CHALMERS
UNIVERSITY OF TECHNOLOGY

The Relationship Between R&D Spending and Firm Economic Performance

A regression study of firms in the industrial equipment manufacturing industry

Master of Science Thesis
in the Management and Economics of Innovation Programme

NIKLAS FREDRIKSSON
JESPER WIKBERG

Department of Technology Management and Economics
Division of Innovation Engineering and Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015
Report No. E 2015:023

MASTER'S THESIS E 2015:023

The Relationship Between R&D Spending and Firm Economic Performance

A regression study of firms in the industrial equipment manufacturing industry

NIKLAS FREDRIKSSON
JESPER WIKBERG

Tutor: Martin Wallin

Department of Technology Management and Economics
Division of Innovation Engineering and Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015

The Relationship Between R&D Spending and Firm Economic Performance
A regression study of firms in the industrial equipment manufacturing industry
NIKLAS. FREDRIKSSON & JESPER. WIKBERG

Master's Thesis E 2015:023

Department of Technology Management and Economics
Division of Innovation Engineering and Management
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Chalmers Reproservice
Gothenburg, Sweden 2015

ACKNOWLEDGEMENTS

We would like to express our gratitude to Martin Wallin for his support in writing this thesis.

ABSTRACT

Despite the importance of innovation for professionals and the considerable attention it have been given by researchers, there are still no unanimous conclusions regarding the relationship between R&D spending and firm economic performance. Most studies have found the relationship between R&D spending and various measures of financial performance to be linear and positive. Other studies that have found it to be linear and negative and some have even failed to detect a relationship all together. Our literature review reveals that a major drawback with previous research is that mainly linear models that did not allow for non-linear relationships have been used.

This thesis aims to provide additional insights to the relationship between the spending on research and development (R&D) and firm economic performance of firms. We aim to make a contribution by providing further empirical evidence on the relationship between the R&D spending and the sales growth and EBITDA margin. This is done by running regressions with linear, quadratic and cubic models for the relationship using a sample of 209 public firms in the industrial equipment manufacturing industry worldwide.

We find that both the average sales growth and the average EBITDA margin can be modeled as single-variable quadratic functions with a parabola that opens downwards. The relationship thus takes the shape of an inverted U-curve, which means that the marginal utility of R&D is first increasing; it then reaches an optimal level of 4%, after which it starts to decrease. The R-squared values for the models are relatively low. Possible explanations for this are the failure to control for variables such as financial strength, R&D capabilities and commercialization capabilities. It is also likely that randomness govern parts of the returns from R&D, which is difficult to model and control for.

The academic contribution of this thesis is the provision of further empirical evidence indicating that the relationship between R&D spending and firm economic performance is non-linear. It also highlights the need for a deeper qualitative understanding for how R&D spending affects firm economic performance. For R&D managers in the industrial equipment sector, this paper is relevant as it provides evidence of the existence of an optimal level of R&D intensity at which firm economic performance is maximized.

Keywords: *research and development, R&D, R&D spending, firm economic performance, Sales growth, EBITDA margin, industrial equipment, inverted U-curve*

TABLE OF CONTENTS

1 INTRODUCTION

This chapter will begin by providing some background to the research problem, followed by a specification of our research question. It will also provide a discussion around the academic and professional contributions and end with an overview of the structure of the report.

1.1 Background

Most firms today consider innovation crucial to competitiveness. In the PwC Global Innovation Survey 2013 (Shelton & Percival, 2013) 83% of respondents answered that innovation was very or quite important to the success of their companies today, and 88% of respondents answered that this would continue to be the case the next five years.

While some innovation occurs accidentally, most new products and processes stem from intentional research and development (R&D) efforts. Despite R&D spending being an important point on the agenda of managers responding to the PwC Innovation Survey, it has not been determined in which ways R&D is beneficial from a firm economic performance point of view. While this question has been researched thoroughly, there are still no unanimous conclusions. Scholars are still debating the direction, magnitude, and whether the relationship is constant or dynamic over time and for different levels of R&D spending.

1.2 Research Question

Considering the importance of innovation and the yet conflicting research results, we believe that additional research is needed to fully understand the relationship between R&D spending and firm economic performance. Consequently, our research question is:

How is R&D spending related to firms' economic performance?

Unlike most previous studies, we will model both linear and non-linear relationships and examine a more comprehensive set of performance measurements. As both the concept of R&D spending and firm economic performance are subject to interpretations, we have defined R&D spending as firms' bookkept R&D expenses and firm economic performance as sales growth and EBITDA margin. For a further discussion and motivation of our performance measurements, please refer to section 3.2 Performance Measurement.

We will investigate this research question using a data sample consisting of 209 public manufacturers of industrial equipment (MSCI: 201060) from Europe, Asia, and North America. We will be looking at the averages of R&D spending and firm performance during 2008 - 2014 in order to manage the stochastic time lag between R&D spending and R&D returns.

1.3 Contributions

Our aspirations are to provide new insights that can drive the process of creating a more generalizable theory and unify the currently diverse research field. These insights are naturally relevant for professionals involved in R&D spending decisions. Our results will help R&D professionals in understanding how an R&D investment will impact the economic performance on average as well as provide guidance on how R&D intensive a firm should be in general.

1.4 Thesis Structure

In the theory chapter, we will discuss relevant theory relating R&D spending to firm economic performance and present a review of the previous empirical research. After reviewing the current body of theory and previous literature we will present a hypothesis.

In the Methodology chapter we will describe the research design and method used to carry out the study. This chapter will also include a description of the data sample and provide a discussion regarding the reliability, validity and generalizability of the results. In the Empirical Findings chapter we will highlight the most important regression results, which we will analyze and discuss further in the Analysis and Discussion chapter. In the final chapter, Conclusions, we summarize the most important findings and key takeaways from the discussion.

2 THEORY

This chapter will first describe the theoretical mechanisms that govern the relationship between R&D spending and firm economic performance. This is followed by a review of past empirical research with focus on the relationships identified these studies.

2.1 R&D Spending and Temporary Monopoly Rents

The universal point of reference defining R&D is the OECD Frascati Manual, which was first published in 1963 (Djellal et al., 2003). The Frascati Manual defines R&D as the following:

"R&D is a term covering three activities: basic research, applied research and experimental development. Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective. Experimental development is systematic work, drawing on existing knowledge gained from research and or practical experience, that is directed towards producing new materials, products and devices; to installing new processes, systems and services; or to improving substantially those already produced or installed." (OECD, 1993)

This definition can be interpreted as that the ultimate aim of R&D activities in a firm is to improve or create new products, services or processes. There are also empirical findings suggesting that these goals are achieved in practice. As an example, Ulku (2007) finds that R&D intensity increases rate of innovation in the chemicals, electronics and pharmaceutical industry. Another example is given by Denicolò (2007) that have reviewed previous studies and found that the relationship between R&D spending and inventions often have an elasticity that is as high as 0,5 or more.

McDaniel (2002) argues that when an organization have developed a new or improved product or service, the novelty of the product or service will grant the organization a temporary monopoly, as it is the only organization able to offer the product or service on the market.

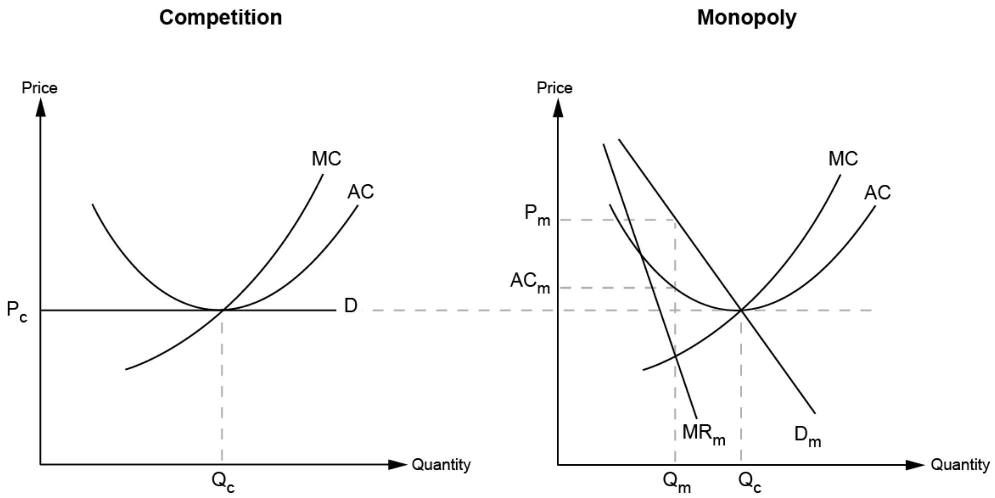


Figure 1 - Profits under competition and monopoly conditions (McDaniel, 2002)

As can be seen in figure 1, firms with homogenous offerings face a horizontal demand curve D and are forced to compete based on price. This drives down the prices to the firms' minimum average cost and they will produce Qc units. At this point the marginal cost equals the marginal revenues and profits are zero, under the assumption of perfect competition and efficient markets. Monopolistic firms on the other hand face a temporary downward sloping demand curve D_m, which enables the firms to set a monopolistic price P_m above their minimum average cost. At this point the firms produce Q_m units and generate monopoly rents of $(P_m - AC_m)*Q_m$. The monopoly rents will continue as long as the offering is unique (McDaniel, 2002). Firms can protect their product or service innovations through intellectual property or by keeping them as trade secrets. However, with time the intellectual property will expire and competitors will be able to reverse engineer the product and service (Thomson, 2011). At that point, new firms will enter the market, pushing down the prices to the minimum average cost, which will erode any potential excess profits (McDaniel, 2002).

McDaniel (2002) claims that improved processes leads to lower unit costs, the ability to produce higher volumes, and higher quality, through standardization and improvement of the production process. Firms that innovate their processes will, for at least a temporary period of time, have a competitive advantage against other firms. Firms that gain a temporary competitive advantage can use it to gain monopoly rents, either through cost or quality advantages.

As stated previously, McDaniel (2002) argues that a novelty of a new product or service will grant the innovator a temporary monopoly. However, to determine the size and the value derived from this temporary monopoly additional models for explanation is needed. Teece (1986) presents a framework that can be used to determine which actors in an industry will appropriate the returns from new products or services under different conditions. This framework can be used to determine the value a new product or service will generate for the innovator, and hence the return to R&D spending.

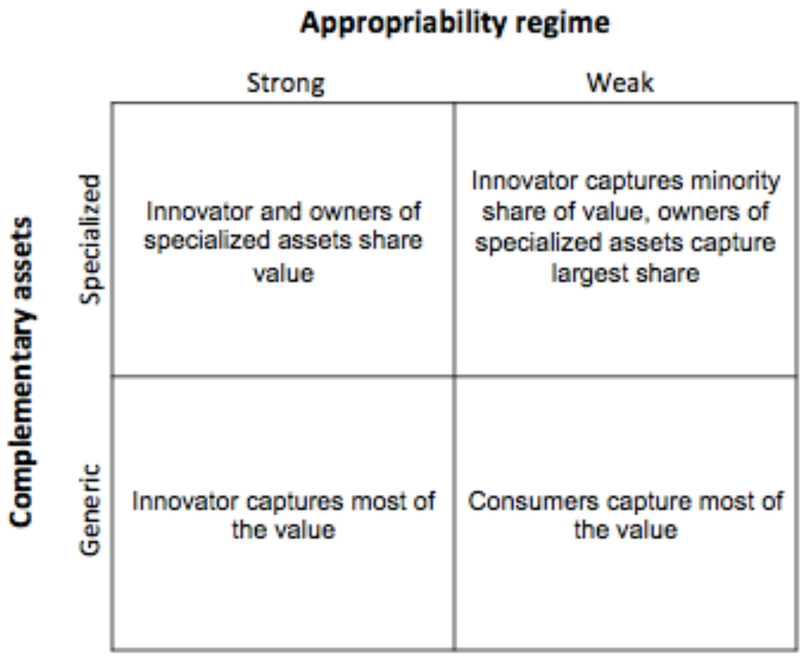


Figure 2 – Appropriation of new returns from products and services depending on complementary assets and appropriability regime (Teece, 1986)

As can be seen in figure 2, which actors in an industry will capture the value from new products or services depends on the appropriability regime and the type of complementary assets required for commercialization of new products or services. The strength of the appropriability regime is dependent on legal and technological factors, where legal factors include e.g. intellectual property rights and technological factors include e.g. the degree of codification and the ease of reverse engineering. Complementary assets are assets or capabilities needed to support commercialization and marketing of new products or services. Teece (1986) categorizes these as being either specialized or generic. Generic complementary assets are assets that do not need to be adjusted to a certain new product or service and can easily be acquired. Specialized assets are assets where there is dependence between the new product or service and the complementary asset. According to Arora and Ceccagnoli (2006) specialized assets are often costly and time consuming to acquire.

As furthermore follows from figure 2, the innovator will capture a larger share of the value if the appropriability regime is strong and if the innovator either has ownership of specialized assets, or if no specialized assets are needed in the commercialization.

2.2 R&D Spending and Firm Economic Performance

McDaniel (2002) argues that new or improved products, services or processes can lead to temporary monopoly rents, which impact sales growth and profitability positively. However, in order to evaluate the impact on R&D on firm economic performance it is necessary to compare the necessary R&D spending with the related returns.

The relationship between R&D spending and firm economic performance can be described in terms of the direction of the relationship and whether the marginal utility of R&D is constant or not. Concerning the direction of the relationship, if the benefits from temporary monopolies outweigh the associated investment, then R&D spending is positively related to firm economic performance. On the other hand, if the associated R&D spending outweighs the benefits from temporary monopolies then R&D spending is negatively related to firm economic performance. However, if the value from the temporary monopolies equals the associated R&D spending then the net effect of R&D spending on firm economic performance will be zero. Lastly, if the returns from R&D are random, R&D spending will be unrelated to firm economic performance.

If the marginal utility of R&D is constant, the relationship between R&D spending and firm economic performance is linear. This theory rejects the notion of diminishing or increasing returns and claims that the marginal utility of R&D is on average the same over a longer period of time. However, another possibility is that the marginal utility of R&D is dynamic and changes with e.g. the level of R&D spending and over time. This would imply that the relationship between R&D spending and firm economic performance is non-linear.

Yang (2010) puts forward several factors, which he argues makes the marginal utility of R&D dynamic and dependent on the level of R&D spending. Firstly, Yang (2010) claims that R&D is subject to economies of scale. He argues that firms that are able to spread out fixed R&D-related costs such as facilities and R&D equipment over a larger number of R&D projects will lower the average cost of an R&D project. Consequently, such firms will gain a cost advantage compared to firms that are unable to spread out the fixed costs to the same extent. However, a greater number of R&D projects require a greater deal of coordination and management. As such, after a certain point the average cost of an R&D project is likely to start to increase with further R&D spending, resulting in diseconomies of scale, as it becomes more difficult to use the fixed assets time and cost efficiently.

Yang (2010) similarly argues that R&D is subject to returns to scale. He claims that firms can improve the output ratio between R&D spending and finished R&D projects by conducting more R&D due to productivity gains from improved project execution. However, productivity will start decreasing at some point, as it will be increasingly difficult to successfully execute numerous projects simultaneously.

The inherent time lag between an R&D investment and the returns of that R&D investment is another factor making marginal utility of R&D dynamic (Yang, 2010). An R&D project might span several years with investments continuously made over the course of those years. Even when the project is finished, it might take additional time before it will be commercially successful. As a consequence, the return to R&D for a given year will be dependent on the number of projects in the various stages of the commercialization process during that year.

Yang (2010) also claims that firms' learning and absorptive capability contributes to the dynamic features of the marginal utility of R&D. He claims that firms gain R&D capabilities through conducting R&D, where R&D capabilities refer to technical competencies and the ability to execute R&D projects successfully. This should for lower levels of R&D spending result in a positive marginal utility. However, if the R&D initiatives as a result of higher R&D spending become too diverse and too many, the knowledge becomes increasingly difficult to internalize and apply to future projects, possibly causing negative returns to additional R&D spending.

There are further arguments for non-linearity in the relationship between R&D spending and firm economic performance. E.g. assuming that firms have limited funds, there should be a tradeoff between spending on R&D and spending on commercialization activities such as sales and marketing where high R&D spending could lead to under spending on commercialization. The effect of this would be decreasing returns to R&D spending for high spending levels.

If the marginal utility of R&D changes sign once, then the relationship between R&D and firm economic performance is quadratic, with a parabola that opens either downward or upwards. However, if the marginal utility changes sign twice, then the relationship between R&D is cubic and can either take an s-curve or inverted s-curve form.

2.3 Firm Region of Origin and Firm Size

Porter and Stern (2001) have shown that some regions are better at conducting and commercializing R&D than others. They argue that firms in regions with e.g. more generous R&D policies, more developed innovation clusters, and greater access to qualified employees are better at conducting and commercializing R&D. Consequently, firms from regions with a good R&D climate might yield a greater returns on R&D than firms from regions with a bad R&D climate.

Previous studies have presented evidence that the R&D capabilities differ between smaller and larger firms. For example, Scherer and Ross (1990) found that smaller firms had a higher return on R&D spending than larger firms. They have shown that smaller firms are more innovative than larger firms since the inherent bureaucratic processes in large firms inhibit both innovation activities and the speed of development. However, there are several counter-arguments. Mintzberg (1993) claims that R&D capabilities become increasingly specialized as firms grow. Consequently, larger firms should have a competitive advantage in R&D compared to smaller, less specialized firms. Cohen and Klepper (1996) also argue that large firms can earn higher returns on R&D due to the advantages of cost spreading. They have demonstrated that R&D spending can be spread over R&D output, hence, larger businesses can gain higher returns on their R&D then their smaller competitors.

2.4 Review of Previous Research

The nature of the relationship between R&D spending and firm economic performance has been studied extensively during the last four decade. Despite this fact, no unanimous findings exist and research is still being conducted. In table 1 we present a non-exhaustive compilation of the most influential work from the past 40 years.

Table 1 - Summary of notable previous research

Year	Author	Country	Sector	Nature of Relationship	R&D and Revenue Growth	R&D and Profitability
1974	Branch	USA	Manufacturing	Linear	Positive	Positive
1977	Schoeffler	USA	Cross sectors	Linear	-	Depends on industry growth rate
1980	Nolan et al.	UK	Pharmaceutics	Linear	Positive	-
1987	Hall	US	Manufacturing	Linear	Positive	-
1988	Morbey	USA	Cross sectors	Linear	Positive	Unrelated
1990	Morbey & Reither	USA	Cross sectors	Linear	Positive	Unrelated
1994	House et al.	USA	Cross sectors	Linear	-	Positive
1994	Singh	India	Manufacturing	Linear	Positive	-
1996	Caves	UK	Cross sectors	Linear	Negative	Negative
1998	Lefebvre et al.	Canada	Cross sectors	Linear	Positive	-
2000	Mank & Nystrom	USA	Technology	Linear	Negative	Negative
2002	Grabowski et al.	USA	Pharmaceutics	Linear	-	Positive
2003	Del Monte & Papagni	Italy	Cross sectors	Linear	Positive	Unrelated
2007	Tubbs	Multinational	Cross sectors	Linear	Positive	Positive
2008	Coad & Rao	Multinational	Cross sectors	Linear	Positive	-
2009	Yang et al.	Taiwan	Manufacturing	Non-linear	Negative/positive/negative	Negative/positive/negative
2011	Chiou & Lee	Taiwan	Biotechnology	Non-linear	Positive/negative	Positive/negative

Table complied by authors

While research from the USA and the manufacturing sector dominate, one can see that the previous research span countries and several industry sectors. As can be seen the table, some of the results from the studies are conflicting. While most studies have found a positive relationship between R&D spending and growth, some have identified a negative relationship. The conclusions are even more disperse regarding the relationship between R&D spending and profitability where studies have found this relationship to be both positive, negative and non-existent.

Nonetheless, the majority of the previous research has found a positive relationship between R&D spending and firm economic performance. For example, Coad and Rao (2009) use a quantile regression approach to find a positive relationship between R&D spending and sales growth for high growth firms in high-tech sectors, arguing that R&D is of crucial importance for high growth firms and not necessarily as much for the average firm with average growth. Another example is Del Monte and Papagni (2003) that hypothesizes that firms with "a strong commitment to R&D have a higher rate of growth because they succeed in the product market" and finds evidence for this in their analysis of 500 Italian firms. However, they find no significant relationship between R&D spending and other measures of financial performance such as profitability. The conclusion drawn is that R&D does not create significant barriers to entry for the sample of firms analyzed.

Still some researchers have found a negative relationship between R&D spending and firm economic performance. Studies that have found negative relationships include Mank and Nystrom (2001) who researched firms in the computer industry between 1992 and 1997 and concluded that R&D spending and shareholder returns had a negative relationship. They note overspending in evolutionary R&D, as opposed to revolutionary R&D, and weak R&D management as possible causes. An additional example is provided by Caves (1996) that found a negative relationship in a cross sector study of UK firms.

Most of the previous research has identified a linear relationship between R&D spending and firm economic performance. However, a number of researchers claim that the relationship is more complex and dynamic, suggesting that it is non-linear in nature. In this category of studies that have found non-linear relationships, there are examples of quadratic and cubic relationships. Chiou et al. (2011) finds a quadratic relationship between R&D spending and firm performance for a sample of 20 Taiwanese biotechnology firms. They also identify a threshold value for R&D spending, where an increase in R&D spending to a number not exceeding this value leads to increasing profits, but increases past the threshold result in decreasing profits. Furthermore, Yang (2009) found a cubic relationship between R&D spending and financial performance public Taiwanese might-tech manufacturing firms.

When comparing the research that have found linear and non-linear relationships one can see an interesting difference in that researchers that have identified a linear relationship have used econometric models that only modeled linear relationships. By definitions, such models are only able to determine whether there is a linear relationship or not, regardless of the nature of the actual relationship. On the other hand, the research which have found a non-linear relationship have used more comprehensive theoretical frameworks which incorporates the possibility of dynamic marginal utility of R&D and designed econometric models able to detect linear and non-linear relationships.

2.5 Hypothesis

After reviewing the existing body of theory and previous empirical research we hypothesize that R&D spending has a dynamic marginal utility and that the relationship between R&D spending and firm economic performance is non-linear. This hypothesis is based in the reasoning that the aggregate effect of the dynamic mechanisms identified is also likely to be dynamic, resulting in a non-linear relationship between R&D spending and firm economic performance.

3 METHODOLOGY

This chapter will describe the methodology that was used to investigate the relationship between R&D spending and firm economic performance. Firstly the research design and method will be presented, followed by a description of the variables. Thereafter, the econometric model and the data sample will be presented. The chapter will end with a discussion regarding the research quality with regards to the methodology and data.

3.1 Research Design and Method

In order to investigate the relationship between innovation and firm economic performance we utilized a cross-sectional research design, where we examined a number of performance measurements for a set of 209 companies. In order to account for the stochastic time lag between R&D spending and R&D return we looked at the over-time averages of the performance measurements for each company. As a research method we used multiple linear regression analysis. This method was deemed appropriate, as it would allow us to describe the relationship in terms of statistical and economical significance as well as examine the causality of the relationship.

3.2 Declaration of Variables

In order to investigate the relationship between R&D spending and firm economic performance there is a need to establish quantitative measurements for these factors. In this chapter the dependent, independent and control variables to be included in the regressions are presented.

3.2.1 Dependent Variables

As measurements of firm economic performance, we will use average sales growth and profit margin. By using both two variables compared to only one of them, a more comprehensive view of the economic performance of the firms in the sample is obtained. This is also a distinction in relation to previous research where usually only one measure of economic performance has been used in each study. Furthermore, as is apparent from the compilation of previous research in the theory chapter most previous research have investigated sales growth measures leaving profitability measures under-researched

EBITDA margin is chosen as the profitability measurement. This is since it represents the earnings before taxes, depreciation and amortization, and is therefore less sensitive to variations in taxation and accounting practices compared to e.g. the net profit margin. Thus, the comparability of the sample data will be higher.

Relative measurements are used in both cases in order to remove firm size as a factor and increase comparability.

3.2.2 Independent Variables

As the measure for R&D efforts we have used R&D intensity defined as the average R&D spending to total revenues. A ratio is used in order to make the variable independent of firm size, increase comparability and thus make the regression results more reliable.

3.2.3 Control Variables

Considering the differences established by previous research there is reason to believe that the region of a company can impact the relationship between R&D spending and firm economic performance. Firms from a region with better innovation climate might yield higher returns to R&D spending than firms from region with a bad innovation climate. Consequently, we will control for firm region of origin. By region of origin we refer to the region where a firm has its headquarter and main operations. The regions we have included are Asia, Europe and North America.

Previous research have also found that firm size might influence the relationship between R&D spending and firm economic performance. We will therefore control for firm size in our regressions as well. We will be controlling for size with a control variable called firm size, which is defined as the logarithm of the revenues.

3.2.4 Time Series Averages

Intuitively there should be a lag in time between the point when a firm spends funds on R&D projects and when the funded activities have an effect on the firm economic performance. It is likely that the time gap varies significantly, both between R&D projects within a firm and between firms. In order to mitigate the issue of determining the size of the time gap we will use the time series averages and run a cross-sectional regression. This is based in the reasoning that the time lag effect will cancel itself out over an extended period of time. In essence this means that we will investigate the relationship between the over-time average level of R&D intensity and the over-time average financial performance. This approach is not uncommon in research and have previously been adopted by researchers such Fama and French (1996), Baysinger et al. (1991), and Ravenscraft and Scherer (1982).

The appropriateness of using the averaged variable approach will depend on whether the averages are representative R&D spending behavior. This can be evaluated by reviewing the standard deviation of the averaged variables. In figure 3 the standard deviation for each variable and each firm is presented in histograms.

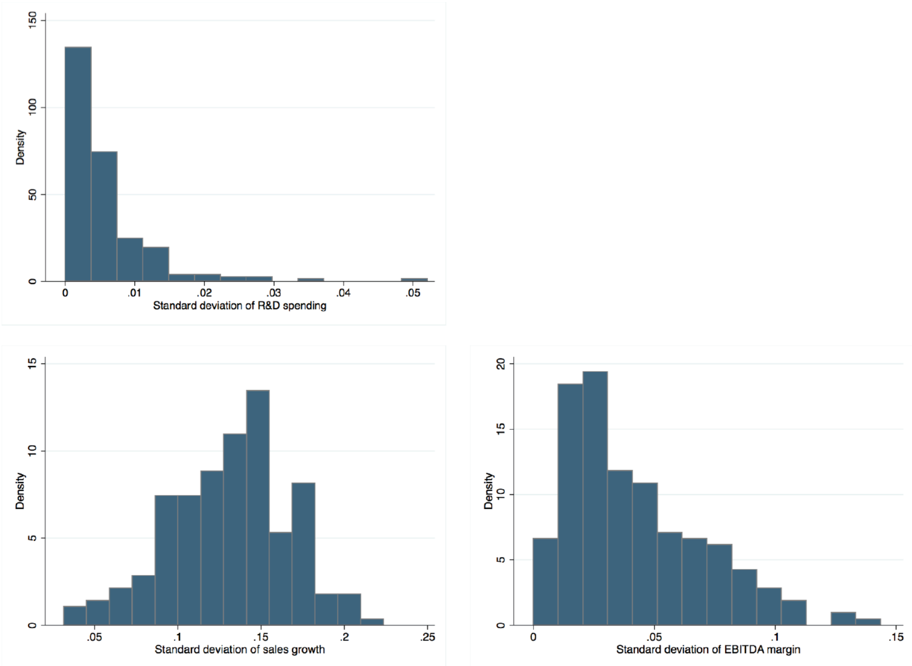


Figure 3 - Distribution of standard deviations for R&D spending, sales growth and EBITDA margin

As is apparent from figure 3, the standard deviation for all variables is relatively low. Consequently, the averages should provide a good representation of firms R&D intensity, sales growth and EBITDA margin over time and by implementing time series averages we will be able to manage the time lag issue without losing relevant information.

3.3 Data Sample

As it is possible that the relationship between R&D spending and firm economic performance depends on the industry studied we have delimited ourselves to study one sector, manufacturers of industrial equipment (MSCI: 201060). This sector includes, but is not limited to, manufacturers of e.g. industrial robots, mining equipment, and automation solutions. We chose to examine manufacturers of industrial equipment as they are highly R&D intensive and depend on a steady stream of new innovations in order to compete (Manyika et al., 2012). Our sample consists of 209 public firms for which we have collected data on R&D spending, sales growth and EBITDA margin for the period 2008-2014. All the data was sourced from Bloomberg. The firms were randomly selected from the entire universe of public industrial equipment firms. After performing a random selection, we performed a Cook's Distance test to remove extreme outliers with high leverage, as such data points may distort the outcome and the accuracy of the regression. We used a cutoff distance of 0,05 and after removing observations above that threshold, no more influential observations existed in the data sample. Consequently, the removal of remaining observations would not impact the regression results.

The data set used in the regressions contains data on the 2008-2014 average R&D spending, sales growth, EBITDA margin and firm size. As can be seen in Table 2, the average sales growth for the firms in our sample is 1%. However, there are some variations in the sales growth between firms resulting in a standard deviation of 0,06. The highest average growth a firm experienced during the period was 15% in while the lowest average growth a firm had was -16%. On average, the firms had an average EBITDA margin of 9% during the entire period. The average EBITDA margin also varies between companies with a standard deviation of 0,05. The highest average EBITDA margin of any firm was 20% while the lowest average margin was -8%. The average R&D intensity was on average 3% and less volatile than the other variables with a standard deviation of 0,02. The highest average R&D spending of a firm was 14% of its revenue while the lowest average R&D intensity was 0%. The mean firm size measured as average revenues was 1823,44 million USD, with a maximum of 51880,14 million USD, a minimum of 6,02 million USD and a standard deviation of 4952,92.

Table 2 - Summary of data sample

	Mean	Standard Deviation	Max	Min
Average Sales Growth	1,01	0,06	1,15	0,84
Average EBITDA Margin	0,09	0,05	0,20	-0,08
Average R&D Intensity	0,02	0,02	0,14	0,00
Firm Size	1823,44	4952,92	51880,14	6,02

Table 3 - Correlation matrix

	Sales Growth	EBITDA Margin	R&D Intensity	R&D Intensity^2	R&D Intensity^3	Firm Size
Sales Growth	1,00					
EBITDA Margin	0,33	1,00				
R&D Intensity	0,01	-0,09	1,00			
R&D Intensity^2	-0,06	-0,22	0,91	1,00		
R&D Intensity^3	-0,08	-0,26	0,80	0,97	1,00	
Firm Size	0,11	0,29	0,07	-0,01	-0,04	1,00

When analyzing the correlation matrix in Table 3, one can detect a strong, positive correlation between the average EBITDA margin and average sales growth of 0,33. Furthermore, the average EBITDA margin exhibit a negative correlation with the linear, squared and cubic average R&D intensity variable. Average sales growth showed a similar relationship to average R&D intensity as EBITDA apart from the linear variable. The correlation between average R&D intensity variables and average sales growth is lower than the correlation between average R&D intensity variables and average EBITDA margin. Finally, firm size exhibits a correlation of 0,11 with sales growth and 0,29 with EBITDA margin, while it is barely noticeable for the R&D intensities.

3.4 Econometric Method

This section will first describe the used econometric method and then evaluate the robustness of the model using post-estimation diagnostics.

3.4.1 Overview of Regressions

We will run 3 regressions for each of the two dependent variables, sales growth and EBITDA margin. For each variable we will perform the regression with a linear, a quadratic and a cubic model with the control variables included. By doing this we will test for relationships of different shapes and be able to determine which of these models that provide the best representation of the data.

3.4.2 Ordinary Least Square Regression

In order to investigate the potential relationship between R&D spending and firm economic performance we use multiple linear regression. In general, a multiple linear regression equation can be written as:

$y = \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k + u,$

where

β_0 is the intercept, β_i is the coefficient associated with x_i and u is the error term (Wooldridge, 2014).

The estimated ordinary least square (OLS) equation of the general multiple linear regression equation can consequently be written as:

$\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 x_1 + \cdots + \hat{\beta}_k x_k,$

where

$\hat{y}$ is the estimate of y and $\hat{\beta}_i$ is the estimate of β_i (Wooldridge, 2014).

The ordinary least square method generates the estimates which minimizes that sum of the squared residuals:

$\sum_{i=1}^{n}(y_i - \hat{\beta}_0 - \hat{\beta}_1 x_{i1} + \cdots + \hat{\beta}_k x_{ik})^2$ over all observations $i = 1, \ldots, n$

The solutions to this minimization problem can be characterized as:

$$\underset{b_0, b_1, \ldots, b_k}{min} \sum_{i=1}^{n}(y_i - \hat{\beta}_0 - \hat{\beta}_1 x_{i1} + \cdots + \hat{\beta}_k x_{ik})^2$$

By taking the partial derivatives with respect to each of the b_j, evaluating them at the solutions, and setting them equal to zero gives:

$$-2\sum_{i=1}^{n}(y_i - \hat{\beta}_0 - \hat{\beta}_1 x_{i1} + \cdots + \hat{\beta}_k x_{ik})^2 = 0$$

$$\vdots$$

$$-2\sum_{i=1}^{n}x_{ij}(y_i - \hat{\beta}_0 - \hat{\beta}_1 x_{i1} + \cdots + \hat{\beta}_k x_{ik})^2 = 0$$

After cancelling out the -2s, one obtains $k + 1$ linear equations with $k + 1$ unknown coefficients,

$$\sum_{i=1}^{n}(y_i - \hat{\beta}_0 - \hat{\beta}_1 x_{i1} + \cdots + \hat{\beta}_k x_{ik})^2 = 0$$

$$\sum_{i=1}^{n}x_{i1}(y_i - \hat{\beta}_0 - \hat{\beta}_1 x_{i1} + \cdots + \hat{\beta}_k x_{ik})^2 = 0$$

$$\vdots$$

$$\sum_{i=1}^{n}x_{ik}(y_i - \hat{\beta}_0 - \hat{\beta}_1 x_{i1} + \cdots + \hat{\beta}_k x_{ik})^2 = 0$$

which often referred to as the OLS first order conditions. Through solving the OLS first order condition equations one attain the OLS estimates (Wooldridge, 2014).

3.4.3 Econometric Post-Estimation Diagnostics

The OLS estimates are unbiased if the first four multiple linear regression (MLR) assumptions hold and have the lowest variance if the fifth holds as well (Wooldridge, 2014).

MLR Assumption 1: Linear in Parameters

The model in the population can be expressed as a combination of linear parameters.

MLR Assumption 2: Random Sampling

The sample population consists of a random sample.

MLR Assumption 3: No Perfect Collinearity

None of the independent variables in the sample are constant and there are no exact linear relationships among the explanatory variables.

MLR Assumption 4: Zero Conditional Mean

The error term has an expected value of zero given any values for the independent variables.

MLR Assumption 5: Homoscedasticity

The error term has the same variance given any values of the explanatory variables.

After conducting post-estimation diagnostics we can confirm that the MLR assumptions holds for our data set and that our OLS estimates are unbiased and have the lowest variance. All the post-estimation diagnostics statistics and plots can be found in Appendix 1.

In order to analyze whether MLR assumption one holds for our data set, we have analyzed component plus residual plots for the residuals and each explanatory variable (Wooldridge, 2014). As can be seen in the plots, the residuals exhibit linearity, especially for the average R&D intensity and the average R&D intensity squared. It thus seems like the data can be modeled through linear regression and that the assumption holds.

Moreover, we believe that assumption two holds as well as the companies in our sample were selected randomly.

The third MLR assumption, no perfect collinearity, was evaluated by analyzing the variance inflation factor (Wooldridge, 2014). The variance inflation factors for the EBITDA margin and the sales growth reveal that multicollinearity is present among our explanatory variables, which is expected due to the squared and variables. However, while it exists, it is not perfect and thus the assumption holds for our data set.

The validity of MLR assumption four was examined using the Durbin-Watson test, scatter plots, and the Link test (Wooldridge, 2014). The Durbin-Watson test is used to detect correlation between the residuals. The Durbin-Watson test statistic has a range of zero to four where below two implies positive correlation, two no correlation and above two negative correlation (Wooldridge, 2014). Our tests statistics were approximately two, which indicates that our residuals are uncorrelated, which can also be confirmed visually by scatter plots of the companies and the residuals. We also conducted a Link test, which is a model specification test. The Link test is based on the idea that if a regression model is properly specified, one should not be able to find any additional independent variables that are significant, except by chance. It tests whether non-linear combinations of the fitted values help explain the dependent variables (Wooldridge, 2014). The tests statistics show that the non-linear combinations have no explanatory power for our dependent variables. Consequently the diagnostics indicate that MLR assumption 4 holds for our data sample.

To evaluate MLR assumption five we conducted a Breush-Pagan Tests. The Breusch-Pagan Test tests whether the variance of the residuals is homogenous using a chi2 test (Wooldridge, 2014). Our test statistics for both the EBITDA margin and sales growth regressions indicate that our residuals exhibit homoscedasticity and that the assumptions hold for our data sample.

Additionally, in order to affirm that our t-tests and corresponding p-values are valid for our coefficients we analyzed the normality of our residuals (Wooldridge, 2014). As can be seen in charts X and Z, both the sales growth and the EBITDA margin residuals are approximately normal. We have thus no reasons to distrust the significance of our estimates.

3.5 Reliability, Validity, and Generalizability

According to Bryman and Bell (2011) the most critical aspects to determine the quality of quantitative research is reliability and validity.

The concept of reliability concerns the consistency of measures used in a study (Bryman & Bell, 2011). We believe that our findings are reliable, as the performance measurements have been defined in the same manner for companies throughout all the years. Additionally, differences in accounting and reporting practices has been minimized through sourcing the data exclusively from Bloomberg which adjust its data to be published in a consistent manner.

The concept of validity deals with the issue of whether a measure really captures what it is intended to capture (Bryman & Bell, 2011). To examine the relationship between R&D spending and firm economic performance we use the measurements R&D intensity, sales growth, and EBITDA margin. We believe that we have high construct validity between R&D spending and R&D intensity, as R&D intensity is simply used to increase the comparability between companies of different sizes. Similarly, we believe that there is high construct validity between sales growth and EBITDA margin for firm economic performance, as those measures are important KPIs in determining the impact from new products and processes (Koller et al., 2010).

To ensure high generalizability, we sampled companies randomly for our data set. Consequently, we believe that we are able to infer our conclusions on the larger population of public manufacturers of industrials equipment. It is also likely that our findings are relevant for adjacent sectors with similar business logics. However, it is important to acknowledge that our sample consists of only public companies, which might limit the generalizability to firms with such ownership structure and firms in the same size category as public firms typically are in.

4 EMPIRICAL FINDINGS

This chapter will present the results from the performed regressions. All regression estimates and some relevant post-estimation diagnostics can be found in table 4. The remaining post-estimation diagnostics can be found in Appendix.

Table 4 - Regression Results

	Average sales growth			Average EBITDA margin		
	Linear model	Quadratic model	Cubic model	Linear model	Quadratic model	Cubic model
Independent variables						
Average R&D Intensity	-0,127	0,687*	1,640*	-0,278*	1,080***	1,382**
	(-0,734)	(1,670)	(1,953)	(-1,941)	(3,285)	(2,050)
Average R&D intensity^2		-8,326**	-33,624*		-13,838***	-21,843
		(-2,179)	(-1,697)		(-4,546)	(-1,377)
Average R&D intensity^3			147,522			46,609
			(1,301)			(0,514)
Constant	1,065***	1,058***	1,049***	0,140***	0,127***	0,124***
	(19,435)	(19,429)	(19,140)	(3,108)	(2,939)	(2,844)
Control variables						
Firm size	0,011	0,007	0,006	0,027***	0,020**	0,020**
	(1,132)	(0,652)	(0,556)	(3,244)	(2,410)	(2,359)
Asian firms	-0,061	-0,063	-0,060	-0,056	-0,059	-0,058
	(-1,109)	(-1,160)	(-1,115)	(-1,231)	(-1,370)	(-1,349)
European firms	-0,034	-0,034	-0,032	-0,033	-0,033	-0,033
	(-0,619)	(-0,628)	(-0,587)	(-0,730)	(-0,770)	(-0,752)
North American firms	-0,033	-0,033	-0,030	-0,042	-0,042	-0,041
	(-0,602)	(-0,613)	(-0,562)	(-0,927)	(-0,980)	(-0,957)
Observations	206	206	206	204	204	204
R-squared	0,076	0,098	0,105	0,132	0,214	0,215
F-test	3,304***	3,597***	3,335***	6,005***	8,944***	7,676***

t-statistics in parantheses, p-values in brackets
*** p<0.01, ** p<0.05, * p<0.1

4.1 Average R&D Intensity and Average Sales Growth

The regression results indicate that the linear and the cubic regression model have no explanatory power for the average sales growth. However, as can be seen in table 4, the quadratic regression model is statistically significant. For the quadratic model, the linear variable has an estimated coefficient of 0,687 with a p-value below 0,1. The quadratic variable has an estimated coefficient of -8,326 with p-value below 0,05. Furthermore, the quadratic regression model has a R-squared value of 0,098 and a F-test value of 3,597, which is highly statistically significant.

4.2 Average R&D Intensity and Average EBITDA Margin

With regards to the EBITDA margin regression we found that the linear and quadratic regression models produced statistically significant coefficients, while the cubic model lacked explanatory power.

For the linear model, the coefficient is weakly significant with a value of -0,278. Additionally, for the linear model, the large firms control variable is highly significant with a coefficient of 0,027. The linear regression model produced an R-squared value of 0,132 and an F-test value of 6,005, which is highly statistically significant.

The quadratic regression model gives a highly significant linear coefficient of 1,080 and a highly significant quadratic coefficient of -13,838. For this model, the large firms control variable is moderately statistically significant with a coefficient of 0,020. This regression has an R-squared of 0,214 and a F-test value of 8,944, which is highly statistically significant.

5 ANALYSIS AND DISCUSSION

This chapter will analyze and interpret the regression results. It will also discuss possible explanations and implications of the findings.

5.1 Interpretation of Empirical Findings

Based on our regressions and post-estimation diagnostics we can conclude that the average sales growth can be modeled using a quadratic regression model. While the linear and the cubic regression models failed to provide statistically significant results, the quadratic model generated both statistically and economically significant results. For the average sales growth, neither of the control variables firm region of origin nor firm size had any explanatory power. The quadratic model has a R-Squared value of 10%, meaning that it explains 10% of the variance of the response data around the mean. This means that the average sales growth can be modeled as a single-variable quadratic function with a parabola that opens downwards. In figure 4, we have plotted our estimated regression line with the sales growth data points to illustrate the shape and the fit of our regression.

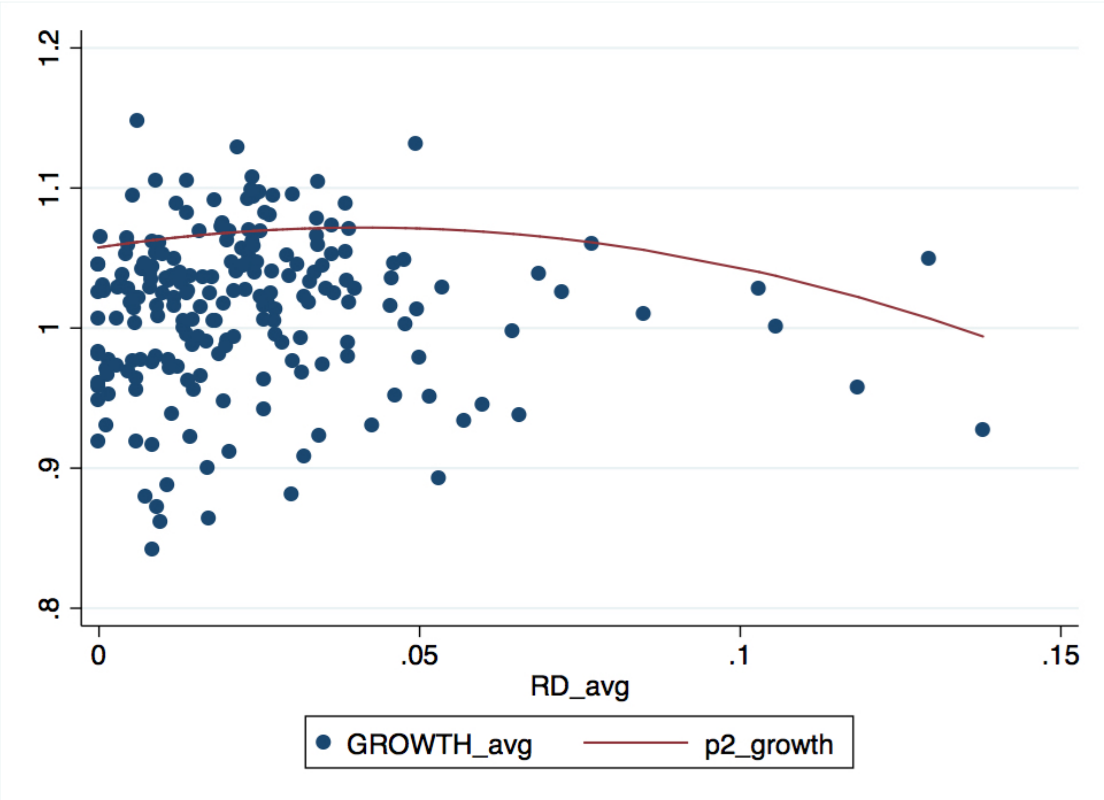


Figure 4 - Illustration of the estimated regression line for the average sales growth with the average sales growth data points

Similarly, we can also conclude that the average EBITDA margin is also best modeled with a quadratic regression model. For the EBITDA margin both the linear and the quadratic regression model provides statistically and economically significant results. However, the quadratic model provides a superior fit as it provides more significant results and manages to explain a higher degree of the variability around the mean for the response data. While firm region of origin did not influence the average EBITDA margin we found that larger firms yielded greater EBITDA margin improvements on spent R&D than smaller firms. In conclusion, the relationship between average R&D intensity and average EBITDA margin is best represented as a single-variable quadratic function with a parabola that opens downwards. In figure 5 the estimated regression line is plotted against the average R&D intensity and average EBITDA margin.

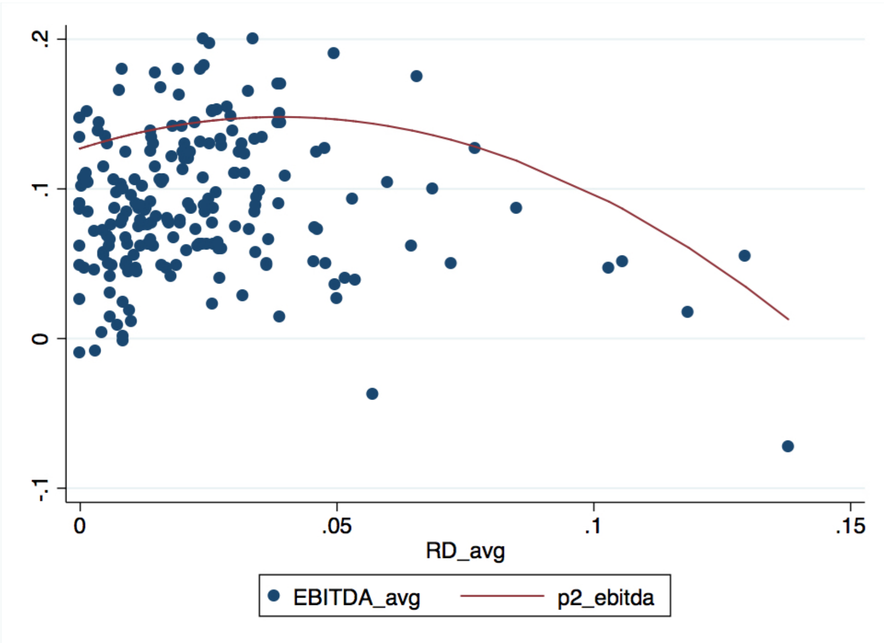


Figure 5 - Illustration the estimated regression line for the average EBITDA margin with the average EBITDA margin data points

Consequently, we have found that both the average sales growth and the average EBITDA margin can be modeled as single-variable quadratic functions with a parabola that opens downwards. The relationship between R&D spending and firm economic performance exhibit some interesting and noteworthy characteristics. First of all, we can conclude that initially there is an increasing marginal utility of R&D. This means that R&D spending will have a positive impact on firm economic performance and up to a certain point, the return to R&D will increase with higher R&D spending. Secondly, there exists an optimal level of R&D spending where firms yield the highest return on R&D. For our data sample, this optimal level of R&D spending were around 4% of sales for both measures of firm economic performance. Lastly, after this optimum, the relationship experiences a decreasing marginal utility of R&D. That means that additional R&D spending will have a negative effect on firm economic performance and that the effect will become increasingly negative with further R&D spending.

Our findings stand in sharp contrast to older previous research. The majority of the older studies has found a positive linear relationship, see for examples the studies by Bransch (1974), Nolan et al. (1980) and Hall (1987). However, others have found a negative liner relationship (Caves, 1996) or no relationship at all (Del Monte & Papagni, 2003). While we have had a different industry sector focus, we argue that the most significant difference between older studies and ours is that we have allowed for non-linear relationships. Older studies did not test the fit of non-liner relationships. For example, we found a statistically significant positive linear relationship for the average EBITDA margin. However, after we preformed the non-linear regressions and some post-estimation diagnostics, we could conclude that the quadratic model provided the best fit. It is thus possible that these older studies would have found non-linear relationships if they had had allowed for other relationships as well.

Our findings are much more in line with more recent studies, which also have found support for non-linear relationships. Similar to Chiou and Lee (2011) we also found a quadratic relationship with positive marginal utility for low levels of R&D and negative marginal utility at higher levels. Yang et al. (2009) on the other hand found a cubic relationship with a negative marginal utility for low levels of R&D, positive for medium levels and negative again at high levels.

5.2 Explanation of Empirical Findings

In chapter two we hypothesized that R&D spending should have a dynamic marginal utility and that the relationship between R&D spending and firm economic performance should be non-linear. In line with this hypothesis, we find that the relationship between average R&D spending and average firm economic performance can be modeled as a single-variable quadratic function with a parabola that opens downwards.

Our results indicate that R&D spending gives rise to some temporary monopoly rents, which supports the argumentation put forward by McDaniel (2002). These rents stem from the introduction of new products, the ability to charge premium prices and the ability to lower costs, which influence both average sales growth and average EBITDA margin positively.

While having found support of temporary monopoly rents, some uncertainties still remain regarding the actual size of the average temporary monopoly rent. McDaniel's (2002) theoretical model of temporary monopoly rents is based on the assumptions of perfect competition. The assumption of perfect competition refers to market characteristics such as profit maximization, no barriers of entry and exit, perfect information, homogenous products, and a large number of buyers and sellers. As few markets exhibit these characteristics in reality, the assumption is generally questionable. While we would argue that most firms in the industrial equipment market are probably profit maximizing, their products are certainly not homogenous. Additionally, as the products are relatively complex, one can also doubt if consumers have access to perfect information. Due to the large initial investment and ongoing capital expenditure involved in manufacturing industrial equipment, one can also question if there is a large number of sellers and whether firms can freely enter and exit the industry. This argumentation is also strengthened by the fact that the firms in the sample experience on average profits greater than 0. Consequently, one can certainly question if perfect competition holds for the industrial equipment market. If it does not to hold, new products and process would still yield temporary monopoly rents, but the rents would be smaller than under perfect competition. Consequently, depending on whether a market has more or less competition than the industrial equipment market, the temporary monopoly rents might be smaller or greater than indicated by our regressions.

Additionally, according to Teece (1986) a firm's ability to appropriate the value of a new product or process depends on the appropriability regime and the necessary complementary assets. The appropriability regime in the sector of industrial equipment is arguably moderately strong. While some new inventive products and processes can be protected by intellectual property rights such as patents, less novel and obvious products and processes will not fulfill the patentability requirements. Non-patentable products and processes are commonly protected as trade secrets. However, this is likely to be a poor protection as industrial equipment often is relatively simple to reverse engineer by professionals, with e.g. the help of CAD scanners Zhang (2003). Without a legal exclusivity on the market, imitators are likely to follow close, which will reduce the temporary monopoly rents.

Furthermore, the necessary complementary assets are arguably relatively specialized. Selling industrial equipment requires a knowledgeable sales force, the ability to educate new customers, and in some cases the ability perform aftermarket services such as maintenance and repairs. However, as these assets are so specialized, manufacturer of industrial equipment tend to develop and own these assets themselves (Carmeli & Tishler, 2004). Consequently, as they are the owners of the assets they are able to capture the value from the new product or process themselves.

It is thus likely that manufacturers of industrial equipment are able to appropriate a significant part of the value from introducing a new product or process. However, when the firms are unable to gain market exclusivity, the value will be split between other firms with specialized assets and customers. As a consequence, firms' individual ability to appropriate value will thus influence the size of the temporary monopoly they can expect on average.

In contrast to Porter and Stern (2001), our findings indicate that the origin of a firm does not influence the relationship between R&D and the average sales growth. This might be because the difference between the regions in our sample is relatively small. While North America and Europe is arguably similar in terms of R&D policies, innovation clusters, and qualified labor, one might expect lower firm economic performance from Asian firm, as Asia is generally less developed than North America and Europe. However, the sample companies in the Asian region are predominantly from Japan, which is arguably as progressive as both North America and Europe. Consequently, while differences among regions probably exist, it is not surprising that the effect is insignificant in our sample.

Our research also indicated that larger firms gained a higher average EBITDA margin improvement on R&D spending than smaller firm. While we are unable to say for sure, it might be the case that larger firms have more specialized R&D than smaller firms and are thus able to charge a higher premium, which influence the margins positively (Mintzberg, 1993). They might also be able to spread out the fixed R&D costs over a larger number of R&D projects, which decreases the average R&D project costs and improves the margins (Cohen & Klepper, 1996). An alternative explanation might be that larger firms spend more on process R&D than smaller firms. Process improvement often contributes to higher margins as it leads to higher productivity and lower costs. In contrast to Scherer and Ross (1990), we do not find that larger firms are held back compared to smaller firms.

Interestingly enough, we found no statistically significant difference between large and small firms with regards to the average sales growth from R&D. It thus seems that firm size is unrelated to average sales growth from R&D or that the advantages and disadvantages from size cancel each other out.

Regarding the shape of the relationship, our findings suggest that the marginal utility of R&D changes form positive to negative once. This implies that the marginal utility is dynamic and that the relationship can be described as a single-variable quadratic function with a parabola that opens downwards. Yang (2010) argues that the dynamic nature of the marginal utility can be attributed to factors such as economics of scale, return to scale, time lag between R&D investment and return as well as learning and absorptive capabilities. Our findings suggest that the aggregate effect of such factors first impact the marginal utility positively and then negatively, after the optimal level have been reached. However, due to the quantitative nature of this report, we are unable to say whether this list of factors is exhaustive or comment on the importance of respective factor. Instead we encourage further qualitative research of the factors, which influence the dynamic nature of the marginal utility of R&D.

Even though our results are statistically significant, it is important to acknowledge that it has a R-squared value of 10% for average sales growth and 21% for average EBITDA margin. This implies that the models have relatively low explanatory power of the variance around the mean. This indicates that it might exist important variables with explanatory power, which have not been controlled for.

However, as we performed Link Test, we can at least be confident that no other linear combination of the independent variables might be of importance for the models. We can thus be sure that the omitted variables consist of other exogenous variables. We have identified several categories of possible omitted variables. The financial strength of a firm is likely to be a prerequisite to carry out R&D. Firms without cash or the ability to generate additional free cash will probably underinvest in R&D. This would yield worse results compared to other firms, which are able to invest at their optimal R&D level. Consequently, variables such as cash, cash conversion, and capital structure might be variables with some explanatory power.

Firms R&D capabilities is also likely to impact the relationship. By R&D capabilities we refer to firms ability to imagine and develop new products and processes. Consequently, a firm's access to qualified employees, research facilities and equipment, and accumulated knowledge and experience, might be important factors with explanatory power. When firms have developed a new product or process, their ability to monetize on it depends on the firm's commercialization capabilities. Commercialization capabilities include various competencies that are important for successfully selling the product to customers. This could be proficiencies related to activities such as marketing, brand building and pricing. Another possibility is that randomness governs a major part of the outcome. Due to the uncertainties of early stage R&D, it might be difficult to say whether a technology will be successful or not. It might be even more difficult to say which firm and technology will be commercially successful in a competitive market. A challenge with some of these possible omitted variables is that they are qualitative in nature and therefore hard to measure and unsuitable for regression analysis.

5.3 Implications of Empirical Findings

Our research has implications for both academia and businesses conducting R&D. The majority of previous research have come to the conclusion that the relationship between R&D spending and firm economic performance is either positively or negatively and linear. However, during our literature review, we discovered that those papers consistently did not investigate the existence other possible relationships. Consequently, if they allowed for a non-linear relationship, they might have found one. Another possibility is that the research that found a positive linear relationship did not include firms with particularly high R&D spending. Similarly, the research that found a negative linear relationship might be lacking firms with lower levels of R&D spending. However, as this is speculative we have to presuppose that there exist linear, quadratic and cubic relationships between R&D and firm economic performance. Consequently, we argue that there is a need for further research about the theoretical factors that drive the relationship. On the other hand, the existence of several relationships opens up the possibility that the relationship differs between industries. As such, more research is also necessary to detect if there exists a generally applicable relationship or whether it varies between industries.

For businesses, our research highlights that the marginal utility of an R&D investment is dynamic and dependent on the firms' current R&D intensity. Consequently the expected return of an R&D investment need to be related to the firms existing R&D

initiatives. At low levels of R&D spending, firms can expect a positive marginal utility of further R&D spending, and at high levels of current R&D spending, firms can expect a negative marginal utility of additional R&D. Our research thus suggests that there exists an optimal level of R&D spending that firms should strive towards in order to maximize firm economic performance. On average the firms in our sample had an average R&D intensity of 2%. As such, several firms would be better off by increasing their average R&D spending to around 4%, which was the optimal level detected for the sample used in this study.

While we have found some evidence of temporary monopoly rents from R&D spending, we are unable to explain all the variance around the mean. This can be due to the fact that the innovator is not always able to capture all the value from new products or processes. According to Teece (1986), in order for a firm to capture value from a new product or process it needs to have an appropriate appropriability regime and ownership of the necessary complementary assets. Consequently and considering that the model have not explained all the variance around the mean, this suggests that appropriation might be an important factor and that firms should develop the appropriate appropriability regime and complementary assets needed to appropriate the value they create.

We have also seen that larger firms have a higher average EBITDA margin improvement on R&D spending. Consequently, firms that prioritize EBTIDA margin improvements may consider to scale up their R&D.

Considering our sampling methodology we believe that the results are generalizable to the entire population of public manufacturers of industrial equipment. Due to the similarities in R&D policies of adjacent industries such as e.g. automotive, it is possible that the results are further generalizable to this population. However, it is important to note that these results might be less generalizable all industries due to different industry logics. In general, it is likely to expect a different relationship in industries with a different ratio between the temporary monopoly and the associated R&D spending as well as the firms' ability to appropriate the value from the new product or process.

6 CONCLUSIONS

This chapter will present the most important conclusions from our research, highlight some interesting contributions, and point at relevant topics for further research.

This thesis has examined the relationship between the average R&D spending and the average firm economic performance. OLS regression analysis has been used on a data set consisting of 209 public manufacturers of industrial equipment over the period of 2008-2014. In order to account for the time lag between the R&D investment and the returns to the R&D investment, averages of the longitudinal data for the entire period for each respective company was used. In order to increase comparability, R&D intensity was used instead of absolute R&D spending as the measurement of R&D spending. Firm economic performance was defined as sales growth and EBITDA margin.

The majority of the previous research has found positive or negative linear relationships between R&D spending and various measures of firm economic performance. However, others have identified non-linear relationships while some have found no relationships at all. An important note regarding earlier research is that most studies have only used one predetermined regression model, in most cases a linear one.

In our research we have taken a broad approach exploring the possibility of linear, quadratic, and cubic relationships. In addition, we have also controlled for firm size and differences in the innovation environment between regions. We find that both average sales growth and average EBITDA margin are best modeled as single-variable quadratic functions with a parabola that opens downward.

First of all, we can conclude that initially there is an increasing marginal utility of R&D spending. This means that R&D spending will have a positive impact on firm economic performance and up to a certain point, the return to R&D will increase with higher R&D spending. Secondly, there exists an optimal level of R&D spending where firms yield the highest return on R&D. For the data sample and regression model in this study, the optimal level of R&D spending is at around 4% of sales. Lastly, past the optimal level, the relationship infers a decreasing marginal utility of R&D. That means that additional R&D spending will have a negative effect on firm economic performance and that the effect will become increasingly negative with further R&D spending. The nature of the relationship highlights two interesting conclusions. Firstly, R&D managers in the industry studied should strive to have an R&D intensity of 4% in order to maximize firm economic performance. As the mean R&D intensity in the sample was 2%, there are firms that are underinvesting in R&D and thus could increase firm economic performance by increasing R&D spending. The second interesting conclusion is that the expected marginal utility of an R&D project needs to be related to the firms other R&D initiatives as the marginal utility is dependent on the current level of R&D intensity.

The R-squared values were of 10% for the average sales growth regression and 21% for the average EBITDA margin regressions. This implies that the models have relatively low explanatory power, as they do not explain more than 10% and 21% of the variance around the mean respectively. This means that there might exist variables that influence the relationship that have not been controlled for. Possible uncontrolled variables are financial strength, R&D and commercialization capabilities. It is also likely that there is a random element to the returns of R&D, which is by definition impossible to control for.

Our findings can be generalized to the entire population of public manufacturers of industrial equipment. However, as our research is limited to this industry, the results cannot be further generalized. We therefore encourage further research investigating the relationship for other industries. Specifically with the inclusion of non-linear models, as this is an area we consider to be under-researched. Additionally, we encourage further research regarding the theoretical factors that influence the marginal utility of R&D to better understand the mechanisms behind the relationship.

7 REFERENCES

Arora, A., & Ceccagnoli, M. (2006). Patent protection, complementary assets, and firms' incentives for technology licensing. *Management Science*, *52*(2), 293-308.

Baregheh, A, Rowley, J, Sambrook, S. (2009) Towards a multidisciplinary definition of innovation. *Management Decision, 47*(8), 1323-1339.

Baysinger, B. D., Kosnik, R. D., & Turk, T. A. (1991). Effects of board and ownership structure on corporate R&D strategy. *Academy of Management Journal*, *34*(1), 205-214.

Branch, B. (1974). Research and development activity and profitability: a distributed lag analysis. *The Journal of Political Economy*, *82*(5) 999-1011.

Bryman, A., & Bell, E. (2011). *Business research methods* (3rd ed.). Oxford: Oxford University Press.

Carmeli, A., & Tishler, A. (2004). Resources, capabilities, and the performance of industrial firms: A multivariate analysis. *Managerial and Decision Economics*, *25*(6-7), 299-315.

Caves, R. E. (1996). *Multinational enterprise and economic analysis*. (2nd ed.). Cambridge: Cambridge University Press.

Chiou, J. Lee, Y. (2011). Efficiency and Profitability on Biotech-Industry in Small Economy. *International Journal of Business and Commerce, 1*(2), pp. 1-24.

Coad, A., & Rao, R. (2008). Innovation and firm growth in high-tech sectors: A quantile regression approach. *Research Policy*, *37*(4), 633-648.

Cohen, W. M., & Klepper, S. (1996). A reprise of size and R & D. *The Economic Journal, 106*(437) 925-951.

Del Monte, A., & Papagni, E. (2003). R&D and the growth of firms: empirical analysis of a panel of Italian firms. *Research Policy*, *32*(6), 1003-1014.

Denicolò, V. (2007). Do patents over-compensate innovators?. *Economic Policy*, *22*(52), 680-729.

Fama, E. F., & French, K. R. (1996). Multifactor explanations of asset pricing anomalies. *The Journal of Finance*, *51*(1), 55-84.

Foster, R. N. (1986). *Innovation: The attacker's advantage*. New York: Summit Books.

Grabowski, H., Vernon, J., & DiMasi, J. A. (2002). Returns on research and development for 1990s new drug introductions. *Pharmacoeconomics*, *20*(3), 11-29.

Hall, B. H. (1986). The relationship between firm size and firm growth in the US manufacturing sector. *Journal of Industrial Economics, 35*(4), 582-606.

House, W. C., Parks, D. M., & Lindstrom, G. L. (1994). Relationships between R&D and Profitability: An Exploratory Comparison of Two Business Simulations with Two Real-World Technology Intensive Industries. *Developments in Business Simulation and Experiential Learning*, *21,* 75-78.

Kleinknecht, A., & Mohnen, P. A. (2002). *Innovation and Firm Performance: econometric explorations of survey data*. Basingstoke: Palgrave.

Koller, T., Goedhart, M., & Wessels, D. (2010). *Valuation: measuring and managing the value of companies*. Hoboken: John Wiley and Sons.

Lefebvre, E., Lefebvre, L. A., & Bourgault, M. (1998). R&D-related capabilities as determinants of export performance. *Small Business Economics*, *10*(4), 365-377.

Leifer, R. (2000). *Radical innovation: How mature companies can outsmart upstarts*. Cambridge: Harvard Business Press.

Mank, D. A., & Nystrom, H. E. (2000). The Relationship Between R&D Spending and Shareholder Returns in the Computer Industry. *Engineering Management Society, 2000. Proceedings of the 2000 IEEE,* 501-504.

Manyika, J. (2012). *Manufacturing the future: The next era of global growth and innovation.* McKinsey Global Institute.

McDaniel, B. A. (2002). *Entrepreneurship and innovation: An economic approach*. New York: ME Sharpe.

Mintzberg, H. (1993). *Structure in fives: Designing effective organizations*. Englewood Cliffs: Prentice-Hall.

Morbey, G. K. (1988). R&D: Its relationship to company performance. *Journal of Product Innovation Management*, *5*(3), 191-200.

Morbey, G. K., & Reithner, R. M. (1990). How R&D Affects Sales Growth, Productivity And Profitability. *Research Technology Management*, *33*(3), 11-14.

Nolan, M. P., Oppenheim, C., & Withers, K. A. (1980). Patenting, profitability and marketing characteristics of the pharmaceutical industry. *World Patent Information*, *2*(4), 169-176.

Organisation for Economic Co-operation and Development. (1994). *The Measurement of Scientific and Technological Activities: Proposed Standard Practice for Surveys of Research and Experimental Development: Frascati Manual 1993*. OECD.

Porter, M. E., & Stern, S. (2001). National innovative capacity. *The global competitiveness report*, *2002*, 102-118.

Ravenscraft, D., Scherer, F. M. (1982) The Lag Structure of Returns to Research and Development, *Applied Economics, 14*(6), 603-620

Scherer, F.M., Ross, D., (1990) *Industrial Market Structure and Economic Performance*. Boston: Houghton Mifflin.

Schoeffler, S. (1977). Cross-sectional study of strategy, structure, and performance: Aspects of the PIMS program. *Strategy and Structure Performance*, 108-121.

Shelton, R., & Percival, D. (2013). *Global Innovation Survey.* PwC.

Singh, L. (1994). Productivity, competitiveness and export growth in a less developed economy: a study of Indian Punjab. *In Working Paper, Yale Economic Growth Center Discussion Paper No. 714.*

Smith, K.H, (2005), *Measuring innovation. The Oxford Handbook of Innovation.* Oxford: Oxford University Press.

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research policy*, *15*(6), 285-305.

Thomson, R. (2011). Economic Perspectives on Innovation*. The Australian Economic Review, 44*(4), 480-489.

Tubbs, M. (2007). The relationship between R&D and company performance. *Research-Technology Management*, *50*(6), 23-30.

Utterback, J. M., & Abernathy, W. J. (1975). A Dynamic Model of Process and Product Innovation. *Omega*, *3*(6), 639-656.

Ulku, H. (2007). R&D, Innovation, and Growth: evidence from four manufacturing sectors in OECD countries. *Oxford Economic Papers*, *59*(3), 513-535.

Wooldridge, J. (2014). *Introductory Econometrics: a Modern Approach*. Nashville: South-Western College Publishing.

Yang, K. P., Chiao, Y. C., & Kuo, C. C. (2010). The Relationship Between R&D Investment and Firm Profitability Under a Three-Stage Sigmoid Curve Model: Evidence From an Emerging Economy. *IEEE Transactions on Engineering Management*, *57*(1), 103-117.

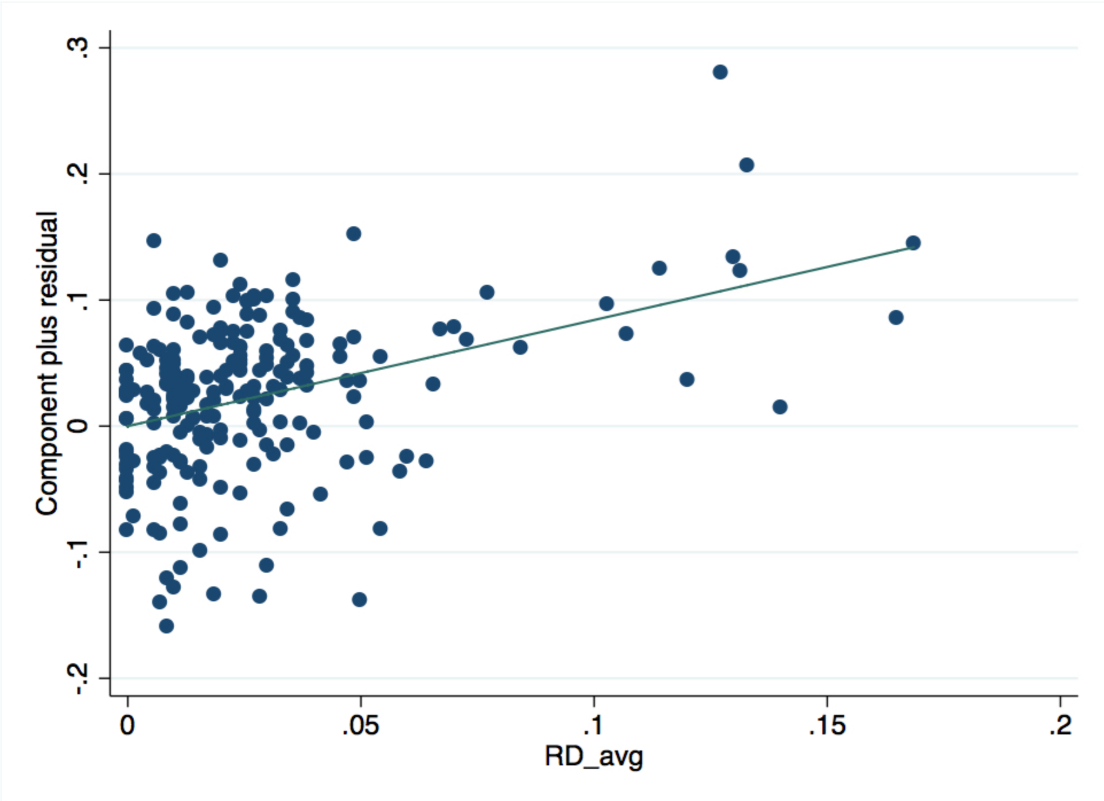
Zhang, Y. (2003). Research Into the Engineering Application of Reverse Engineering Technology. *Journal of Materials Processing Technology*, *139*(1), 472-475.

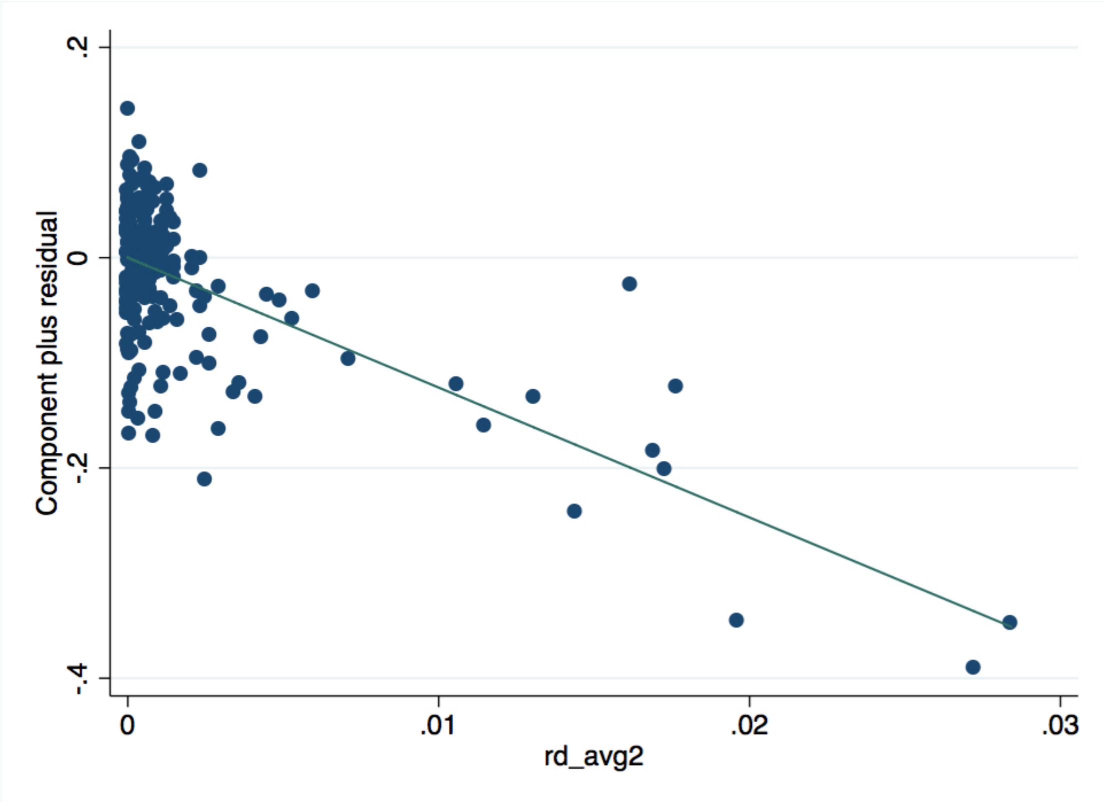
8 APPENDIX

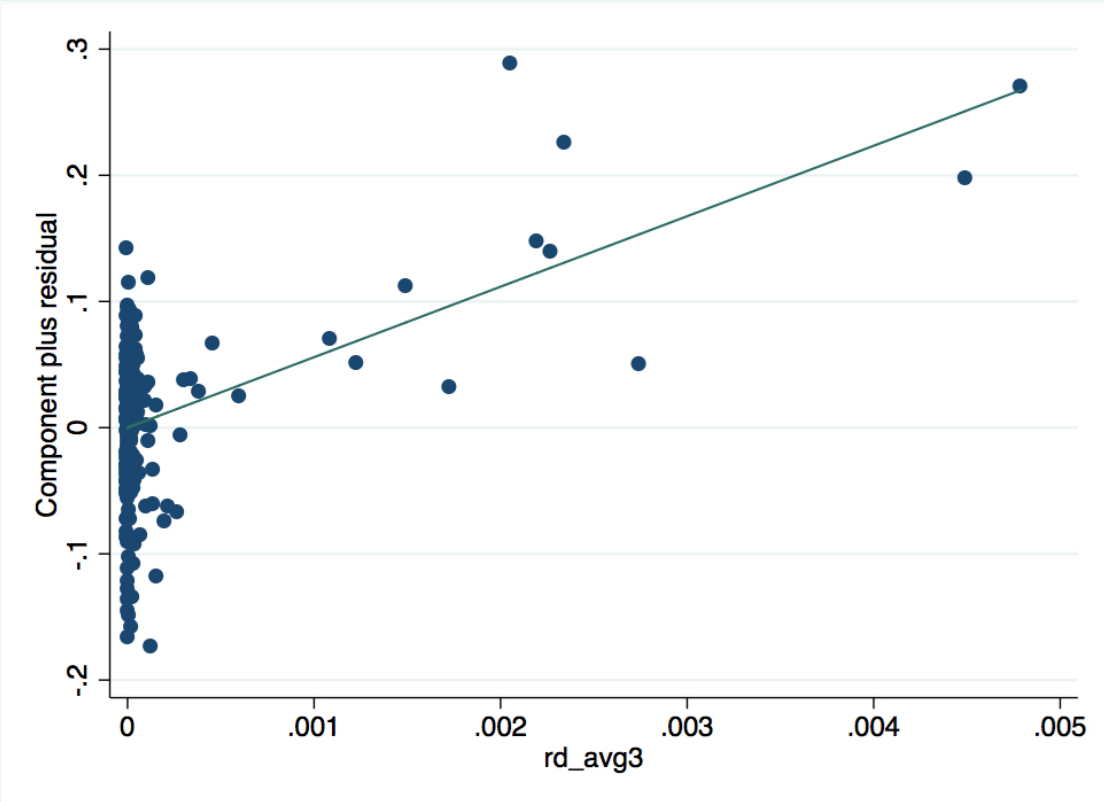
This chapter will present the appendix material, which consists of post-estimation diagnostics.

Component Residual Plots

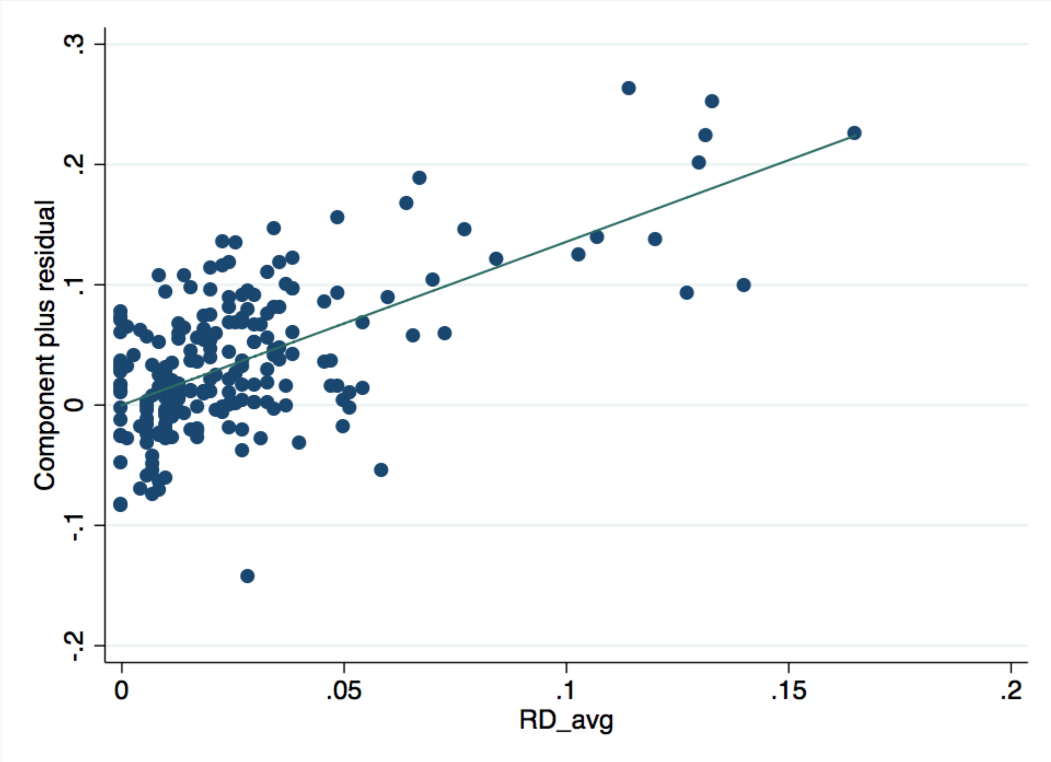
Component Residual Plots – Sales Growth and R&D Intensity

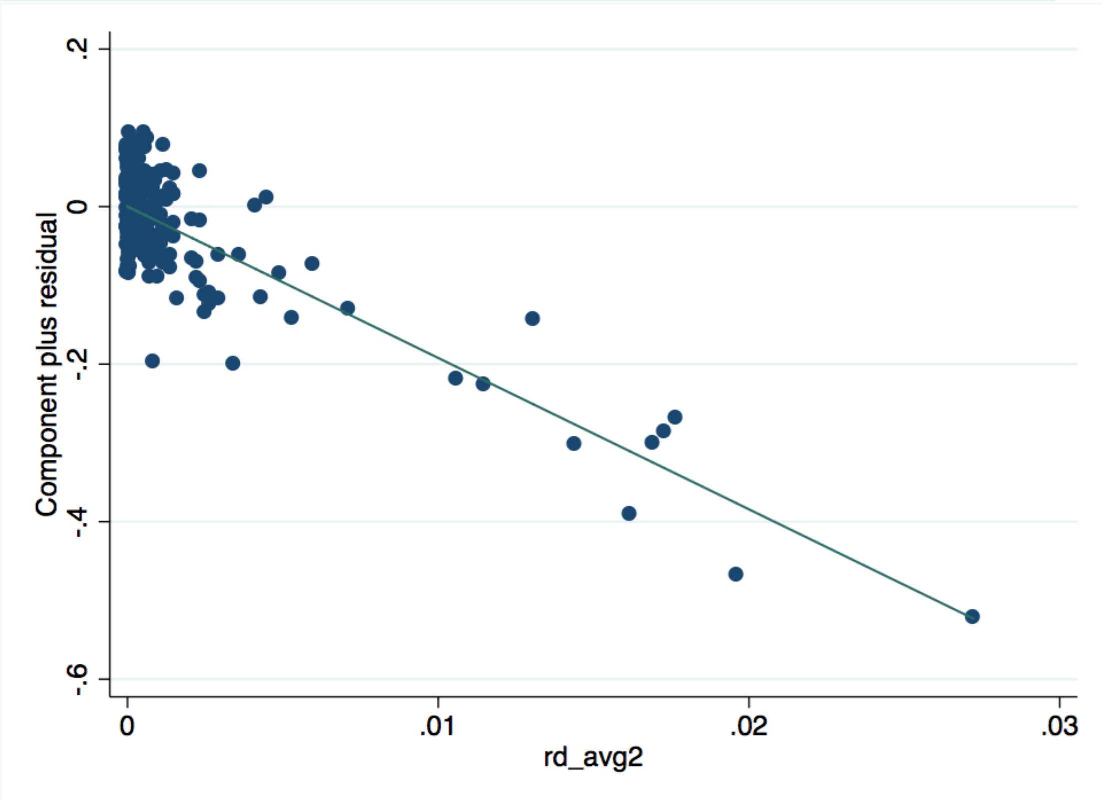


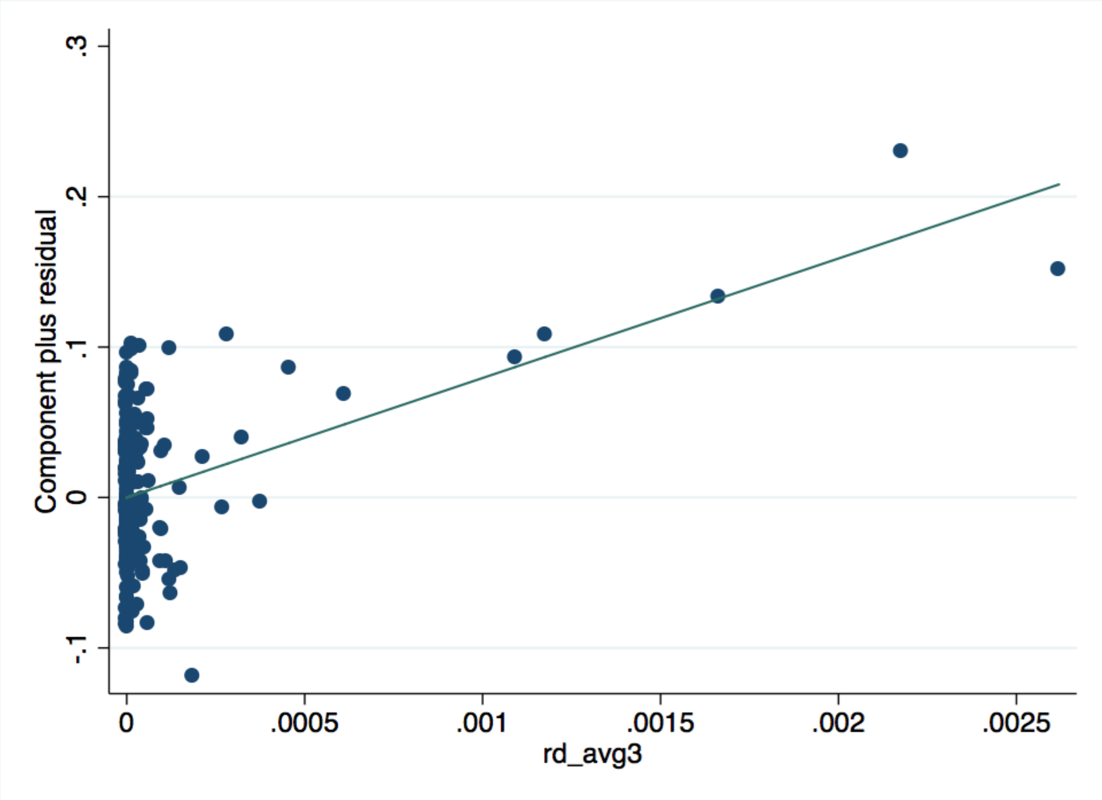




Component Residual Plots – EBITDA Margin


.3
.2
.1
0
-.1
-.2
Component plus residual
0
.05
.1
.15
.2
RD_avg


.2
0
-.2
-.4
-.6
Component plus residual
0
.01
.02
.03
rd_avg2



Variance Inflation Factors

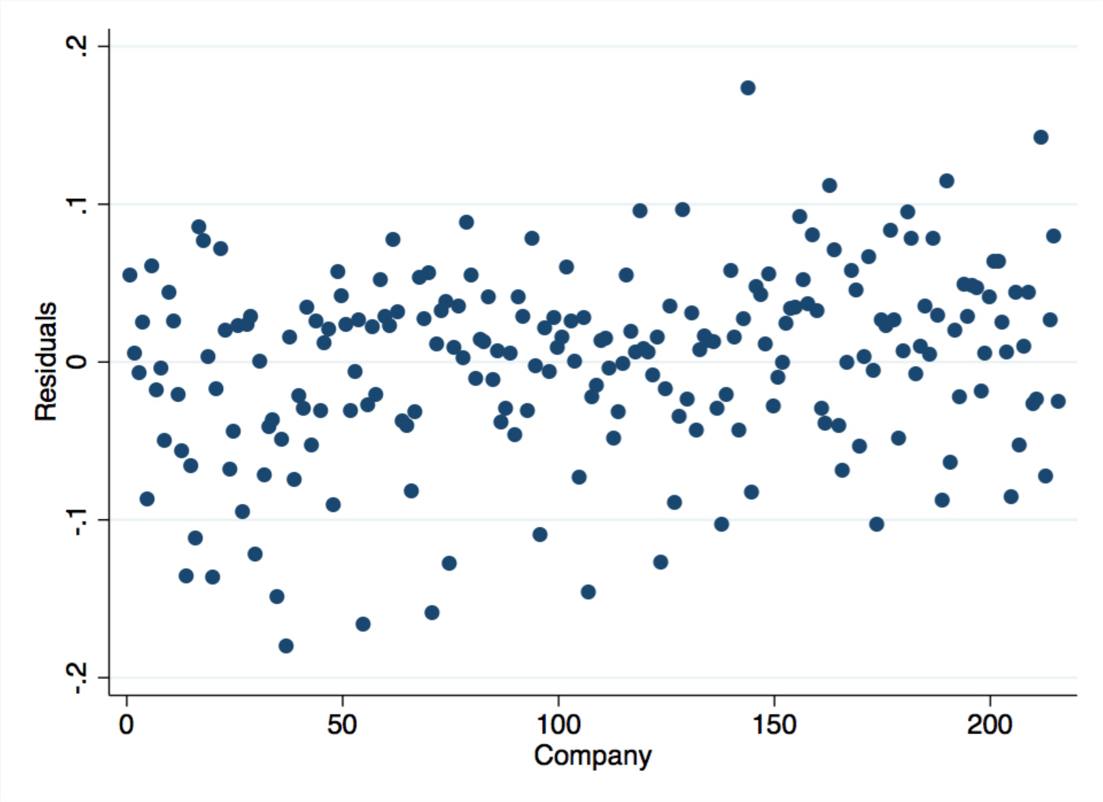
Dependent Variable	Variance Inflation Factor
Sales Growth	
Average R&D	165
Average R&D^2	79
Average R&D^3	25
Mean	90
EBITDA Margin	
Average R&D	165
Average R&D^2	79
Average R&D^3	25
Mean	90

Durbin Watson Tests

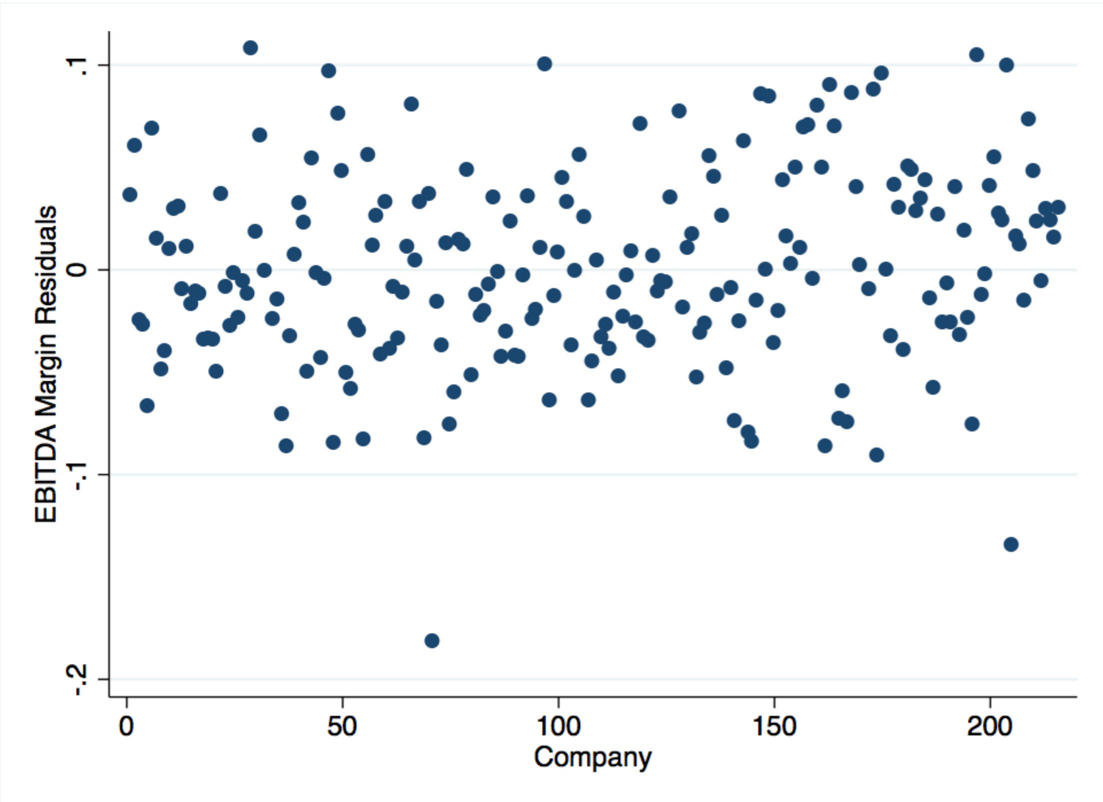
Dependent Variable	Durbin-Watson D-statistic
Sales Growth	2,11
EBITDA Margin	1,98

Residuals Scatter Plots

Residuals Scatter Plot – Sales Growth



Residuals Scatter Plot – EBITDA Margin



Link Tests

Dependent Variable	Hat	Hat^2
Sales Growth	41,2	19,71
EBITDA Margin	1,09	-0,73

Breush-Pagan Tests

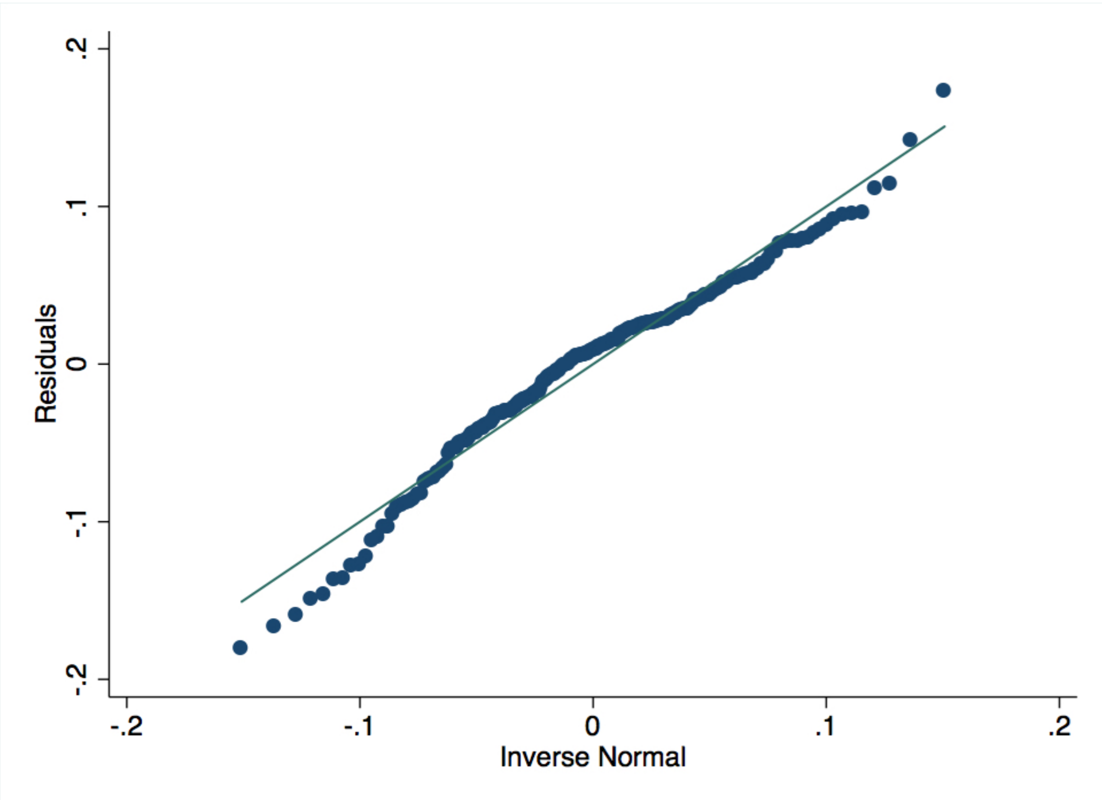
Dependent Variable	Breusch-Pagan Test Statistic
Sales Growth	0,05
EBITDA Margin	1,07

Shaprio-Wilk W Tests

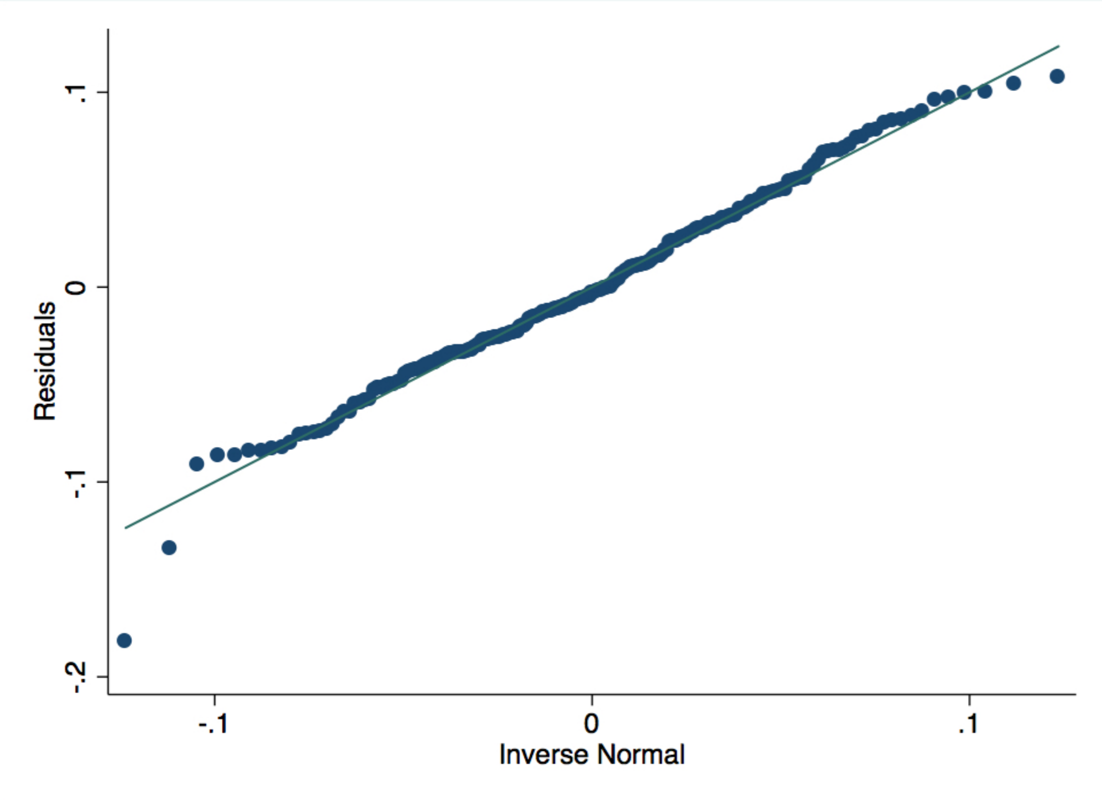
Dependent Variable	W	V	Z
Sales Growth	0,98	1,71	1,24
EBITDA Margin	0,97	2,25	3,34

Qnorm plots

Qnorm Plots - Sales Growth

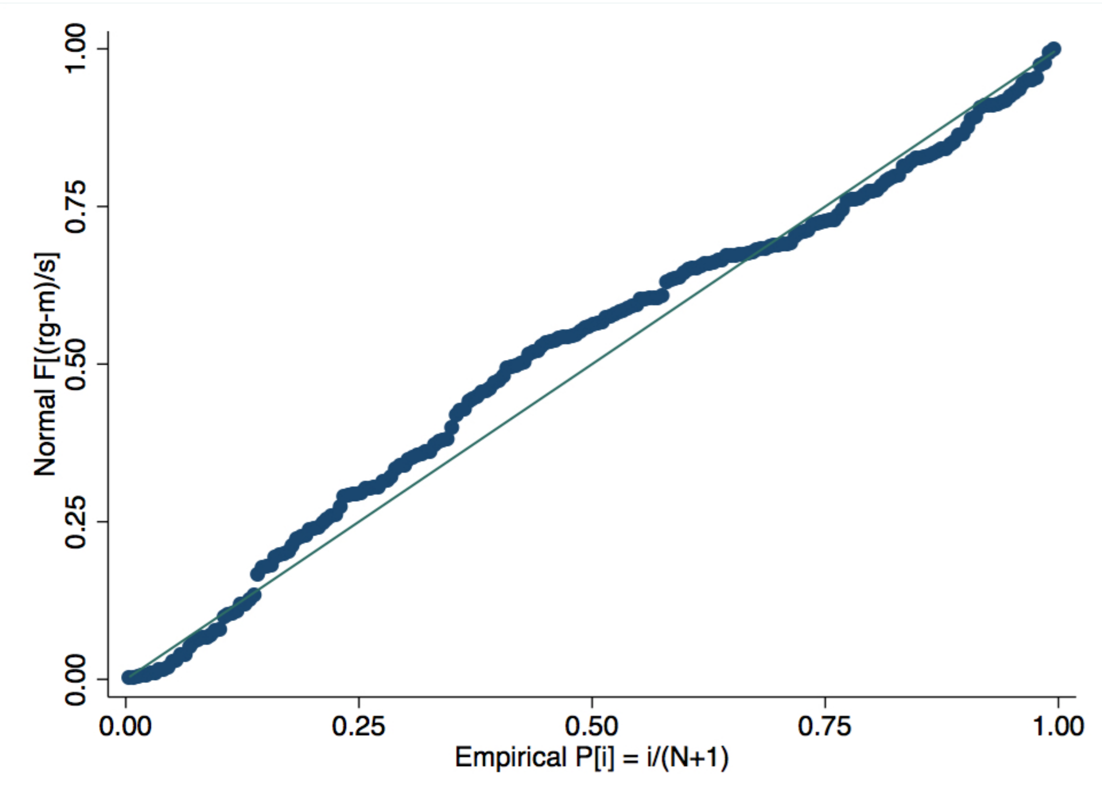


Qnorm Plots – EBITDA Margin

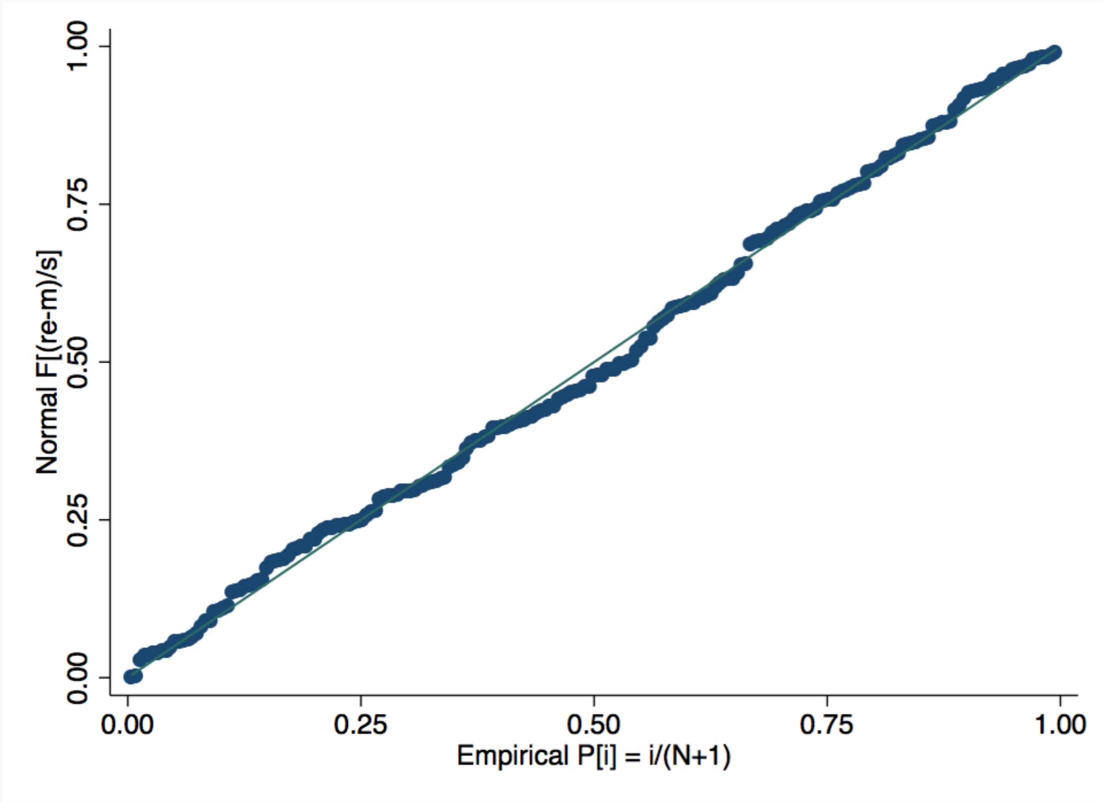


Pnorm Plots

Pnorm Plots – Sales Growth

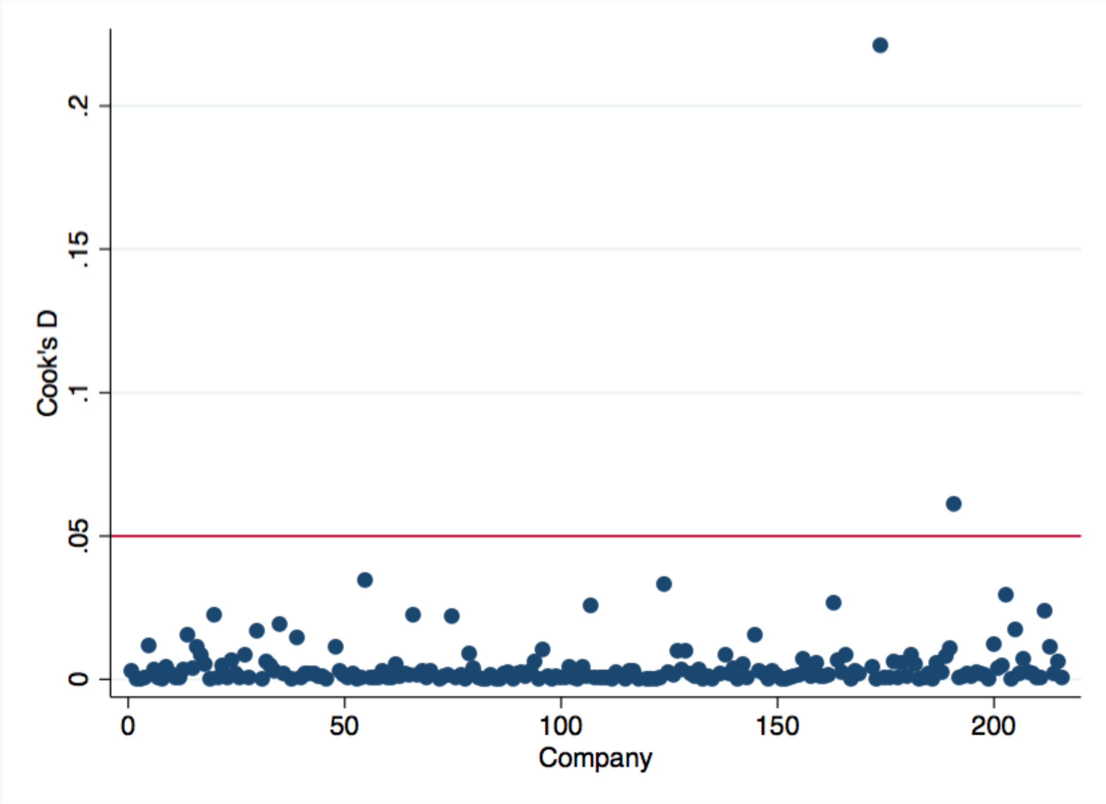


Pnorm Plots – EBITDA Margin

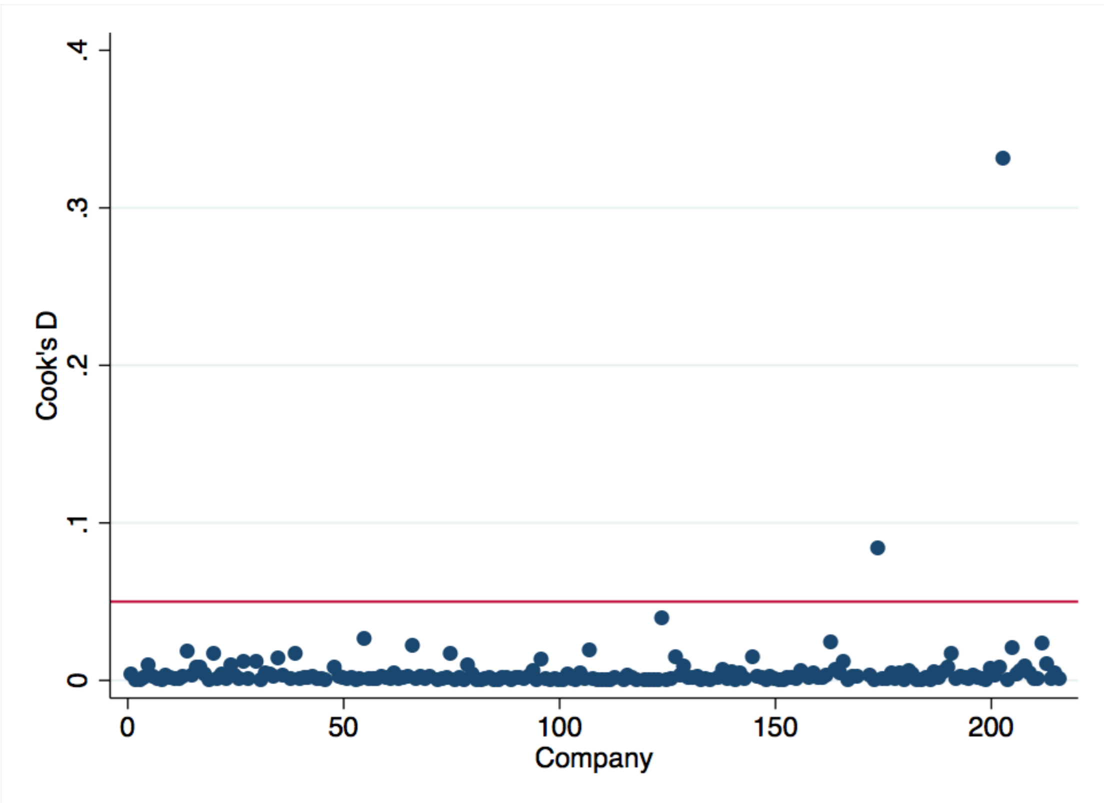


Cook's Distance

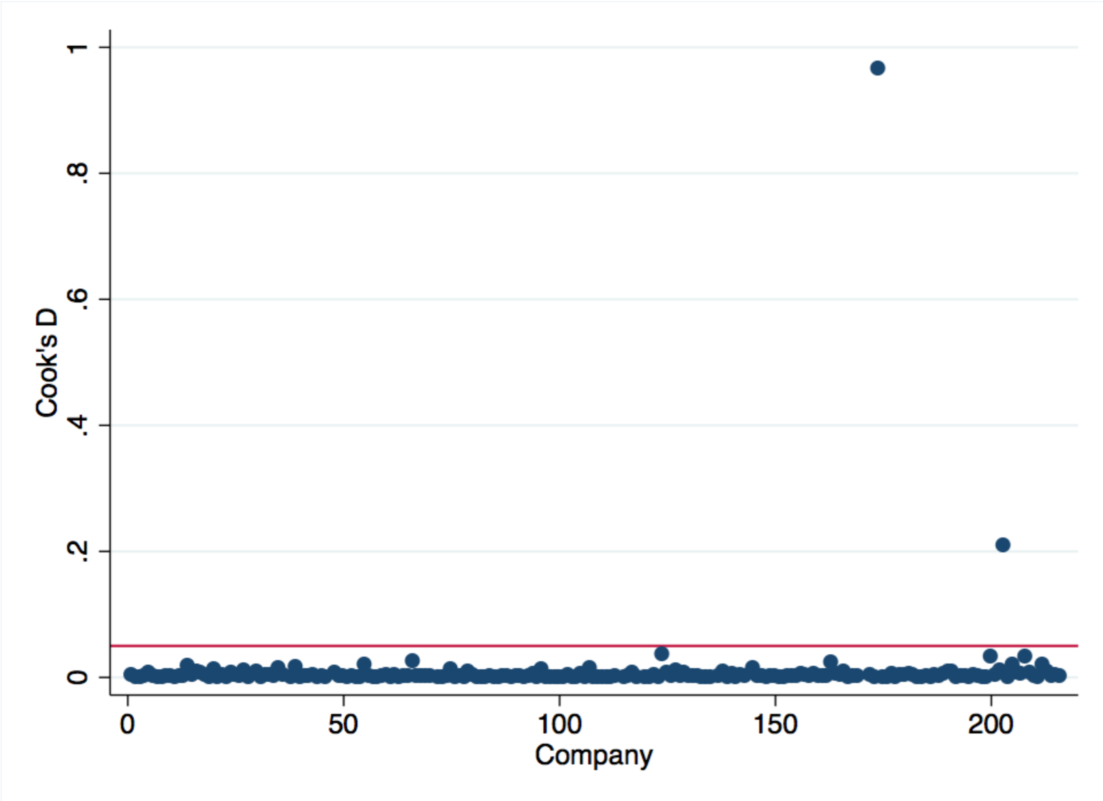
Cook's Distance – Sales Growth, Linear Model



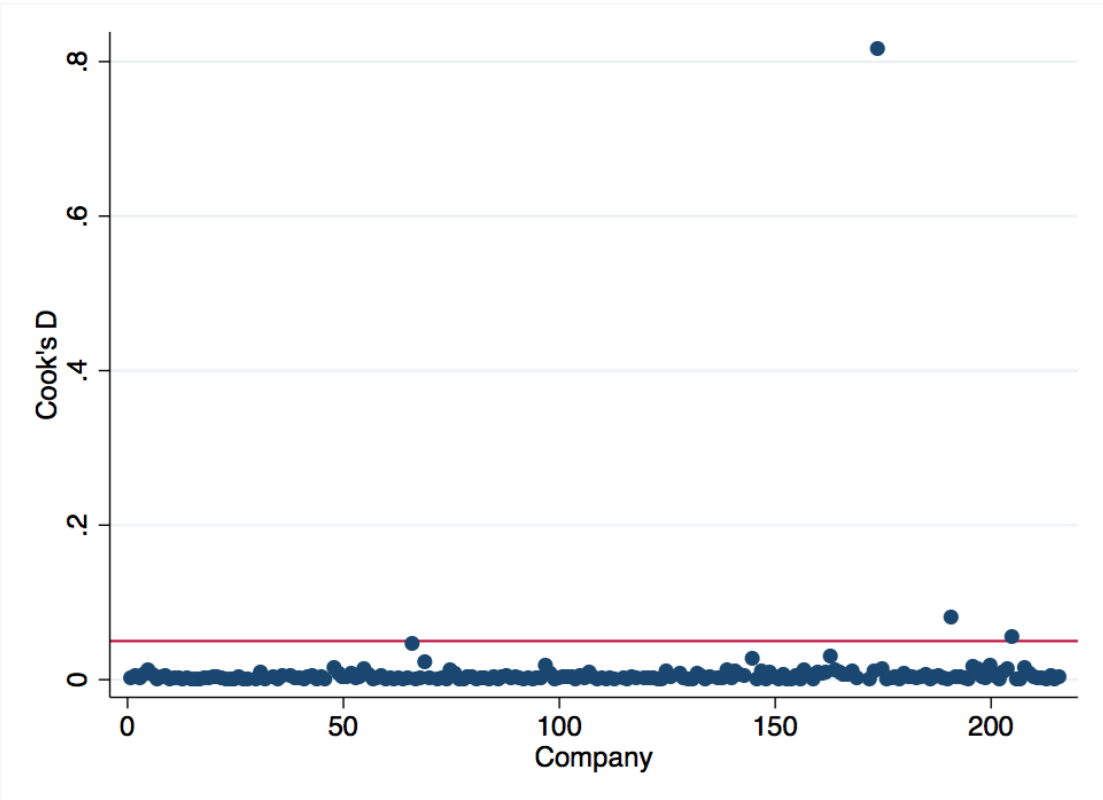
Cook's Distance – Sales Growth, Quadratic Model



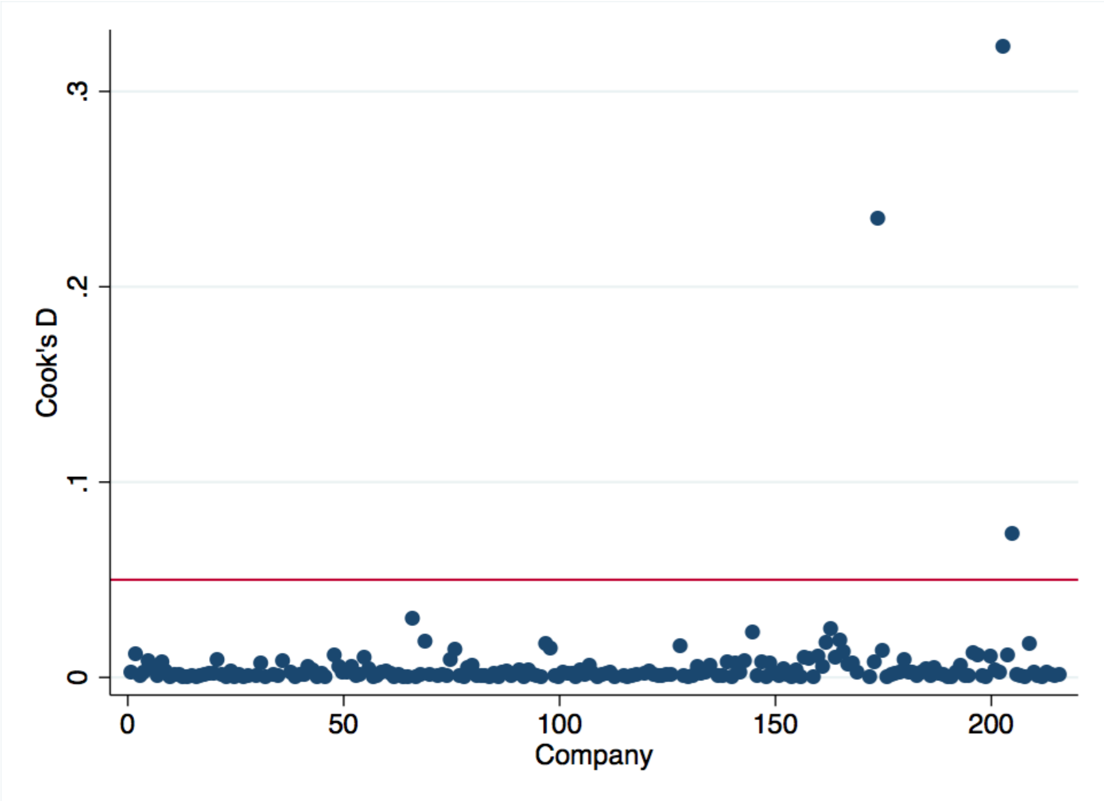
Cook's Distance – Sales Growth, Cubic Model



Cook's Distance – EBITDA Margin, Linear Model



Cook's Distance – EBITDA Margin, Quadratic Model



Cook's Distance – EBITDA Margin, Cubic Model