1999) also highlight three variables related to the investment process: government grants, continuous R&D and cooperations. They describe additional factors as push and pull, previous cash flows, sales, sales development, technological opportunities, firm age, and the company sector and size. Furthermore, they find that technological opportunities arising from customers, competitors and suppliers have a larger impact on the innovative output than scientific research.

This means that strategy, size, country effects, innovation clusters, human capital and financing, play a role in the decision to invest in R&D. However, the final question as to whether R&D impacts future firm performance is still unresolved.

2.4. Literature conclusions on the implications of R&D on firm performance

Concerning the overall relationship between R&D and future firm performance, several previous studies find a positive relationship between R&D and firm performance. (Branch, 1974: Morbey, 1988; Long and Ravenscraf, 1994, Aguiar and Gagnepain, 2017) An example of this is Sougianni (1994), who found an increase in R&D spending by one dollar resulted in a two-dollar increase in profit over seven years.

In comparison, others find a non-significant relationship. One of these is the study by Lin et al. (2006), which studies the influence of commercialisation efforts such as marketing play on the performance increase of R&D. They find that R&D only boosts shareholder value if combined with an adequate commercialisation strategy. Specifically, technology-based firms have to develop their knowledge base and invest in communication and relation-building with customers.

In contrast, other scholars find a negative relationship. Caves (1996) found a negative relationship across industry sectors in the UK. Another example is Mank and Nystrom (2000), who analyse the return of corporate R&D spending on growth in stock value among companies in a fast paced industry, the computer industry. They point towards the possibility that companies overspend on R&D to keep up with the industry rather than spending on R&D because they believe they can revolutionise the product portfolio or production process. Furthermore, they point poor management of the innovation process as a possible reason.

Curtis et al. (2020) provide evidence that the profitability of R&D has declined. They compare US companies from 1980-1990 and find that return on investment in R&D has declined. To explain their findings, they point towards three possible explanations. Firstly, they provide evidence that companies change toward safer and incremental innovations, including successive cohorts and industry shifts, contributing to lower average profitability in recent years. Secondly, the lower interest rates reduced borrowing cost which means that firms might have accepted projects with lower NPV. Thirdly, they hypothesis that the type of R&D performed by the companies in their sample could have shifted. This means that they believe a higher degree of R&D spending was allocate to maintenance R&D rather than strategic R&D.

Furthermore, they developed an empirical model that considers alternative variables that explain future performance and so correct the estimator of R&D investments, and their model is helpful to predict relationship shifts over time.

Since the change in R&D profitability has not been tested for the new wave of technologies that started shaping the fourth industrial revolution, a knowledge gap needs to be addressed. Technology has increased its relevance in business processes, environmental challenges, and customer preferences more extensively than in previous industrial revolutions. Furthermore, markets have also adapted, and intangibles have increased their relevance over other types of assets. In addition, investors have been increasing their demand for a commitment to the innovation process (e.g. the rise of ESG reporting). Therefore, it is interesting to analyse a determinant industry for the change, which is the automotive industry. Challenges to developing technological and environmental vehicles have required a strategical readjustment for the companies in the short term. Given that a highly technological changing environment provides opportunities for those who innovate, leads to the assumption that companies increase their risk by investing more in R&D to achieve a frontrunner position within the completive environment. In theory, this would give them a monopoly position, which should positively influence future firm performance.

Hypothesis:

1) *Investments in R&D have increased future firm performance*

2) *Investments in R&D has increased future firm performance due to the technological shift in the automotive industry*

3. INDUSTRY ANALYSIS

This section aims to provide the reader with an understanding of why the global automotive industry is relevant to explain the research question. The goal is to make the reader aware of the basic industry structure, and highlight the shift the industry is currently undergoing. Thereby, the reader should further understand how the technological shift within this industry could potentially affect the relationship between R&D and future firm performance.

The first two sections will give a brief introduction to the industry. It will start with a simplified description of the global automotive industry operations concerning R&D, production and product distribution. Subsequently, it will explain the economics of this industry by looking at the key drivers of value creation in the global economy. Afterwards, the value drivers of the industry will be explained. Then legal issues and industry challenges are explained, which ultimately leads to an analysis of the trends within the industry.

3.1. Industry operations

The global automotive industry contains a wide range of companies and organisations, which main objective is to design, develop and manufacture automotive vehicles. The industry is divided into two segments: the manufacturers of automotive vehicles, also called original equipment manufacturers (OEM), and their suppliers of parts and raw materials (TIER 1, 2 or 3 supplies). This network of tier-one, two, and three suppliers makes the automotive industry unique regarding its long-reaching value chain, which entails every step from sourcing raw materials to waste disposal (Townsend and Calantone, 2013). These long supply chains require close collaboration, which is also deeply manifested in how the industry conducts its R&D efforts.

The global automotive market is dominated by fierce R&D competition. Factors such as lead time and high-quality output are imperative to global OEM´s (Clark, 1989). Therefore, they actively engage in close relationship with vertical suppliers to communicate new product expectations and required R&D efforts from suppliers. The automotive industry is increasingly moving towards collaborative approaches so called R&D networks. (Nobelious, 2004). This holds explicitly in times of information-technology enabled applications.

The R&D process of automotive manufacturing is divided into two main phases. Those phases are called project phases since they describe the entire project development process from initial research to serial production. The first phase is called the technology period, which describes the actual research period—the second phase consists of the vehicle development period and serial production (Development & commercialisation).

The technology period starts with a definition phase, where initial market research is conducted. After this period, the R&D process moves to the concept phase, where the OEMs start developing innovative technologies and test the feasibility. Afterwards, it moves into the pre-development phase, drivetrain and technology test runs take place. When the concept is confirmed, they start the vehicle development period. This phase starts with the series development process phase. In this phase, procedures focus on practises like production process development, component design and supplier coordination and integration occur. Finally, the pre-series and series production phase takes place (Brunner et al., 2017). The R&D phase within an automotive manufacturer takes multiple reiterations to complete. This feature can make R&D projects length extend on the long term, one proxy could be around five years. **Figure 4** represents the product lifecycle and shows how the initial phases of the project cost the manufacturer resources. After the product has been finished and reaches the market, the manufacturer starts recouping the initial investment.

The production process of cars is undoubtedly a complex undertaking. This complexity also impacts automotive manufacturers supply chain. The production of a single car often requires thousands of components, which outside suppliers largely provide. These suppliers are often located in different parts of the world, which increases complexity in terms of production planning and timely delivery.

The OEM's mainly source parts for automotive manufacturing from tier-one suppliers, focusing on supplying the automotive sector. Tier-two suppliers supply the automotive sector but also supplies other industries. Lastly, the tier-three supplier refers to the suppliers who supply raw materials like plastics and metals.

This section helped specify the steps within the automotive industry and have to be taken into account when looking at the overall development of new vehicles.

3.2. Industry economics

The automotive industry is one of the largest revenue-generating industries in the world. Currently, the industry produces around 91 million vehicles per year, with Germany being the biggest exporter of cars worldwide, serving China as its biggest export market. The industry is highly competitive and is dominated by large players were the top ten OEM's account for approximately 77% of the total automotive production in 2019.

This industry is shaped by global economic conditions, consumer demand, globalisation, technological innovations and government regulations.

Economic conditions play a vital role in the revenues of the automotive industry. Vehicles often represent the second biggest purchases consumers make after their house. This means that consumers are more likely to purchase a new car when economic conditions are good. This is underlined when looking at **Figure 5,** where the consequences of the global financial crisis show a significant drop in sales volumes. This can be led back to the fact that manufacturers plan their production capacities in line with sales predictions, depending on economic cycle forecasts. Planning their production capacity is crucial for automotive manufacturers since it enables them to realise economies of scale. Since the dependency on a wide range of suppliers is present in this industry, wrongfully estimating the production can decrease the flexibility, causing potential bottlenecks which might affect project performance.

Consumer demand is significantly impacting industry economics. Consumers demand more choices, which means that mass-market producers have become more similar to premium car manufacturers because they have to offer consumers multiples choices for customisation when they order a vehicle. An example of this growing consumer demand for customisation is that the industry more and more allows customising the body shape and styling of the car. This change has led to a growing amount of vehicles being produced on a standardised platform. Returning to the production planning, it es important to estimate customer demand when planning a new product launch. Wrongfully planning in the definition phase where market research is conducted can lead to fatal consequences on the R&D profitability. Overestimating the demand can lead to a market-led price decrease, which risks meeting the desired profit goals for the investment outlay. Another factor that has had a significant impact on the industry is the consumer demand for sustainable drivetrain solutions, which will be analysed in-depth in a later section

Globalisation and the influence of global trade on the industry represent another economic factor that shapes this industry. Today, the automotive sector operates in a highly competitive environment. The globalisation of the industry has highly increased since the late nineteen-nineties due to the construction of overseas production plants and the rising amount of mergers among leading industry players, which has led to the increasing synergy effect experience. The largest OEMs have heavily invested in production plants in developing economies to reduce their production costs. However, SG&A expenses have increased due to distribution costs, given the long distances. This is the case since transportation cost has been increasing over recent years (**Figure 6**) distribution costs represent a significant proportion of the OEMs expenses.

The increasing competition between the big players in the global automotive industry and their positioning in newly emerged markets has led to a split within the industry. Today, the industry can be classified into three tiers where GM, Ford, Honda, Toyota, Nissan, Fiat and Volkswagen, among others, represent tier-one. The other two tiers manufacturers fight for market share through consolidation to compete with tier-one producers. The competitive position of the tier-one companies represents a market barrier for new entrants and the large number of small companies that do not have access to the resources to develop new technologies. Therefore, those companies have severe limitations to grow and are doomed to either be acquired or disappear.

3.3. Industry value drivers

Value drivers can be classified into the following three categories: Growth drivers, efficiency drivers and financial drivers. The following section will analyse the automotive industry for those value drivers.

Growth drivers

As previously discussed, the automotive industry is heavily dependent on the global economy. Additionally to the growing world economy, the middle classes in developing countries are growing, which increase the market of potential customers for OEMs. Mobility, for many, represents a luxury, which is why a bulk of the increasing demand for vehicles comes from developing countries. Given that vehicles on the road have a definite lifetime, new car sales in developed countries will continue to represent a growth driver within the industry.

The automotive industry is one of the worlds most R&D intensive industries, which has been highlighted as one of the innovation value drivers on future firm performance. High competition leads to a constant need to innovate. This means R&D is central to the business operations of automotive manufacturers. A high degree of innovation experience can therefore be seen as a value driver for the business. Therefore, continuous R&D investments will create an intangible asset on the human knowledge base present in the company.

The idea of exploiting a potential monopoly out of an innovative investment aims encourages companies to put more effort into their innovation processes. Until spillover takes place, the company benefit through increased sales of the newly developed product.

Efficiency driver

Competition drives efficiency. This means automotive manufacturers increase operational efficiency to stay ahead of the competition. The high amount of competition will create the incentive for the most operationally efficient to undercut costs and push competitors out of the market. These competitive forces can lead to a consolidation within the market since big players will eventually acquire smaller, less efficient competitors.

Given that the R&D investments in the automotive industry are diverse (e.g. zero-emission, and autonomous driving.) and costly, possible cooperations with other automotive manufacturers become a feasible option. This is the case of the current strategic alliance among Renault-Mitsubishi-Nissan, where these three jointly develop a new generation of engines. Furthermore, leveraging synergies can lead to cost savings.

Financial drivers

Having a low cost of capital (optimal capital structure) represents an opportunity for companies since they can realise higher profits on R&D projects. This is explained by the fact that the spread between project return and the cost of capital is higher. Assuming that a competitor could invest in the same project with the same payoff but a higher cost of capital, their profitability would be lower since they have to pay more to finance the project. However, this can also lead to companies accepting projects with lower NPV: Assuming there are no higher NPV projects, companies might decrease their average profitability.

Furthermore, diversity represents a value driver for the industry. Having several products in different markets spreads the OEMs risk. Thereby, it can withstand low sales within one market by selling product in other markets.

Alternative investments represent other opportunities a company can invest in to achieve profitability. Considering that capital is limited, companies need to decide between generating or acquiring growth. Apart from innovation, internally generated growth can be realised through CAPEX investments aiming to find value in tangible assets by exploiting them in their production value chain; SG&A and advertising expenses enable companies to gain and retain customers, thereby ensuring sales realisation. External investment opportunities (M&A), both vertical and horizontal, can be found through acquired synergies or growth opportunities represented by assets that cannot be developed internally or by extending the product portfolio.

Outsourcing represents another possibility to increase company performance and profitability. With increasing capabilities from close suppliers, automotive manufacturers can outsource more of their assignment, thereby saving cost. However, in this case, the OEM´s are losing their knowledge base and become more dependent on outsiders.

3.4. Industry background and challenges

The automotive industry currently faces unprecedented pressure to change. Technological advancements and sustainability concerns have become the centre of attention for customers and regulators alike.

A digitalised customer preferences shift has made the automotive industry rethink the concept of the vehicle. The integration of mobile devices, connected vehicles and driver assistance systems have become key in developing new vehicles. Even more, the challenges are going further towards an independent, autonomous vehicle. These innovative projects require additional efforts by companies to develop new products that meet the constantly changing customer requirements.

Sustainability has become a topic among policy-makers around the globe and has led to increasing regulation concerning CO_2 emission. The Paris and Kyoto agreements have impacted the way governments try to create a positive change for the environment. For the automotive industry, those regulations have led to increasingly strict policy concerning CO_2 emissions. Europe, for example, has set the ambitious goal to lower greenhouse gas emissions by 55% by 2030 and be climate neutral by 2050 (Climate Action, n.d). To enforce this change among OEMs, the European Union set forward CO_2 emission standards, which need to be met. If producers do not meet these standards, they face heavy fines. Previous attempts by the government to reduce CO_2 emissions were based on reducing fuel consumption. However, ambitious goals call for more drastic solutions to meet the required targets.

Therefore, policy-makers push for a change by subsidising consumers when purchasing a vehicle with battery-electric powertrain technology. However, this increasing sustainability focusing policy is not just on the European agenda but is prevailing around the globe.

As a result of growing concern about the environmental impact of global mobility, governments started introducing vehicle emission standards. These standards regulate how much CO_2 cars are allowed to emit through their exhaust systems. Standard-setting started in 1966 with the California agreement. Europe was bound by the Kyoto agreement to submit a valid plan to reduce air congestion by 2010 and start the second phase of the agreement by 2012. The United States (Environmental Protection Agency, EPA) introduced regulation to limit fuel consumption in 2009. In Japan, the Ministry of Environment has in 2008 further increased NOx and PM Laws, which are among the most restrictive regulation. This showcases that regulators have made a drastic decision to fight climate change. Events like those mark the final push towards a greener and more sustainable future. Given those political changes in line with technological changes the year 2011 was set.

This section highlights how the automotive industry is challenged to develop a technology-integrated and sustainable vehicle of the future in the short term. Moreover, it has become a target to counteract global warming. Therefore, government pressures are increasingly shaping the decisions automotive manufacturers make. Innovation in sustainability becomes the only alternative forward to commercialise mobility solutions in the future successfully.

3.5. Industry transition towards the vehicle of the fourth industrial revolution.

As established in the last section, automotive manufacturers are facing a changing business environment. This change is not only led by policy-makers but also has a consumer dimension to it. Additionally, the fourth industrial revolution drives changes in both “hardware” and software. These changes can primary be led back to a change in consumer behaviour. Today’s consumer expects a highly technological car that offers state of the art software solutions while emitting low amounts of CO_2.

Even though this shift has not come as a surprise, many manufacturers have not anticipated the fast pace of this change. By looking at the electric car, many automobile producers have already recognised the possibility of battery electric vehicles (BEV) in the nineteen-seventies and eighties. However, few have seriously invested in driving the change until the renowned car manufacturer, Tesla, has debuted.

Today, Tesla has overtaken automotive giants such as Ford and GM in terms of market capitalisation. If this is due to its technological breakthroughs remains to be seen. The fact is that investors see potential in the company and its products. Tesla has revolutionised the industry by focusing on BEV in combination with a high level of technical know-how in software development. The company has built a viable alternative to combustion-fuelled engines at an affordable price to a broad customer range.

The switch to BEV is seen as the way out of the CO_2 emission problem. This shift represents significant changes in the industry since the BEV requires fewer parts than a combustion engine vehicle. These changes will severely impact suppliers and force them to reinvent their product offering in the future. Consumers and policy-makers alike see the future of mobility as being electric. However, to make this switch possible, it is essential to consider that BEV’s need energy to be charged. The idea is that renewable energy sources will provide electricity to power the mobility of the future.

Nevertheless, the BEV is still in its early days of adoption and still suffers from some infancy diseases. Firstly the milage represents a problem many early adopters fear. Comparing the charging time of an electric car like the Porsche Taycan, which is currently the fastest charging car on the market, to internal combustion fuelled car, it is evident that it takes substantially longer. Additionally, the range and charging infrastructure play a significant role for many consumers, which is another factor currently restricting the BEVs. Furthermore, batteries are susceptive to cold, which means that mileage decreases in cold environments.

Connected cars are a necessary step to autonomous driving. The Connected car refers to the ability of the car to connect with external systems. This means that connected cars will be able to connect with other cars and outside applications such as traffic lights. Additionally, this connection will enable passengers to fully take advantage of the cars as an entertainment and working place. For automotive manufacturers, the connected car is still dependent on developing and implementing 5G technology (Barney,2019).

The automotive industry is moving towards the self-driving car. Fast mobile internet connection and rapid progress in artificial intelligence and machine learning make what once seemed like a utopia soon become a reality. The autonomous car will change how people move, especially in urban areas. These changes in the car of the future already today impact how OEMs spend their R&D, since they carefully have to balance their investment with the potential payoffs (Giffi et al., 2017). A high degree of automotive research and development is moving towards software applications. However, the fully autonomous car is still a long way ahead for the regular automotive user. The degree of automation is divided into five levels. Where level zero represents no automation and level, five is fully automated. The current level of automation is either one (Driver assistance) or two (partial autopilot). To fully automate the driving, further development in sensor technology and software is needed.

Consumers in urban areas are increasingly shifting towards shared mobility with an expected increase by 20% through 2030 (McKinsey, n.d). The first applications such as drive now and Sixt share have already entered the market. This means that automotive manufacturers see a shift away from the trend of owning an own car to shared mobility. For manufacturers, shared cars open up opportunities for new business models where cars are no longer sold but used as shared cars and rented out.

Even though personal ownership of cars will most likely decrease in the future, the cars in use will be used more extensively. This is caused by lower overall cars in the market. Additionally, previously excluded customers will be able to use autonomous shared electrical vehicles such as elderly, sick or people without a driving license (Kuhnert, Stürmer and Koster, n.d.). This shift will most affect the lifetime of a vehicle, which means that manufacturers would be able to sell or rent out new cars frequently.

In conclusion, the choice of the industry finds its reason when understanding how external pressures (e.g. government and customer forces) have forced the firms to create the green and technological vehicle of the future in the last ten years. The automotive industry faces many challenges and uncertainties but has finally opened its eyes to other possibilities. Nevertheless, these possibilities are still in their infancy and require much work before they become commercially viable. This means that automotive manufacturers will be forced to invest considerable amounts in R&D to eradicate feasibility problems and drive the integration of information technology. Therefore, now more than ever, it is crucial to understand if R&D investments will continue to bring the growth automotive manufacturers desire. One thing is sure, demand for mobility will be there in the future. However, the question is, who will be delivering it to the consumer? This means it is necessary to understand the value that R&D brings in a technologically changing environment like the automotive industry.

4. EMPIRICAL FRAMEWORK

This section aims to provide statistical support to the research question to explain whether the theory presented in the previous sections holds in an empirical study; this is a model that tests to which extent R&D contributes to future firms performance in the industry and whether the shift to a more technological industry has impacted the relation.

The empirical approach to address the research question is held from a forecasting perspective meaning that, the model proposed intends to provide an accurate prediction of the future payoffs generated in the automotive companies as a whole from each unit invested. Therefore, a Pooled cross-section method is best suited to fit the research question. The central assumption about the data collected is that it is a group of independent cross-sections collected at different points in time.

As shown in Section 2, the year and the country in which the investment is made are relevant to invest in R&D; therefore, unobserved factors are expected to affect the regression. Therefore, the regression is forced to include dummy variables that control for those effects. Moreover, to avoid the serial correlation, the model will be estimated using robust standard errors clustered by year and by company since the company is the unit that is finding the cross-sectional correlation due to overlapped sampling over time. (Wooldridge, 2020)

A Company Fixed Effects model was not chosen (also agreed with Curtis et al., 2020) because a Pooled cross-section solves the research question better. The main focus is whether R&D has changed its relationship with future firm performance regardless of the company investing. Therefore, there is no interest in providing inferences based on a within-firm estimator around the central hypothesis. However, as a robustness test, a Company Fixed Effects specification is provided in section 6.2.

4.1. The models

Once known how the data is structured, and following the models proposed by Curtis et al. (2020), a single regression model (SLR) that captures the effect of R&D expenditures on future firm performance was chosen to see the nature of the relationship *(Model 1)*:

(Model 1) $$NI_{it+1,t+n}^{Adj} = \beta_0 + \beta_1 R\&D_{it} + u_{it}$$

First, the dependant variable ($NI^{Adj}_{it+1,t+n}$) is chosen as a performance indicator since it captures the effects of R&D of increased sales, decreased expenses, and gains on sales of assets. This variable is a return-on-assets variable with returns measured as an aggregate of future Net Income divided from the period *t+1* until the investment is expected to generate those incremental returns (*t+n*). This refers to the positive side of the bell curve (Figure 5). E.g. if the horizon in which the companies in the sample are expected to reap their benefits is three years, the dependant variable will consist of the sum of the net income generated over the three years after the year in which that investment is made.

The adjustment on Net Income is calculated by adding back R&D, advertising and depreciation expenses, thereby avoiding mechanical associations with the cost of the different investments controlled by the model (Lev and Sougiannis, 1996).

The independent variable ($R\&D_{it}$) is the measure of R&D intensity calculated as the R&D expenditure of the year *t* scaled by Total Assets at the end of the period *t* to address the size effect. The choice is made based on the R&D intensity value creation previously explained.

The R&D intensity impact on future firm performance will be tested by looking at the coefficient associated with the variable $R\&D_{it}$, this is:

$$H_0: \beta_1 > 0$$
$$H_1: \beta_1 \leq 0$$

If the null hypothesis is not rejected, the inference on the relationship will show a positive impact of R&D expenses on future firm performance. Otherwise, there will not be enough statistical evidence to support this statement.

While this first model helps to understand the economic significance of the R&D expenses on future firm performance, it is not sufficient to solve the research question fully. In order to test if the technological shift has positively impacted the relationship, a multiple regression model (MLR) is specified *(Model 2):*

(Model 2) $$NI^{Adj}_{it+1,t+n} = \beta_0 + \beta_1 R\&D_{it} + \beta_2 R\&D_{it} * Tech.Shif_{\ it} + \beta_3 Tech.Shif_{it} + u_{it}$$

$Tech.Shif_{it}$ is an exogenous dummy variable defined as one if the observation is made after 2011 and as zero if it is made before. The choice of a fixed year for the shift is based on the increased regulations on CO_2 emission reductions and demand for self-driving BEVs in the automotive industry. However, an alternative specification allowing a transition period will be provided in the robustness test section (6.2). A change in the slope after the technological shift is enabled by interacting this dummy variable with the main explanatory variable.

After setting *Model 2,* the second hypothesis can be assessed by testing if the coefficient associated with the change in the slope due to the technological shift ($R\&D_{it} * Tech.Shif_{it}$) is significant, so:

$$H_0: \beta_2 > 0$$
$$H_1: \beta_2 \leq 0$$

An interesting critique of both *Model 1* and *Model 2* could be how efficiently they deal with endogeneity. As presented in Section 2, there is a possibility that alternative investments can drive future firm performance together with innovation and that there are other market effects that may distort the analysis. Since funds are limited and companies need to decide among alternative investments, variables that reflect those investments will be correlated with the main explanatory variable. Therefore, not including those variables could lead to a problem of omitted variable bias. Hence, the assumptions of exogeneity cannot be satisfied, causing biased and inconsistent estimates, thereby making it impossible to make ceteris paribus interpretations of the coefficients. The sign of the bias is expected to be positive since those alternative investments should contribute positively to the economic performance of the companies.

To address this problem, Curtis et al. (2020) proposed including alternative investment opportunities, current profitability and market variables as control variables to help explain future performance; the alternative investments variables chosen are SGA_{it} to account for Selling General and Administrative expenses, ADV_{it} for Advertising expenses, and $CAPEX_{it}$ for capital expenditures. NI_{it}^{Adj} , ΔNI_{it}^{Adj} are included because the current investment decisions depend on current profitability and are good predictors of future profitability. The Book-to-Market ratio is also included to measure market effects (e.g. the investors premium paid in reaction to the expectations generated on future feasible, innovative projects, therefore NPV positive projects); this variable is often seen as an explanatory variable in other valuation models such as the Fama-French three-factor model. Furthermore, this variable will measure the effect of market valuation adjustments to the book value.

All control variables (except Book-to-Market) are scaled by the total assets to mitigate size effects. All control variables are also interacted with the variable *Tech. Shif* to account for their change in slope caused by the technological shift (*Model 3*)[1]

(Model 3) $NI_{it+1,t+n}^{Adj} = \beta_0 + \beta_1 R\&D_{it} + \beta_2 R\&D_{it} * Tech.Shif_{\ it} + \beta_3 CAPEX_{it} + \beta_4 CAPEX_{it} * Tech.Shif_{\ it} + \beta_5 SGA_{it} + \beta_6 SGA_{it} * Tech.Shif_{\ it} + \beta_7 ADV_{it} + \beta_8 ADV_{it} * Tech.Shif_{\ it} + \beta_9 NI_{it}^{Adj} + \beta_{10} NI_{it}^{Adj} * Tech.Shif_{\ it} + \beta_{11} \Delta NI_{it}^{Adj} + \beta_{12} \Delta NI_{it}^{Adj} * Tech.Shif_{\ it} + \beta_{13} BM_{it} + \beta_{14} BM_{it} * Tech.Shif_{\ it} + \beta_{15} Tech.Shif_{\ it} + u_{it}$

As an alternative to interacting the $R\&D_{it}$with a dummy variable, two separate equations, one for before 2011 and one for after 2011, can be estimated. Therefore, comparing the coefficient associated to $R\&D_{it}$ in both sub-sample models will derive to the same conclusion as the previous model (See *Model 4*)

(Model 4) $NI_{it+1,t+n}^{Adj} = \beta_0 + \beta_1 R\&D_{it} + \beta_2 CAPEX_{it} + \beta_3 SGA_{it} + \beta_4 ADV_{it} + \beta_5 NI_{it}^{Adj} + \beta_6 \Delta NI_{it}^{Adj} + \beta_7 BM_{it} + u_{it}$

4.2. Theoretical assumptions

Before testing the hypothesis presented, some theoretical assumptions need to be made regarding the model and the estimators to pursue the OLS best estimators, also referred to as BLUE. Therefore, it is needed to make assumptions on linear parameters, random sampling, the variation on the explanatory variable, and the zero conditional mean. Leading to the assumptions: Firstly, the changes on all the explanatory variables have a linear impact on the returns as written in the models *(Model 1)*, *(Model 2)*, *(Model 3*) and (*Model 4*); Secondly, the explanatory variable changes across companies and time, this is fulfilled by finding a significant

[1] The variable that captures the M&A deals number (and its subsequent Tech. Shif interaction) has not been included due to the impossibility to access the data as they did from Thomson SDC Platinum.

coefficient for β_j; Thirdly, none of the explanatory variables are biased, meaning that they are not correlated with the error term, so $cov(u|x) = E(u) = 0$. Hence it can be stated that, on average, for all the estimates of the model (j), the following statement is fulfilled: $E(\hat{\beta}_j) = \beta_j$. As a measure of dispersion, especially after using cluster robust standard errors, a constant variance or homoscedasticity for all values of the explanatory variables is assumed, so $Var(y|x) = \sigma^2$.

To ensure the efficiency of the estimators, the models are estimated under OLS assumptions. In this case, because of the nature of the data, all the cross-sectional regressions are pooled (POLS). The significance of the estimators under this methodology should remain, even after allowing the model to control for time effects -to account for unobserved time effects- and country effects -the legal, regulatory, financial and institutional framework-. Also, to guarantee consistency, they should keep significance after using robust and cluster robust standard errors; here is essential to highlight that the observations are clustered on companies and on years to control for the time effects in each company. For the first hypothesis test about the significance of the coefficients, normality on the error term needs to be assumed $u \sim N(0, \sigma^2)$, this guarantees that the errors are independent and identically distributed.

5. DATA & DESCRIPTIVE STATISTICS

This section aims to motivate the choice of the sample, provide a description and analysis of the data and variables chosen, and examine potential undesired relationships that might be found when associating those variables in linear regressions. Additionally, the section will give an understanding of the data given the context in which the companies studied have been brought.

5.1. Sample choice

First, the data collected to test the change in the relationship between R&D expenditures and future firm performance comprises all publicly listed companies within the automotive industry (according to GICS) worldwide. The data collected is observational data because the sample is pooling all companies and analysing their behaviour without any special treatment to any of the groups. The information collected is a set of different financial information publicly reported in each company’s annual reports that will be described later in this section. The data has been compiled through the Eikon Reuters Databases as of fiscal years (FY) from 2001 to 2020. The choice of the first year is 2001 because the previous periods have a significant drop in sample size for many of the variables chosen, and it might blur the inference; 2020 is the last financial period (as of FY) reported for all the sample. This leads to the total amount of companies included being 149.

Secondly, in the same way Curtis et al. (2020) did and to ensure the sample is reflecting the reality of the relation studied as closely as possible, the company-year observations are required to have positive R&D expenditures, sales and total assets; net income must be reported in the periods t-1, t and t+1; the rest of the missing values are set to zero. All the variables have been inflation-adjusted as dollar values of 2020 to avoid distortion for the price changes over the sample. After all the adjustments, the sample consists of 1.115 company-year observations, including 109 firms over the 20 years horizon.

5.2. Descriptive statistics

Table 1 presents a summary of statistics of the variables used. The table shows the average values, the distribution of the sample over the three first quartiles, and the standard deviation of each variable.

Panel A pools all the observations taken over the 20 years of study. There it can be observed that the average expenditure in R&D is USD 1.072M which represents more than half of the average capital expenditures (CAPEX) and almost a third part of the Selling, General and Administrative Costs (SG&A). These results align with the expectations since the automotive industry is forced to keep innovation constant to survive in the industry environment. In contrast, Advertising expenses (ADV) are minor (USD 233M) compared to other alternative investments. In most cases, the high stake of SG&A expenses is explained for the considerable part of the distribution expenses in the automotive industry.

The average year profitability in terms of Net Income adjusted by depreciation, R&D and advertising (NI_t^{Adj}) is USD 4B with an annual average turnover of USD 27.9B. However, comparing the mean and the different quartiles shows a positive skewness on all the absolute variables because of the broad supplier network, from OEMs to niche suppliers. Variables closer to a normal distribution are more likely to find efficient estimators. The variables are scaled by total assets reported (except by Book-to-Market) to avoid skewness on the models. Scaling by the number of sales is not practical since the skew on the variables remains after adjusting (R&D/Sales: Mean 0.24 vs Median 0.03); this explains that many companies have low sales in the sample.

After scaling, the intensity of investments can be analysed; R&D represents on average a 3% of the total assets (a 13% of the total investment controlled in this study), CAPEX represents 5%, SG&A a 12% and Advertising a 1%. The year return on assets, considering as return NI_t^{Adj}, is 9%; however, the return on assets over five years is 70%. It is essential to highlight that the drop in observations in this variable is due to the requirement for firms to have five years of future net income reported. The book-to-market ratio shows an average value of 91%, which can be interpreted as the average company market valuation in this sector is 9% over book value.

Panel B shows the mean and the median split by period analysed and is helpful to analyse the changes in trends. The industry is presenting growth in its financials since both balance sheet items and income statement items are increasing. However, in relative terms, only the R&D and the advertising expenses have substantially changed. The R&D has shifted from 2% to 3% of the total assets. These investments have also increased relative to the total amount invested, which could be explained by the increasing need of integrating newly emerging technologies in their portfolios. Concerning the current profitability, an increase in the absolute number and a decrease relative to total assets is observed; this means that the profitability has not increased at the same level as the companies' size had grown. Another relevant change is observed in the Book-to-Market ratio, which has deteriorated from 1.27 to 0.76. This means that the market has increased its valuation of the companies assets after 2011; even more, before 2011, the book values were higher than the market prices.

The next step is to analyse the relationship between the variables of the sample. Since the model proposed is a linear regression, it is vital to start by looking at the linear relationship between the different variables. This relation should help predict the coefficients when estimating the linear models proposed. The correlation matrix is a valuable tool to analyse with the estimators in the regressions to detect potential non-linear relations between variables.

Table 2 is the correlation matrix, and it is structured in three panels, Panel A for the whole sample, Panel B for the subsample before the technological shift and panel C after the shift.

The first and most important thing is that all alternative investments in the industry (R&D, SG&A, CAPEX, Advertising) are positively correlated with the performance variable $NI_{it+1,t+5}^{Adj}$. This could tentatively support the idea that investments create financial wealth, and so, after a five-year time horizon, they can realise their returns. However, to test the causality direction, a linear regression model needs to be conducted. This analysis also confirms the predictions of positive bias estimators for *Model 1* and *Model 2,* as discussed in Section 4.1. The linear correlation between R&D and future firm performance has increased after 2011. However, as said above, from this table, it cannot be confirmed that increases in R&D cause higher performance after 2011.

6. EMPIRICAL ANALYSIS

In this section, the base model is estimated, the regression results are described and contrasted with the economic theory. In the robustness test section, additional specifications basing on the main models are included to test for the robustness of the results.

6.1. Analysis of the results

This empirical study anticipates five years for the investments taken to realise their returns. This is referred to as the payoff horizon. Therefore, the profitability is measured as the aggregate of the net income from the periods as of FY *t+1* till *t+5*

However, since R&D expenditures include a wide variety of investment projects with different realisation horizons, choosing a fixed payoff horizon for all the investments in one industry can be problematic. In the following subsection, shorter investment horizons will also be tested to analyse whether the profitability is realised in a shorter period or not.

Table 3 presents the coefficients for all the models estimated in this section. Firstly, Panel A is helpful to test whether the relationship is robust to company and year effects and to robust and cluster robust standard errors on country and year. For simplification, this first part only tests models without $Tech.Shif_{it}$ interactions (*Model 1* and *Model 4*).

The results of the SLR model are presented in columns 1 to 4. In (1), the results show that with a 99% confidence level, one dollar invested in R&D on average represents a 4.58 dollars increase in future profitability. After controlling for country and year effects (2), the average impact increases to 7.65 dollars. This result holds in magnitude and significance when using robust (3) and company and year cluster robust (4) standard errors. The MLR models estimates are presented in columns 5 to 8. In this second model, the future performance explanation is split among different variables, so the omitted variable bias identified is mitigated, and so the goodness of fit of the regression (R^2) increases. (5) shows with a confidence level of 99% that one dollar invested in R&D contributes on average with 3.70 dollars to future firm's performance. The only significant alternative investments found (at 95% confidence level) are CAPEX and SG&A, contributing on average with 0.97 and 0.74 dollars respectively; the current period performance is significantly contributing with 3.66 dollars on average. When including the country and year effects (6), the contribution of R&D increases to 6.96 dollars on average, and only SG&A of the alternative investments remains positive and significant (1.09 dollars on average), these conclusions hold when using robust (7) and company and year cluster robust (8) standard errors.

Panel B provides a summary of the main regression for the hypothesis test with different specifications. (9) and (10) are, respectively, the estimates of *Model 2* and *Model 3*. Therefore in *Model 2,* at a 95% confidence level, it can be assumed that, on average, the R&D investments produced after 2011 are contributing 2.79 dollars more than the investments produced before 2011. Furthermore, in *Model 3,* at a 90% confidence level, the new R&D investments give on average 3.27 dollars more than before 2011. None of the alternative investments found a significant change in the relationship with the future performance. This effect is consistent with the observed when estimating the two subsamples using *Model 4* (see columns 11 and 12).

6.2. Robustness tests

This section aims to provide additional tests to ensure the robustness of the results presented in 6.1. Therefore, limits on the inference can be established.

The residuals of the primary specifications have been estimated to give more visibility over the quality of the predictions generated. Figure 7 can give the reader an idea of how accurate the model is when predicting responses. Even though strong evidence can not be obtained from it, at first sight, there are no signs of potential heteroskedasticity on the *Model 3* and *Model 4* used to test the main hypothesis. Most of the residuals seem to be randomly distributed between the values one and minus one.

As discussed in section 4, a Company Fixed Effect specification of *Model 3* can provide further information on whether the main inference holds when estimating a model with "within company" estimators. Results are presented in *Table 4*. Two things can be observed: Firstly, only the coefficient associated with R&D stays positive in the entire period (2001-2016); Secondly, the significance of the estimator associated with R&D expenses drops after the technological shift. More in detail, the results suggest a negative impact of R&D expenditures on future firm performance before 2011 and a positive impact afterwards. These findings conclude that the shift inferred from the pooled cross-section cannot be extrapolated at the "within company" level. Therefore, the test fails to reject the hypothesis that the technological shift affects the relationship if the firm in which the investment is made is taken into account.

Additionally, it is tested if the results are consistent when using shorter time horizons to realise the payoffs in the dependant variable. Previously the choice of the payoff horizon has been questioned. Since many factors determine the length of the vehicle development period, alternative investment horizons are considered in this part. More specifically, it is tested if the performance is materialising in shorter horizons than the five years assumed under the primary specifications. Table 5 shows the results of *Model 3* for one and three payoff horizons. From columns 18, 20 and 22, it can be inferred that the R&D expenditures contribute to a negative performance on the next period after they are incurred, and no significant change is found due to the technological shift in 2011; also, non of the alternative investments find a significant contribution nor a change in one-year performance. Columns 19, 21 and 23 show a significant change in the R&D profitability measured over three years payback horizon after 2011; all the alternative investments are not finding a significant contribution to the future performance. Since the vehicle development period usually takes several years to reach its commercialisation phase, it is not strange to find inconsistent results when shortening the horizon.

Thirdly, to contrast whether the relationship holds when using different performance measures, an alternative specification with sales scaled by total assets as dependant variables is tested in Table 6. The results show a flip on the sign, and an absolute loss of the economic and statistical significance for all the investment alternatives and for the technological shift. This issue is addressed to the inefficiency of Sales as an indicator of future performance in line with Kleinknecht (2000) findings.

An interesting critique of the primary specification is whether the shift in the relationship is observed immediately in 2011. To allow the model to control for a gradual change in the technological shift, an alternative specification in which 2011 is dropped out is estimated in Table 7. There it can be observed that the magnitude of the coefficients remains. However, the same cannot be said for the statistical significance. Dropping the year 2011 directly affects the number of observations taken into account in the second period (from 292 to 242). This is likely to be the reason why it is not possible to provide inference under these specifications.

7. CONCLUSION

This paper has provided theoretical and empirical proof of the change in the relationship between R&D and future firm performance in the automotive industry with the advent of the technological shift in the last decade. It has contributed to understanding how the coordination of mutual interests among all the automotive companies' stakeholders (e.g. governments, investors, clients, suppliers) has led to successful innovations outcomes. Those innovations have aided global economic growth and have established the first stage in reducing the environmental footprint through sustainable mobility.

After understanding the dynamics that make this industry play a crucial role in technological change, through an empirical analysis, we have contributed to the inconclusive findings of previous scholars by explaining that innovation efforts in a technologically shifting environment contribute positively to future firm performance, even when considering economic distress periods. Additionally, it has contributed by explaining how technological change has become a determinant factor in explaining the increasing relationship between R&D and future firm performance within the automotive industry over the past twenty years. Moreover, it has been inferred that R&D has significantly increased its relation with future profitability over the alternative investments suggested CAPEX, SG&A and ADV. Therefore, based on the findings, it can be concluded that R&D performed distinguished contribution on future profitability with an increased relevance because of the shifting technological environment in the industry. These conclusions can be drawn on an industry level. When considering company-specific trends, the positive effect did not reach statistical significance.

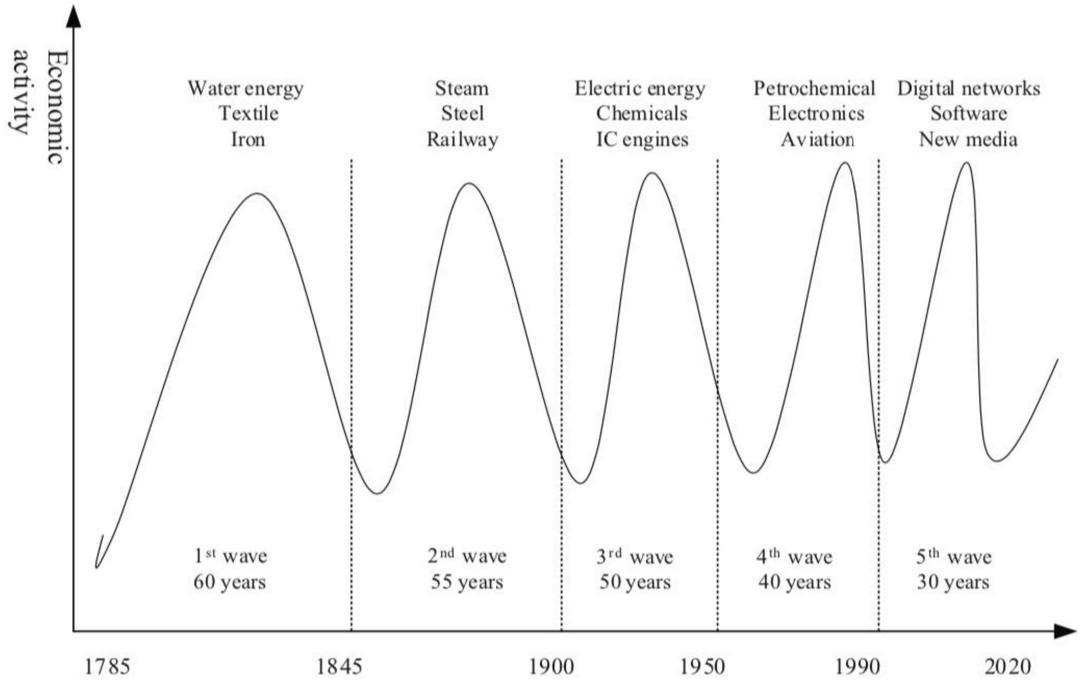
A potential limitation to the model can be found in unobserved effects related to innovation and future performance not considered in this empirical approach. These effects like M&A activity, capital structure, company risk tolerance could have helped control other factors. Nevertheless, the proposed models provide the reader with a tool to make an educated decision on different alternative investments.

Since the study focuses on a single industry over a limited time period, decisions on the payoff horizon and the transition period for the technological shift have been limited because of the constrained sample size.

Ultimately, this research has set the stage for further investigation of the implications of the integrated supplier R&D network on future performance within the automotive industry. Additionally, the proposed research allows for further addition of other factors deemed necessary to explain the relationship. Finally, the research could be further validated by examining other industries and more sample periods. This would then allow the model to increase the payoff horizons for R&D projects and find more accurate predictions on the relationship of R&D on future firm performance.

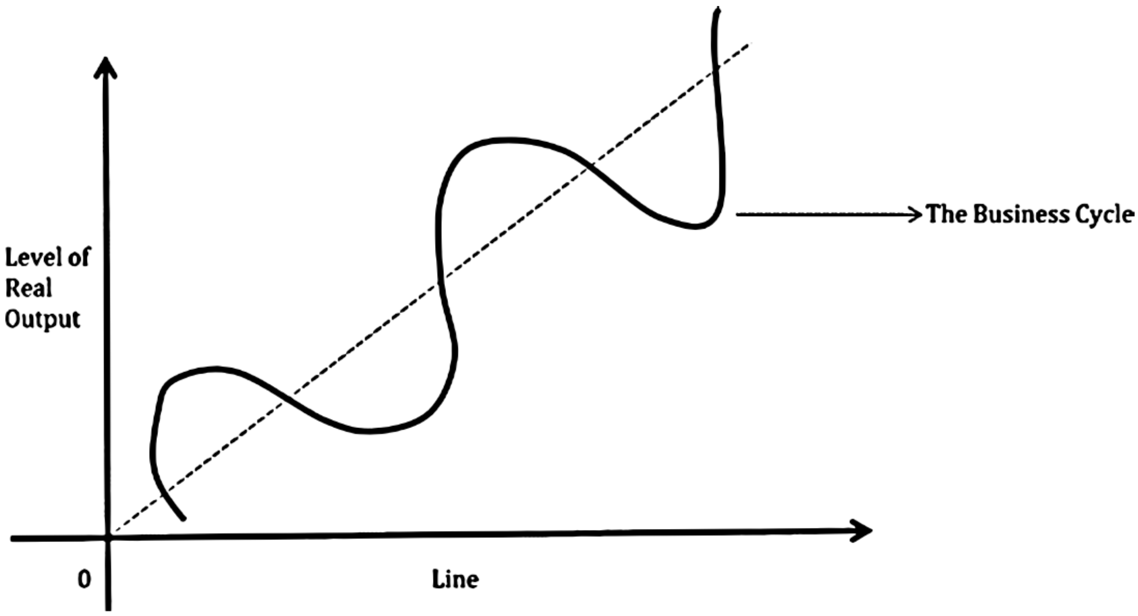
8. APPENDICES

Figure 1 – Innovation waves



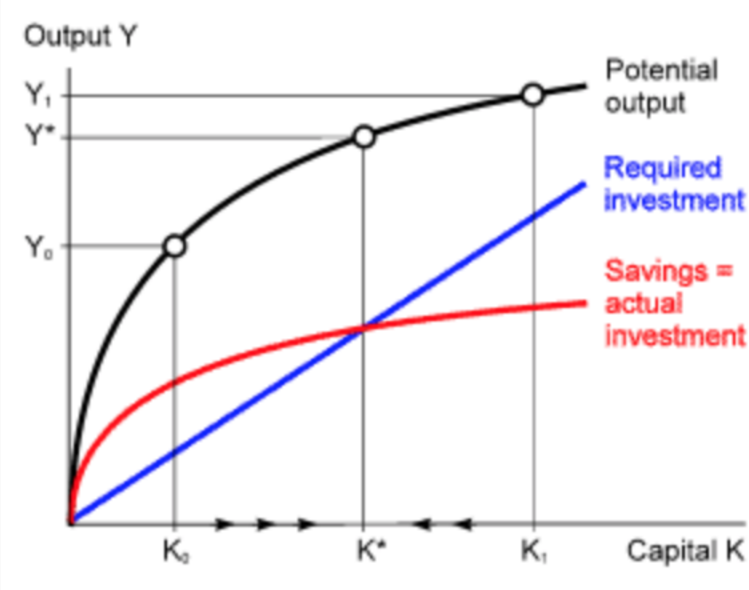
Source: Levi Jakšić et al. (2018)

Figure 2 - Business cycles



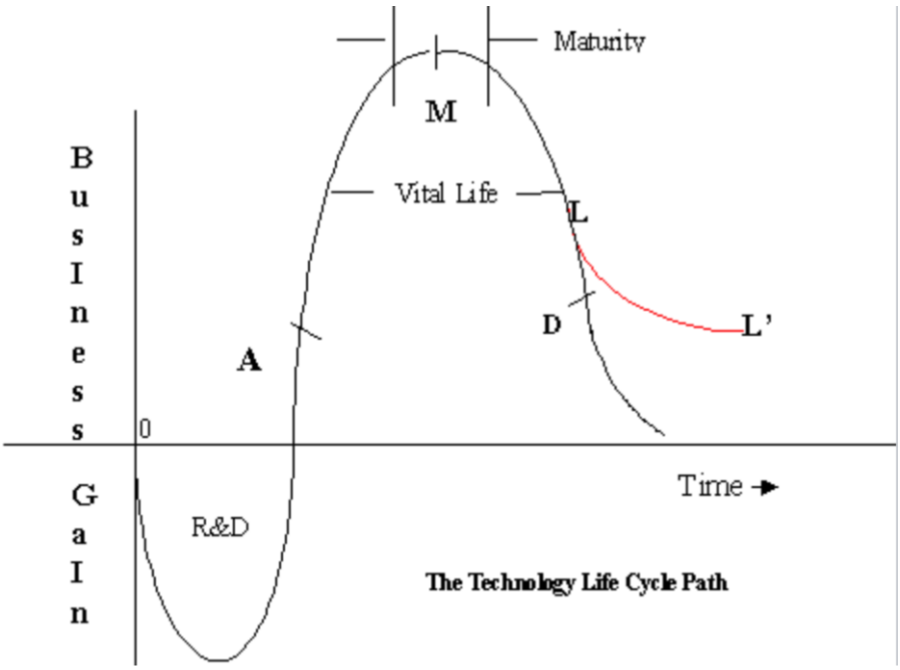
Source: Robert Solows

Figure 3 - Solow’s growth model



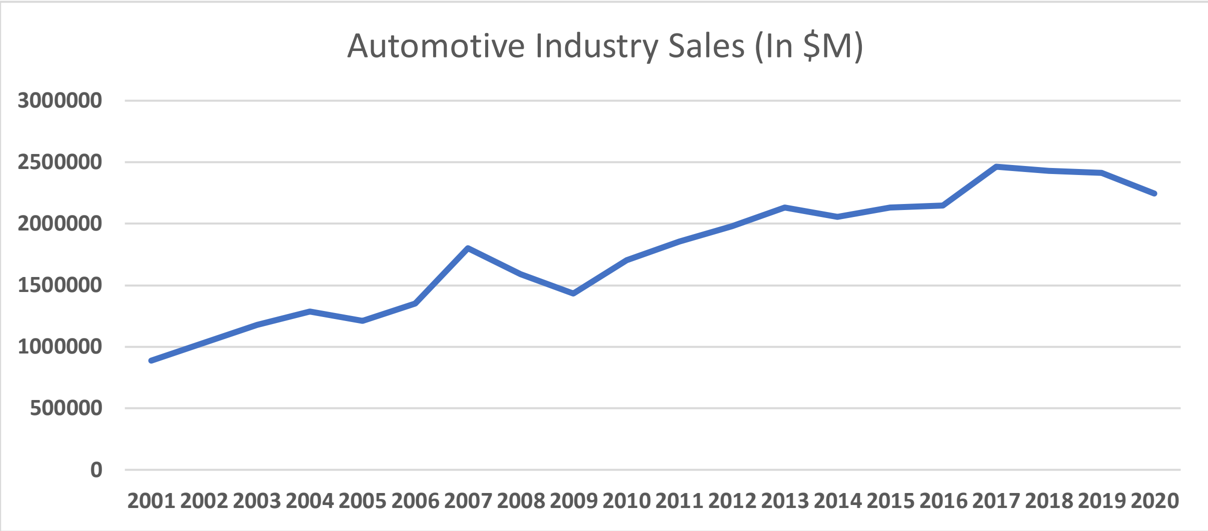
Source:Robert Solows

Figure 4 -Technology lifecycle model



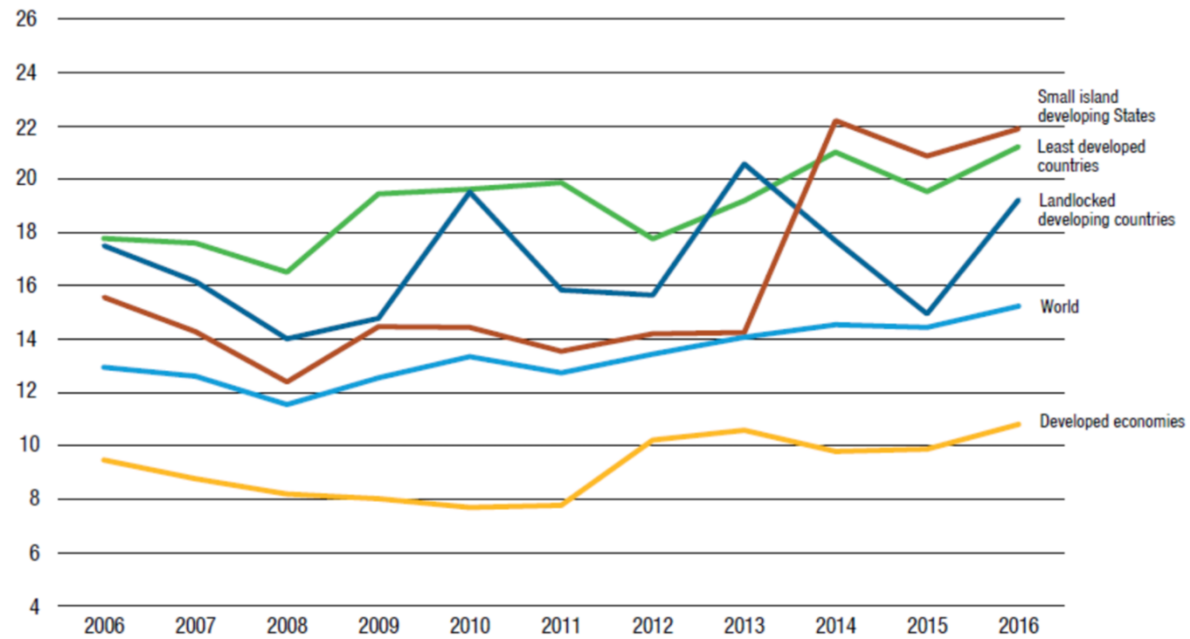
Source: S.Sahani, 2016 How technology shifts can give the first mover advantage

Figure 5 - Global motor vehicle production



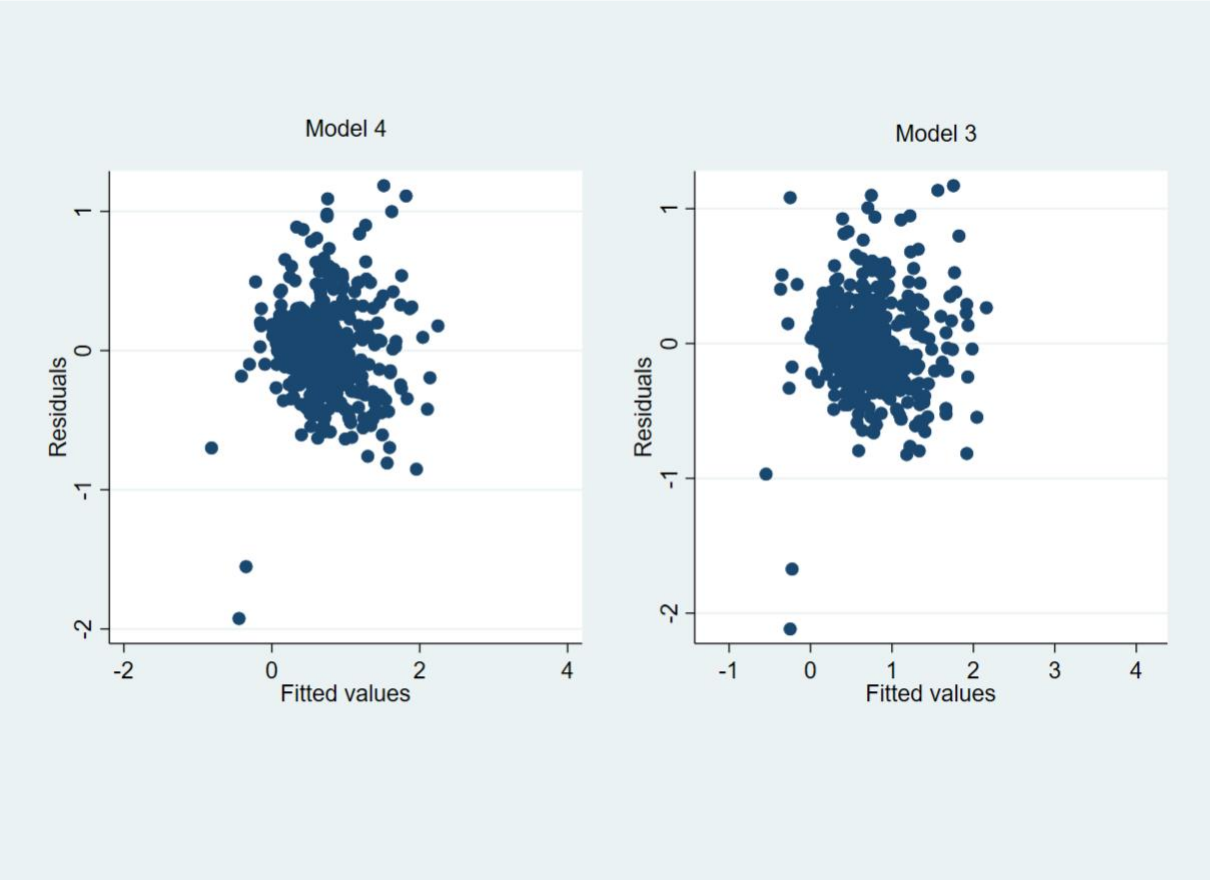
Source: Eikon Reuters Database

Figure 6 - Development of global shipping cost



Source: UNCTAD (2017). Review on Maritime Transport 2017

Figure 7 – Residuals dispersion



Those graphs show the relationship between the predicted values and the residuals.

Table 1 - Descriptive Statistics

Pannel A: Full Sample						
Variable	**N**	**Mean**	**Q1**	**Median**	**Q3**	**Std. dev.**
R&D Expenditures	1,115	1,072.16	7.46	53.73	607.79	2,344.40
R&D/Total Assets	1,115	0.03	0.01	0.02	0.03	0.05
R&D/Sales	1,115	0.24	0.01	0.03	0.04	2.54
R&D/Total Investment	1,115	0.13	0.05	0.12	0.19	0.11
R&D Stock	1,115	3,888.72	22.44	159.28	1,794.44	9,310.25
R&D Stock/Total Assets	1,115	0.09	0.02	0.06	0.13	0.12
CAPEX	1,115	2,101.22	26.14	153.89	1,009.28	4,882.10
CAPEX/Total Assets	1,115	0.05	0.02	0.04	0.07	0.04
SG&A Expenditures	1,115	3,128.56	65.94	309.38	2,608.89	6,147.79
SG&A/Total Assets	1,115	0.12	0.06	0.09	0.15	0.09
ADV	1,115	232.84	0.00	0.00	40.85	687.64
ADV/Total Assets	1,115	0.01	0.00	0.00	0.01	0.02
NIAdj	1,115	4,023.11	57.17	325.00	2,608.47	8,403.66
NIAdj/Total Assets	1,115	0.09	0.06	0.10	0.15	0.12
Book-to-Market ratio	1,115	0.91	0.35	0.63	1.04	1.51
NIAdj/Total Assets(t,t+5)	513	0.70	0.39	0.61	0.96	0.54
Sales	1,115	27,965.20	793.53	3,269.40	18,659.83	55,411.33
Total Assets	1,115	40,786.95	848.19	2,954.80	20,020.24	90,605.05

Panel B: Means and Medians by subsample						
	2001-2010			**2011-2020**		
Variable	**N**	**Mean**	**Median**	**N**	**Mean**	**Median**
R&D Expenditures	333	1,069.51	33.68	782	1,073.29	60.42
R&D/Total Assets	333	0.02	0.02	782	0.03***	0.02
R&D/Sales	333	0.05	0.02	782	0.33*	0.03
R&D/Total Investment	333	0.12	0.10	782	0.14***	0.13
R&D Stock	333	2,532.17	98.18	782	4,466.38***	197.20
R&D Stock/Total Assets	333	0.06	0.03	782	0.11***	0.07
CAPEX	333	2,251.36	152.93	782	2,037.28	154.88
CAPEX/Total Assets	333	0.05	0.05	782	0.05	0.04
SG&A Expenditures	333	3,522.67	258.26	782	2,960.74	348.13
SG&A/Total Assets	333	0.12	0.10	782	0.11	0.09
ADV	333	177.78	0.00	782	256.29**	0.69
ADV/Total Assets	333	0.01	0.00	782	0.01***	0.00
NIAdj	333	3,785.76	301.59	782	4,124.19*	346.11
NIAdj/Total Assets	333	0.10	0.11	782	0.09*	0.10
Book-to-Market ratio	333	1.27	0.74	782	0.76***	0.60
NIAdj/Total Assets(t,t+5)	221	0.74	0.65	292	0.68	0.60
Sales	333	28,349.30	2,660.05	782	27,801.64	3,491.12
Total Assets	333	40,218.62	2,498.67	782	41,028.97	3,338.85

Descriptive statistics for the full sample and for the different peridos before and after 2011. The first row of each expense indicates the absolute value. Subsequent rows show different ratios or scaled variables. All variables except by Book-to-Market ratio are scaled and winsorised annually at the 1% and 99% levels. The difference in means test (two-tailed t-tests) for both subsamples are shown in Panel B. Significance at the 1%, 5%, and 10% levels is represented by *, **, and ***, respectively

Table 2 - Correlations matrix

Panel A: 2001-2020

	$NI_{t+1,t+5}^{Adj}$	$R\&D_t$	$CAPEX_t$	SGA_t	ΔNI_t^{Adj}	NI_t^{Adj}	ADV_t	BM_t
$NI_{t+1,t+5}^{Adj}$	1							
$R\&D_t$	0.23	1						
$CAPEX_t$	0.15	0.21	1					
SGA_t	0.24	0.25	0.13	1				
ADV_t	0.26	0.04	0.16	0.47	1			
NI_t^{Adj}	0.56	0.02	0.04	0.17	0.36	1		
ΔNI_t^{Adj}	0.06	-0.01	0.02	-0.02	0.02	0.03	1	
BM_t	0.00	-0.09	-0.05	-0.09	-0.08	-0.11	0.00	1

Panel B: Subsample 2001-2011

	$NI_{t+1,t+5}^{Adj}$	$R\&D_t$	$CAPEX_t$	SGA_t	ΔNI_t^{Adj}	NI_t^{Adj}	ADV_t	BM_t
$NI_{t+1,t+5}^{Adj}$	1							
$R\&D_t$	0.04	1						
$CAPEX_t$	0.16	0.08	1					
SGA_t	0.19	0.25	0.14	1				
ADV_t	0.15	0.07	0.25	0.33	1			
NI_t^{Adj}	0.39	-0.03	0.16	0.06	0.24	1		
ΔNI_t^{Adj}	0.07	0.00	0.00	0.12	0.01	0.12	1	
BM_t	0.05	-0.11	-0.03	-0.11	-0.07	-0.13	-0.01	1

Panel C: Subsample 2011-2020

	$NI_{t+1,t+5}^{Adj}$	$R\&D_t$	$CAPEX_t$	SGA_t	ΔNI_t^{Adj}	NI_t^{Adj}	ADV_t	BM_t
$NI_{t+1,t+5}^{Adj}$	1							
$R\&D_t$	0.34	1						
$CAPEX_t$	0.14	0.27	1					
SGA_t	0.27	0.26	0.13	1				
ADV_t	0.34	0.02	0.10	0.56	1			
NI_t^{Adj}	0.68	0.05	-0.04	0.24	0.44	1		
ΔNI_t^{Adj}	0.06	-0.01	0.04	-0.14	0.03	-0.05	1	
BM_t	-0.28	-0.12	-0.16	-0.24	-0.17	-0.21	0.03	1

Correlation matrix for the variables of *Model 3* and *Model 4* for the full sample and for the different peridos before and after 2011. The first row of each expense indicates the absolute value. Subsequent rows show different ratios or scaled variables. All variables except by Book-to-Market ratio are scaled and winsorised annually at the 1% and 99% levels. The difference in means test (two-tailed t-tests) for both subsamples are shown in Panel B. Significance at the 1%, 5%, and 10% levels are represented by *, **, and ***, respectively

Table 3 - Main regression estimates (POLS)

Panel A: Standard Error robustness. Models 1 and 4

	2001-2016							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	$NI_{t+1,t+5}^{Adj}$	$NI_{t+1,t+5}^{Adj}$	$NI_{t+1,t+5}^{Adj}$	$NI_{t+1,t+5}^{Adj}$	$NI_{t+1,t+5}^{Adj}$	$NI_{t+1,t+5}^{Adj}$	$NI_{t+1,t+5}^{Adj}$	$NI_{t+1,t+5}^{Adj}$
$R\&D_t$	4.58***	7.65***	7.65***	7.65***	3.70***	6.96***	6.96***	6.96***
	(0.87)	(0.80)	(0.83)	(0.83)	(0.74)	(0.75)	(1.25)	(1.25)
Controls								
$CAPEX_t$					0.97**	-0.52	-0.52	-0.52
					(0.44)	(0.41)	(0.97)	(0.97)
SGA_t					0.74**	1.09***	1.09***	1.09***
					(0.29)	(0.32)	(0.33)	(0.33)
ADV_t					0.23	-1.32	-1.32	-1.32
					(1.45)	(1.45)	(1.17)	(1.17)
NI_t^{Adj}					3.66***	2.89***	2.89***	2.89***
					(0.25)	(0.23)	(0.42)	(0.42)
ΔNI_t^{Adj}					0.01	0.00	0.00	0.00
					(0.01)	(0.01)	(0.01)	(0.01)
BM_t					0.02**	0.00	0.00	0.00
					(0.01)	(0.01)	(0.01)	(0.01)
Intercept	0.59***	1.95***	1.95***	1.95***	0.04	1.24***	1.24***	1.24***
	(0.03)	(0.26)	(0.33)	(0.33)	(0.05)	(0.23)	(0.38)	(0.38)
Year & Country Effects control	N	Y	Y	Y	N	Y	Y	Y
Obs	513	513	513	513	513	513	513	513
$Adj\ R^2$	0.05	0.45	0.45	0.45	0.39	0.61	0.61	0.61

This table shows the coefficients for *Model 1*: (1), (2), (3) and (4) and *Model 3*: (5), (6), (7) and (8). Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Panel B: Estimates of Models 2, 3 and 4

	2001-2016		2001-2010	2011-2016
	(9)	(10)	(11)	(12)
	$NI^{Adj}_{t+1,t+5}$	$NI^{Adj}_{t+1,t+5}$	$NI^{Adj}_{t+1,t+5}$	$NI^{Adj}_{t+1,t+5}$
$R\&D_t$	5.680***	4.467***	5.436***	7.150***
	(1.111)	(1.394)	(1.174)	(1.844)
$R\&D_t * Tech.Shif_t$	2.796**	3.274*		
	(1.392)	(1.779)		
Controls				
$CAPEX_t$		-0.012	-0.805	-0.170
		(0.696)	(0.693)	(1.346)
$CAPEX_t * Tech.Shif_t$		-0.567		
		(1.140)		
SGA_t		1.508***	1.584***	0.660
		(0.427)	(0.454)	(0.428)
$SGA_t * Tech.Shif_t$		-0.677		
		(0.470)		
ADV_t		-0.340	-1.682	-0.654
		(1.838)	(2.213)	(1.434)
$ADV_t * Tech.Shif_t$		-2.060		
		(2.145)		
NI^{Adj}_t		1.856***	1.521***	4.112***
		(0.423)	(0.416)	(0.602)
$NI^{Adj}_t * Tech.Shif_t$		1.842***		
		(0.676)		
ΔNI^{Adj}_t		-0.006	-0.012	0.016***
		(0.009)	(0.011)	(0.005)
$\Delta NI^{Adj}_t * Tech.Shif_t$		0.018*		
		(0.010)		
BM_t		-0.001	-0.009	-0.090
		(0.010)	(0.010)	(0.060)
$\Delta NI^{Adj}_t * Tech.Shif_t$		-0.065		
		(0.063)		
$Tech.Shif_t$	-0.034***	-0.041***		
	(0.010)	(0.012)		
Intercept	2.324***	1.702***	0.583***	-0.064
	(0.344)	(0.395)	(0.136)	(0.129)
Obs	513	513	221	292
$Adj\ R^2$	0.454	0.633	0.612	0.682

This table shows the coefficients for *Model 2*: (9); *Model 3*: (10); and *Model 4:* (11) for the period before 2011 and (12) for the period after 2011. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4 - FE regression estimates (Robustness test)

	2001-2016			2001-2010	2011-2016
	(13)	(14)	(15)	(16)	(17)
	$NI^{Adj}_{t+1,t+5}$	$NI^{Adj}_{t+1,t+5}$	$NI^{Adj}_{t+1,t+5}$	$NI^{Adj}_{t+1,t+5}$	$NI^{Adj}_{t+1,t+5}$
$R\&D_t$	1.232	-0.315	-0.752	-3.096	2.725
	(2.131)	(2.099)	(1.953)	(2.073)	(1.677)
$R\&D_t * Tech.Shif_t$		2.442	2.789		
		(1.564)	(1.719)		
Controls					
$CAPEX_t$			-0.722	-0.169	-0.722
			(0.950)	(0.933)	(1.314)
$CAPEX_t * Tech.Shif_t$			-1.203		
			(1.372)		
SGA_t			1.388	-0.813	0.590
			(0.942)	(1.457)	(0.624)
$SGA_t * Tech.Shif_t$			-0.250		
			(0.926)		
ADV_t			-6.451**	-8.455**	0.433
			(2.718)	(4.074)	(1.593)
$ADV_t * Tech.Shif_t$			6.141**		
			(2.932)		
NI^{Adj}_t			0.489	-0.465	-1.328**
			(0.552)	(0.485)	(0.624)
$NI^{Adj}_t * Tech.Shif_t$			-0.665		
			(0.589)		
ΔNI^{Adj}_t			0.007	-0.003	-0.003
			(0.006)	(0.004)	(0.004)
$\Delta NI^{Adj}_t * Tech.Shif_t$			-0.005		
			(0.006)		
BM_t			0.003	-0.014**	-0.101*
			(0.005)	(0.005)	(0.056)
$\Delta NI^{Adj}_t * Tech.Shif_t$			-0.021		
			(0.093)		
$Tech.Shif_t$		-0.041***	-0.031*		
		(0.009)	(0.018)		
Intercept					-
Obs	513	513	513	221	292
$Adj\ R^2$	0.131	0.142	0.226	0.275	0.181
ID number	76	76	76	49	71

This table shows the coefficients for *Model 1*: (13); *Model 2*: (14); *Model 3:* (15) and *Model 4*: (16) for the period before 2011 and (17) for the period after 2011. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 5 - Alternative Payoff Horizons estimates (Robustness test)

	2001-2016		2001-2010		2011-2016	
	(18)	(19)	(20)	(21)	(22)	(23)
	NI_{it+1}^{Adj}	$NI_{it+1,t+3}^{Adj}$	NI_{it+1}^{Adj}	$NI_{it+1,t+3}^{Adj}$	NI_{it+1}^{Adj}	$NI_{it+1,t+3}^{Adj}$
$R\&D_t$	-0.309**	-0.543	-0.090	-0.130	-0.653*	1.731**
	(0.157)	(1.001)	(0.214)	(1.197)	(0.360)	(0.793)
$R\&D_t * Tech.Shif_t$	-0.293	2.675**				
	(0.345)	(1.096)				
Controls						
$CAPEX_t$	0.097	-0.228	-0.048	-0.788	0.192*	-0.144
	(0.112)	(0.443)	(0.121)	(0.583)	(0.115)	(0.618)
$CAPEX_t * Tech.Shif_t$	0.054	-0.151				
	(0.141)	(0.596)				
SGA_t	0.029	0.353	0.006	0.365	-0.071	0.023
	(0.053)	(0.237)	(0.061)	(0.293)	(0.127)	(0.228)
$SGA_t * Tech.Shif_t$	-0.099	-0.271				
	(0.108)	(0.285)				
ADV_t	0.053	1.363	-0.002	0.355	0.399	1.318
	(0.266)	(0.914)	(0.359)	(1.219)	(0.386)	(0.851)
$ADV_t * Tech.Shif_t$	0.182	-0.740				
	(0.428)	(1.218)				
NI_t^{Adj}	0.867***	1.618***	0.853***	1.534***	1.018***	2.605***
	(0.081)	(0.318)	(0.088)	(0.326)	(0.083)	(0.229)
$NI_t^{Adj} * Tech.Shif_t$	0.142	0.847**				
	(0.114)	(0.366)				
ΔNI_t^{Adj}	-0.000	-0.001	-0.001	-0.004	0.002	0.011***
	(0.000)	(0.004)	(0.001)	(0.005)	(0.001)	(0.003)
$\Delta NI_t^{Adj} * Tech.Shif_t$	0.002	0.012**				
	(0.001)	(0.005)				
BM_t	-0.001	-0.009	-0.002	-0.012*	-0.009	-0.037*
	(0.001)	(0.006)	(0.001)	(0.006)	(0.007)	(0.021)
$\Delta NI_t^{Adj} * Tech.Shif_t$	-0.004	-0.015				
	(0.006)	(0.023)				
$Tech.Shif_t$	-0.003**	-0.033***				
	(0.002)	(0.009)				
Intercept	0.032	0.611***	0.021	0.361***	-0.007	-5.871***
	(0.051)	(0.140)	(0.024)	(0.084)	(0.034)	(0.335)
Obs	954	707	299	249	655	458
$Adj\ R^2$	0.745	0.788	0.677	0.582	0.760	0.849

This table shows the coefficients for *Model 3*: (18) for a payback horizon of 1 year (19) for a payback horizon of 3 years; *Model 4*: for the period before 2011: (20) for a payback horizon of 1 year and (21) for a payback horizon of 3 years; and for the period after 2011: (22) for a payback horizon of 1 year and (23) for a payback horizon of 1 year. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 6 - Alternative independent variables-Sales (Robustness test)

	2001-2016		2001-2010	2011-2016
	(24)	(25)	(26)	(27)
	$Sales_{t+1,t+5}$	$Sales_{t+1,t+5}$	$Sales_{t+1,t+5}$	$Sales_{t+1,t+5}$
$R\&D_t$	-0.062	-0.043	-0.095*	-0.167
	(0.058)	(0.059)	(0.050)	(0.131)
$R\&D_t * Tech.Shif_t$	0.017	-0.138		
	(0.093)	(0.161)		
Controls				
$CAPEX_t$		-0.045	-0.047	0.033
		(0.039)	(0.052)	(0.087)
$CAPEX_t * Tech.Shif_t$		0.089		
		(0.098)		
SGA_t		0.001	-0.017	0.206**
		(0.044)	(0.049)	(0.098)
$SGA_t * Tech.Shif_t$		0.171**		
		(0.084)		
ADV_t		-0.096	-0.157	-0.592*
		(0.111)	(0.143)	(0.319)
$ADV_t * Tech.Shif_t$		-0.444*		
		(0.231)		
NI_t^{Adj}		-0.062**	-0.053*	0.039
		(0.024)	(0.027)	(0.040)
$NI_t^{Adj} * Tech.Shif_t$		0.109*		
		(0.058)		
ΔNI_t^{Adj}		0.002	0.002	-0.000
		(0.001)	(0.001)	(0.000)
$\Delta NI_t^{Adj} * Tech.Shif_t$		-0.002		
		(0.001)		
BM_t		-0.001***	-0.001***	-0.001
		(0.000)	(0.000)	(0.006)
$\Delta NI_t^{Adj} * Tech.Shif_t$		0.002		
		(0.004)		
$Tech.Shif_t$	0.000	-0.002**		
	(0.001)	(0.001)		
Intercept	0.028**	0.044***	0.018**	-0.004
	(0.011)	(0.013)	(0.008)	(0.013)
Obs	513	513	221	292
$Adj\ R^2$	0.106	0.189	0.263	0.182

This table shows the coefficients for *Model 2*: (24); *Model 3*: (25); and *Model 4:* (26) for the period before 2011 and (27) for the period after 2011. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 7 - Gradual change in the technological shift-2011 dropped (Robustness test)

	2001-2016 (except 2011)		2001-2010	2012-2016
	(28)	(29)	(30)	(31)
	$NI^{Adj}_{t+1,t+5}$	$NI^{Adj}_{t+1,t+5}$	$NI^{Adj}_{t+1,t+5}$	$NI^{Adj}_{t+1,t+5}$
$R\&D_t$	5.826***	4.655***	5.436***	7.058**
	(1.134)	(1.347)	(1.174)	(3.192)
$R\&D_t * Tech.Shif_t$	3.802***	3.202		
	(1.375)	(2.447)		
Controls				
$CAPEX_t$		-0.146	-0.805	-0.421
		(0.697)	(0.693)	(1.418)
$CAPEX_t * Tech.Shif_t$		-0.621		
		(1.198)		
SGA_t		1.485***	1.584***	0.707
		(0.430)	(0.454)	(0.594)
$SGA_t * Tech.Shif_t$		-0.707		
		(0.532)		
ADV_t		-0.453	-1.682	-1.035
		(1.863)	(2.213)	(1.822)
$ADV_t * Tech.Shif_t$		-2.123		
		(2.341)		
NI^{Adj}_t		1.817***	1.521***	4.272***
		(0.417)	(0.416)	(0.733)
$NI^{Adj}_t * Tech.Shif_t$		2.016***		
		(0.754)		
ΔNI^{Adj}_t		-0.007	-0.012	0.016***
		(0.009)	(0.011)	(0.005)
$\Delta NI^{Adj}_t * Tech.Shif_t$		0.019*		
		(0.010)		
BM_t		-0.002	-0.009	-0.070
		(0.010)	(0.010)	(0.068)
$\Delta NI^{Adj}_t * Tech.Shif_t$		-0.055		
		(0.071)		
$Tech.Shif_t$	-0.035***	-0.042***		
	(0.010)	(0.013)		
Intercept	2.344***	1.694***	0.229*	1.139***
	(0.345)	(0.404)	(0.119)	(0.432)
Obs	463	463	221	242
$Adj\ R^2$	0.461	0.636	0.612	0.686

This table shows the coefficients for *Model 2*: (28); *Model 3*: (29); and *Model 4:* (30) for the period before 2011 and (31) for the period after 2012. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

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