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FACULTY OF SOCIAL SCIENCES
Institute of Economic Studies

Marginal Effect of R&D Expenditures on Value of Technology Companies

Master's thesis

Author: Lukáš Tuček
Study program: Economics and Finance
Supervisor: prof. Ing. Evžen Kočenda, Ph.D.
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Declaration of Authorship

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Prague, July 31, 2020

Lukas Tucek

Abstract

Research and development is an inseparable part of technology industry as technology companies, unlike most, rely on R&D not only as means of efficiency improvement to existing production, but rather as means of production itself. This thesis presents an alternative approach to R&D intensity measure and applies it in an empirical analysis on technology leaders company data from 2013 through 2018 measuring R&D intensity impact on company market value. Additionally, this thesis explores the differences in impact of R&D on company value dependent on the company's product cycle nature. The results of this thesis are mostly conforming to existing academic literature and show diminishing returns to R&D intensity. A surprising negative effect of a variable comparing given company's R&D expenditures to ones of the segment leader of a given segment has been found. There has been found no lag difference between the groups of companies with open and closed cycle product development.

JEL Classification O31, O32, M21
Keywords research and development, technology, market value
Title Marginal Effect of R&D Expenditures on Value of Technology Companies

Abstrakt

Výzkum a vývoj jsou neoddělitelnou součástí technologického průmyslu, jelikož technologické společnosti se na rozdíl většiny spoléhají na VaV nejen jako nástroj ke zvyšování efektivity výroby, nýbrž jako prostředek výroby samotný. Tato diplomová práce prezentuje alternativní přístup k měření intenzity VaV a aplikuje jej v empirické analýze na datech předních technologických společností v letech 2013 až 2018, přičemž zkoumá vliv intenzity VaV na tržní hodnotu společností. Tato práce dále zkoumá rozdíly v dopadu VaV v závislosti na povaze produktového cyklu společnosti. Výsledky této práce jsou z velké části v souladu s existující akademickou literaturou a vykazují klesající návratnost k intenzitě VaV. Byl nalezen překvapivý negativní efekt proměnné srovnávající výdaje společnosti na VaV s těmito výdaji společnosti ve vedoucím postavení na daném segmentu trhu. Nebyl zjištěn žádný rozdíl v pozorovaném zpoždění zkoumaného efektu mezi skupinami společností s vývojem produktů s otevřeným a uzavřeným produktovým cyklem.

Klasifikace JEL O31, O32, M21
Klíčová slovaa výzkum a vývoj, technologie, tržní hodnota

Název práce Marginální efekt výdajů na výzkum a vývoj na hodnotu technologických společností

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All errors remaining are, of course, solely mine.

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Motivation The general notion of R&D expenditures having positive impact on company value is generally agreed upon in the field of company valuation. Since among technology companies (hardware companies and even more so software companies) the portion of expenses attributed to R&D is substantially higher than in traditional industries, R&D expenditures are a vital factor in cost optimization, company valuation and corporate governance. Thus, in this thesis I would like to explore the impacts of companies' decisions regarding R&D and provide some insights into how the marginal R&D expenditures reflect on company value among major players in the technology industry.

Hypotheses In this thesis, I would like to examine hypotheses regarding the specifics of R&D among technology companies and its marginal impact on company value.

Hypothesis #1: Examining the differences between companies with closed-cycle and open-cycle product development. H_0 : There is no statistically significant difference between the marginal impact of R&D on company value of companies with closed-cycle and open-cycle product development.

Hypothesis #2: Examining the delay between incurring the RD expense and a change in the response variable. H_0 : There is no statistically significant difference between lag of the response variable as a result of R&D expenditures among various groups of technology companies.

Hypothesis #3: Examining marginal impact of R&D among groups of technology companies based on the intensity of R&D expenditures. H_0 : There is no statistically significant difference among the marginal impact of R&D of technology companies clustered based on the intensity of R&D expenditures.

Methodology For the purpose of this study, I am going to separate technology companies based on two of their major traits relevant for this thesis: product development model and R&D intensity.

Product development model will encompass the information regarding the development cyclicality the company is pursuing, categorizing each company into either 'closed-cycle product development', representing companies with discrete release dates of products, typically utilizing one-time payment monetization model and little to no further development on an already released product, and 'open-cycle product development', representing companies with either no specific release date of an updated version of existing product, or open-ended perpetual development of a newly released product, typically encompassing software companies and subscription based monetization model.

I will perform an econometric analysis to uncover the relationship of R&D expenditures and company value among technology companies with respect to the groups described above and examine the marginal effects of R&D expenditures on company value. Since there are differences in reporting practices among the companies, to obtain reliable R&D estimates for the analysis, I will, if proven necessary, perform principal components analysis on relevant variables (such as the reported R&D values, ratio of intangible assets and total assets, or potentially an average value for a given cluster of companies).

To further illuminate the issue of R&D expenditures in the technology sector, I would also like to perform a case study on the effective duopolistic market with processors and examine the case of AMD and Intel, which have undergone a very turbulent competition and vast changes in the past 5 years. Within this case study, I would like to attempt to separate the impact of R&D expenditures on the outcomes of this competitive rivalry.

Expected Contribution Since the academic discourse regarding R&D expenditures specifics regarding technology companies is limited, this thesis might provide some new insights into this topic. Additionally, this thesis may prove to have implications for practical applications in corporate governance worth pursuing further investigation in the future.

Outline I would like to structure this thesis in such a way, the reader would be firstly introduced to the general field of company valuation and the role of R&D in it, as well as into specifics of the technology industry. Further into the thesis, the reader would be led through the primary and secondary research performed and finally would be presented with the findings of the thesis and potential follow-up research.

1. Section 1: Introduction to the role of R&D in company value, brief introduction into the problematic of R&D expenditures, their importance and overview of classical measurements through which they enter company valuation
2. Section 2: Technology industry specifics and brief overview of technology industry and mainly its core specifics when compared to traditional industries
3. Section 3: Literature review
4. Section 4: Methodology
5. Section 5: Econometric analysis, data and results
6. Section 6: AMD and Intel case study
7. Section 7: Conclusion

Core bibliography

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Chapter 1

Introduction

R&D among tech companies is a very important aspect of modern day economy. The vastness of the investment companies undertake in the endeavor to further their technological advancements can be seen on the example of Amazon, whose ‘technology and content‘ item on the income statement is comparable to GDP of Iceland.

In this thesis, we are going to examine the relationship between R&D investment and company value in the technology industry. There is a vast academic research showing the positive impact of R&D expenditures on company performance across industries. The majority of this research does, however, focus on a traditional approach to R&D and examines it from the perspective of R&D being a mean to improvements to processes and technology used in manufacturing of products or providing services. Technology companies, defined in this thesis similarly to how they are understood by the general public, have a much closer connection to technological advancements than companies in other industries, therefore making the relationship between R&D investment and company value even more interesting. Unlike most, technology companies rely on technological advancement as a means of production, since their value added is closely tied to the advancement they are able to provide. Apart from investigating this relationship in the overall industry, we will also examine the specific effects of a given company having an open or closed cycle product development, since there is a significant operational difference between companies which focus solely on development of new products and those whose products are of value only if the company continues to develop it further after the product has already been released and delivered to the customers.

In the empirical section of this analysis, we are going to formulate a fixed effects model building on previous literature and utilize alternative measurement approach R&D indices to overcome some of the difficulties presented by inconsistencies in R&D reporting among technology companies. We are going to attempt to add to the knowledge in this field by re-examining the relationship between R&D intensity and company market value through introduction of the differentiation of companies based on continuity of their respective product development and inspecting the effects of a comparative measure of R&D to the segment leader. Since it is typical for technology companies to operate on competitive markets with few dominant players, such metric might provide more information about the dynamics of the competition in achieving the highest level of technological advancement in a given segment.

In the second section of this thesis we will review existing literature and first focus on insights into R&D, its position in technology industry and specifics of the industry relevant to this thesis in general. We will discuss how economies of scale interfere with R&D in technology industry, including reasoning for the oligopolistic nature of many technology segments and practical limitations to R&D projects. We will examine the timing aspect of R&D in technology industry, both in the sense of the need of correct timing for a project to be successful and in the sense of lagged impact of a successful R&D project on company value. Secondly we are going to review the main findings relevant to this thesis.

The third section of this thesis is devoted to methodology applied in the empirical analysis, describing the categorization process of companies into the open and closed cycle product development categories, construction of the alternative measurement approach R&D index, selection of both, dependent and independent variables and formulation of the model itself. The fourth section describes the process of data collection, their further processing and key insights into the data. Results of the analysis are described in the fifth section of this thesis. A short case study on the recent disruption in the semiconductor market can be found in section six and the thesis concludes discussing main findings and shortcomings of the thesis in section seven.

Chapter 2

Literature Review

2.1 Theoretical Background

R&D is a vital component of most successful businesses, since it furthers technological advancement and provides companies comparative advantage over their counterparts. This relationship is even stronger among technology companies, since technological advancement is a core value they provide.

In review of existing findings and overall insight into the problematic, books by Hall & Rosenberg (2010a & 2010b) were an invaluable asset.

2.1.1 Delimitations

As presented by Salgado *et al.* (2018), there is no singular definition of technology company accepted across either national regulatory bodies, or academia. This ambivalence gives rise to the need to define technology company for the purpose of this analysis. The authors present several varying definitions used across literature, including a broad understanding of technology company as any company dependent on technology, regardless of whether the technology is new or innovative (Dahlstrand, 2007). Such a broad definition of technology company is not suitable for the purpose of this thesis. Technology company, in the sense it is going to be used in this thesis, is a company whose products and services are either considered to be information technology by themselves, or are closely linked to it, including both, software and hardware. This definition follows what is generally referred to as technology company by the general public.

The second core component of this thesis is research and development. As pointed out by Soderquist & Godener (2004), the definition of R&D also suffers from ambiguity, which brings uncertainty in comparability of R&D across companies with potentially different reporting practices with respect to R&D and even across time periods within the same company, as these practices may be subject to change. Healy *et al.* (1999) show that the tradeoff between relevance and reliability ever-present in accounting is an issue for R&D reporting as well, furthering the ambiguity. Lev *et al.* (2005) finds there are consequences to such biases in terms of mispricing. Wyatt (2008) additionally shows the biases differ based on the situation in which the company currently operates. Jeny & Jeanjean (2003) examined signaling with respect to reported R&D expenditures and showed the reported values may vary based on the firms intended message to the investors. They find that the firms with high quality R&D prefer to not disclose their R&D expenditures to its full extent (describing this effect as confidentiality), whereas companies with poor performance are incentivized to show high level of R&D expenditures in order to improve the future prospects of the company as perceived by the market (describing this effect as jamming). Aboody & Lev (2000) go even further, concluding the difference between information regarding R&D available to the management and to the investors is large enough to constitute an opportunity for insider trading.

Additionally, Tou *et al.* (2019) describe the extent to which R&D reporting may be interpreted out of bounds of traditional understanding of R&D on a study of Amazon's R&D processes and reporting practices.

For closer inspection of the term R&D, we can examine official regulatory sources and their delimitations with respect to R&D reporting. Financial accounting standards board online glossary defines research and development as follows.

> ‘Research is planned search or critical investigation aimed at discovery of new knowledge with the hope that such knowledge will be useful in developing a new product or service (referred to as product) or a new process or technique (referred to as process) or in bringing about a significant improvement to an existing product or process.
>
> Development is the translation of research findings or other knowledge into a plan or design for a new product or process or for a significant improvement to an existing product or process whether intended for sale or use. It includes the conceptual formulation, design and testing of product alternatives, construction of prototypes and operation of pilot plants.‘

In comparison, Frascati manual (OECD, 2015), first published in 1963, defines R&D in a broader manner.

> ‘Research and experimental development (R&D) comprise creative and systematic work undertaken in order to increase the stock of knowledge including knowledge of humankind, culture and society and to devise new applications of available knowledge.‘

The document itself acknowledges problematic nature of R&D reporting as it provides guidelines and recommendations, leaving some final decisions as to expense categorization to the company’s best judgement. Lastly OECD Factbook (2015) presents yet a different definition of R&D, focusing on comparability.

> ‘Research and development covers 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 foundation 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, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.‘

Since there are very limited options for this thesis to address the potential discrepancies among the companies reported R&D expenditures and clearly restate the reported values into a comparable form, a proxy measurement (described in detail further) has been created to combat this issue.

2.1.2 Position of R&D in Technology Industry

In many industries, R&D and technological advancement arising from it are used to increase efficiency of existing processes, or create new processes, furthering the productivity of a given company. In comparison, technology companies rely on R&D much more directly, since their products and services are the technology which needs to be developed. This makes technology industry (similarly to e.g. pharmaceutical industry) specific, since instead of utilizing R&D only for furthering mechanisms of production, it must also be utilized as a mean of production by itself. Postula & Chmielewski (2019) argue that launching new technological solutions to the market is a business model of companies in the technology sector, while stating they offer their clients technologically advanced solutions that are used to boost the competitive advantage in the market. This essentially puts the companies in technology industry in the position of the technology supplier, which corresponds to the aforementioned relationship these companies have with R&D.

Kunttu *et al.* (2019) examine the conflicting requirements put on subsidiaries in technology industry demonstrating this specific relationship of new technological advancements and technology companies to its full extent. They argue there is a pressure for these companies to both, provide results in furthering technology requiring high R&D investments and at the same time retain positive performance indicators. Xu & Jin (2016) conclude that companies in technology industry (specifically internet of things industry) should both, encourage innovation and set long-term plans with regard to R&D, since there is a time lag between the latest technology can be implemented into production.

According to Dai *et al.* (2019) among a sample of Chinese companies (not limited to technology companies) approximately 80 percent of R&D expenditures was spent on the development part. This shows companies generally prefer the applied and more certain development over uncertain research. Since technology companies rely on providing innovation, this statistic may differ significantly, however due to aforementioned differences in reporting and varying extent of granularity to which information regarding R&D is provided, such information is not provided.

Hall *et al.* (2009) show the importance and value of intangible assets (specifically patents), however conclude the markets value software related patents to much lower extent than patents on physical subjects. They hypothesize this might be due to lower legal enforceability of such intellectual property, thus not diminishing the concept of value attributed to the intellectual property itself. This furthers the notion of importance on R&D among technology companies, as it shows the intellectual property arising from the activity is indeed valued not only in terms of companies operations, but also by the stock markets and due to technology companies' reliance on such intellectual property, it can be argued any of such effects will have disproportionate impact on the industry at hand.

Ehie & Olibe (2010) conclude that there is a positive effect of R&D on market value regardless of industry, however their results also show significant variations in the impact. They find electronic equipment manufacturing to be among manufacturing industries with the highest benefit from R&D investment. There are obvious issues when comparing R&D impacts across different industries, since typical behavior of companies among those industries may be also reflected in standard reporting practices of companies grouped in one industry. Gammeltoft (2006) emphasizes the important of internationalization of R&D efforts, showing yet another distinction which may be at play when examining different levels of R&D across industries.

Technology companies typically operate on markets with very short product cycles (as can be seen on the consumer markets, consumer technology products with a yearly release intensity are frequent). Xu & Jin (2016) illuminate this effect on the internet of things industry, discussing fast depreciation of this type of technology. Technology companies (as defined in this thesis) strongly rely on similar technological advancement as the ones described by Xu & Jin (2016). This is in line with the observations available on the consumer markets with expedited aging process of technology and steep reduction of value in a short period of time. Bayus (1994), while not addressing technology specifically, attributes this effect rather to an artificial increase in products released with disproportionately lower exit rate of products and higher competitiveness of the markets as a results. Bayus (1998) adds the factor of shortened product cycles of existing products and argues this not necessarily a result of increased rate of technological advancements, but rather a necessity rising from the demand for new products. Chaney et al. (1991) show positive incentives for companies to release products frequently. Awwad & Akroush (2016) state that the overall increased rate at which businesses are expected to release products comes as a result of fast and frequent changes in customer preference and expectations and fast paced technology proliferations. The authors also argue these effects result in an uncertainty, ultimately affecting organizational performance of companies. Regardless of the underlying reasoning for this phenomenon, it is clear there is a strong pressure on technology companies to constantly present new products and since the value of products of technology companies is often measured in their respective technological advancement, it automatically pressures them to constantly focus on R&D, since they have a vital need to implement new technology into their next generation of products. When combined with the common practice among technology companies to outsource their manufacturing, the comparative importance of R&D in terms of new product development is further enhanced.

2.1.3 Economies of Scale

Since technology companies at hand typically do not produce tailor made solutions with low unit volumes and focus rather on ‘confection‘, it can be clearly seen how is the ability to distribute R&D costs among larger volumes beneficial to the capability of a technology company to invest into R&D more heavily in an attempt to gain higher technological advancement. Chen *et al.* 2019 conclude there is a positive correlation between company size and business performance when examining Taiwan’s semiconductor industry and effects of R&D on company performance. At the same time, the authors argue larger companies tend to have better access to resources improving their ability to invest more into R&D, while also having high enough unit sales to spread the expenses and remain competitive.

Kim *et al.* (2018) shows larger companies in general tend to benefit more from R&D investments than smaller companies, thus support the notion of the effect of economies of scale being present in R&D investment. Connolly & Hirschey (2005) provide even stronger conclusion, suggesting there are important differences in R&D expenditures with respect to firm size. They specify that larger companies face a significantly higher benefit from unit investment into R&D than smaller companies. This result suggests a disproportional benefit from R&D expenditures to larger companies. Coad & Rao (2010) find that companies tend to increase their R&D expenditures following a growth period, however are reluctant to reduce their R&D expenditures in a period of decline. These results may suggest companies tend to acknowledge benefits of increased R&D investments and their reluctance to decrease these expenditures when shrinking furthers the perceived disproportionate positive effect of larger R&D.

Another important factor regarding economies of scale with respect to R&D among technology companies is their signaling towards potential customers. Excessive technological advancement featuring technology beyond the expectations of customers which does not meet affordability criterion, as its value is dramatically boosted by artificial advancements not following the demand, can be seen in the light of technology companies as a marketing effort. It can be argued excessive R&D spent on such project might be simply considered a marketing cost to other, more reasonable product. Foroudi *et al.* (2016) provide an insight into literature regarding this topic. Nguyen *et al.* (2016) argue innovation and marketing are the main aspects to company's ability to raise capital, as it provides the company with competitive advantage. Gupta & Malhotra (2013) and Foroudi *et al.* (2014) provide us with the final link, showing how the perceived ability to innovate is involved in public perception drives the company reputation and company loyalty. Finally Dowling (2001) also finds a similar connection with investor, thus not only showing the perception of a company by customers is affected, but there is a direct link to investors (and thus company market value) as well. Based on this phenomena we may argue that the disproportionate benefits available to larger companies in terms of economies of scale are not limited to the final products themselves, but may also be used for this technological signaling.

Another important aspect of the benefits to size of the technology company at hand are barriers to entry. Since there are very high threshold requirements imposed on technology companies in terms of knowledge and know-how required, larger companies are more likely to be able to overcome these barriers due to access to larger funds. Technology industry relies heavily on patents and licensing, which is very common even among the market leaders. Im et al. (2015) observed an inverted U-shape relationship between competition and the value of innovation. Hall *et al.* (2009) confirmed the value of patents. We may argue based on the aforementioned that this leads to higher barriers to entry for potential newcomers, as existing technology potentially necessary for a proposed product may be burdened with licensing fees, further increasing the level of necessary achieved technology advancement for new products.

Chen *et al.* (2019) argue the mechanics of knowledge spillovers play an important role in R&D among technology companies. They find that the firm's R&D intensity and its specific activities may affect the employees, organization of knowledge or general technical level of knowledge in the company, thus in turn affecting business performance beyond the goals of the initial R&D.

Due to the existence of inter-company spillovers, there is however a potential incentive for companies to wait for innovation being created by others and only implementing technology in their own portfolio once it has been developed and tested by another player on the market. This manifests in licensing structures, when it is more economical for companies to purchase a license when a technology they require is already developed and patented than invest into R&D to find an alternative to the technology. Chen *et al.* (2013) present results suggesting such spillovers are predominantly occurring through talent acquisition of companies with spillover inflow.

The aforementioned conditions in which technology companies are operating naturally support creation of monopolistic or oligopolistic competitive environments, since only a few companies are usually able to survive at an emerging sub-market. Combined with the size of the major players on technology markets, smaller companies usually must operate in a niche sphere, otherwise they would not be competitive. Xu & Jin (2016) remark that in the technology subsector internet of things, economies of scale cannot be utilized, thus bringing negative observed returns to R&D. This can be extrapolated into the emerging sectors of technology industry in general, since there tends to be much higher competitiveness, as no established companies have yet captured large enough market share to become a dominant player in the sector. It is, however, very common for the existing multi-segment market leaders in the technology industry to purchase companies in such emerging sectors and attempt to leverage their existing market power in other sectors (utilizing their size and brand recognition) to gain market dominance. It is therefore very important to view the technology industry with respect to its specific sub-segments, as companies very often are either specialized and compete only in a specific segment of the market, or compete on several different segments separately (only leveraging their size across the whole market).

Thus, it can be concluded there are economies of scale to both, the ability of a company to undergo more R&D based on its larger size and the R&D returns themselves, with observable R&D having a significantly stronger positive impact as it grows in size.

On one hand, Madsen (2006) challenges the consensus on existence of diminishing returns to R&D expenditures and presents a model for 21 industrialized countries, for which the hypothesis of linear impact of R&D cannot be rejected. On the other hand, consistently with Griliches & Mairesse (1989), Kim *et al.* (2018) and Ehie & Olibe (2010) find support for diminishing returns at least among parts of the sample.

There are also practical constraints to R&D spendings in the technology industry. On the supply side, there is an obvious limitation of dependence on other players in the field to have existing infrastructure in place to accommodate the new technology. Many products in the technology industry are virtually useless when considered as stand-alone products. Software developers must respect the constraints of currently existing hardware to be capable to run the program they are developing, while hardware manufacturers of networking equipment are limited by the existing capabilities of cables transferring data between their devices. Technology companies are in a way extremely limited in the directions and extent they are able to effectively innovate, since they must either build an infrastructure for a technology for which the market is not ready by themselves, to make it useful, or they must take smaller steps and rely on other companies to also contribute to the advancements. At the same time, there are limitations as to production capabilities of new technology, as pointed out in Xu & Jin (2016).

On the demand side, Lengnick-Hall (1992) shows the importance of of meeting the expectations of customers. This can also be applied to technology, as the findings follow the simple principle that a product must have certain (at least perceived) value to create a demand for it. Mahmoud *et al.* (2017) additionally shows relationship between customer value creation and customer satisfaction. The mismatch of technological advancement and customer preference can be seen for example on Google's failed project: modular smartphone (project Ara). Despite its obvious advantages in terms of advancements in technology compared to existing devices at the time at least in the form of additional modularity and customers ability to customize the smartphone to be tailor fit for various use-cases, this project received a lot of criticism and was ultimately canceled. Several other companies have since attempted bring such technology to market with varying success and in 2017 Facebook has also filed a patent for its own modular electromechanical device resembling a smartphone. This may either suggest the customer expectations were not fulfilled by project Ara and other companies managed to achieve a better fit to the customer expectations, or that customer expectations have changed.

Bridges *et al.* (1995) provides insight into another aspect of the demand side constraints to technological advancements, which is affordability. The authors describe the tendency for technology to improve and prices to decline, which rises the customer expectations in terms of value for money. It may be argued this effect limits the potential for technology companies to focus on R&D which would lead to creation of products, which would deteriorate this ratio, since customers expectations have already been altered. Another limitation regarding affordability also comes into play, as customers are only capable of purchasing products which they can obtain funds for regardless of the value for money parameter. This effect may be even stronger, when willingness of the customers to spend money on certain type of technology in absolute terms is taken into account. Applying the findings of Awwad & Akroush (2016) and Bayus (1994), we may find that the increased product availability in technology sector and changing preferences of customers might have significant effect on the purchasing decisions of customers and potentially pressure companies to focus even more affordable technology, further limiting the benefits of excessive R&D spending.

We can thus clearly see the existing literature supports the traditional notion of diminishing returns to R&D, however it is uncertain at which point the returns to R&D become diminishing and whether such effect does only apply to the absolute or also relative term of R&D (to a reasonable extent).

2.1.4 Time Aspect of R&D

As the matter at hand is technology, it is obvious timing of relevant projects is an important aspect of successful R&D endeavors undertaken by technology companies. This intuitively holds true for both, duration of the effort and beginning of the project, as these two variables determine at which point in time is the final result of such R&D going to be transformed into a finished product. Schumpeter (1934) states that in capitalistic economic system those companies which manage to innovate are rewarded by increased market shares and enjoy temporary monopolistic profits, which he considers to be a key incentive to innovate. McDaniel (2002) further describes the mechanics by which after the monopoly rents have deteriorated due to loss of uniqueness to the singular company, the prices will be reduced to the minimum average cost for such products. This concept strongly supports the notion of timing when applied to technology industry, since it is often seen that companies directly competing in given segments of technology industry attempt to achieve very similar R&D goals and their product lines do drift apart in a significant manner other than technological advancement and design choices across lifecycles of the product.

Githens (2000) argues that the choices of the correct projects are the most important aspect of R&D activity. This does not only rely to focusing on choices projects which will be accepted by the consumers if successful, but also to the timing aspect, as the consumer preferences change in time (discussed at length in previous section). Hay & Morris (1979) hint a tendency for R&D projects to have binary outcomes (namely suggesting R&D is a high risk - high return strategy) - either the project is successful and poses a significant benefit, or the project is ultimately unsuccessful. This seems to correspond to the nature of R&D in technology, since partial solutions may not be viable for practical applications. The project's success may also be in part determined by the time of its completion.

Another important part of time aspect of R&D is the lagged nature of the R&D effect. Ehie & Olibe (2010) describe the payback time for the investment into R&D as market by uncertainty, since it is questionable not only whether the payback is going to happen, but also at what point in time. Chen *et al.* (2019) state that company's R&D expenditure in the current year does not generate immediate output. In their empirical results, the authors find current years R&D intensity to have negative impact on the company's performance, since the expenditure has already taken place, yet the benefits are not yet present. They do, however, find positive lagged effect of R&D intensity. This is in line with the findings of Xu & Jin (2016), who observed non-significant current year impact and a positive impact in the first lagged phase. In this study, contrary to the results of Chen *et al.* (2019), the cumulative effect is found to be negative. Hall *et al.* (1986) finds inconclusive results in terms of timing of effects from patent data, however shows strong link between patent activity and R&D investment. Combined with Pakes (1985) who suggests lag structure between time of invention through R&D process and patent emergence and Hall *et al.* (2009) exploring market value of intellectual property held by companies in the form of patents, this result also supports the notion of lagged effect of R&D on company value.

2.2 Main Findings

Traditionally, the academic research has focused on the effect of R&D on productivity growth. Griliches (1980) finds a decline in R&D effectiveness in the period 1969-1977, however argues there are other factors at play and such results should not be taken at face value. Cockburn & Griliches (1988) show positive relationship between R&D, patents and firm performance. Clark & Griliches (1984) found that R&D investment has a significant positive effect on the growth rate of total factor productivity. Griliches (1998a) shows strong positive relationship between R&D investment of US companies covering years 1966 through 1977 and their respective productivity. Griliches (1998b) examined US companies compared to their Japanese counterparts and found that the contribution of R&D expenditures affected productivity growth in a similar fashion (the null hypothesis of the effects being the same was not rejected).

Ben-Zion (1984) found that the market value of a company is affected by its R&D and investment policy. He found that patent intensity has stronger positive effects on company value when present in the whole industry in which company is operating than its own patent intensity. Chan *et al.* (2001) examined stock data covering the period from 1975 through 1995 and implemented a discounting lagged structure of previous R&D investments into the independent variable. They concluded that 'evidence does not support a direct link between R&D spending and future stock returns'. They do, however, remark that lack of such observed relationship might cause potential mispricing due to R&D not being fully capitalized.

Dietzenbacher & Los (2002) reviewed positive externalities generally associated with R&D and perform an empirical analysis regarding negative externalities of R&D in the form of increased costs downstream from the company engaging in R&D. They found highest costs to the industry associated with additional unit of knowledge in office machinery, pharmaceuticals and aircraft industries. Chauvin & Hirschey (1993) examined a sample of COMPUSTAT companies and found significant positive effects of advertising and R&D on company value. They also showed industrial machinery and computer equipment alongside Electronic equipment among the industries with highest observed coefficients for R&D expenditure as a predictor.

Yang *et al.* (2010) employed an S-curve model and found non-linear relationship between R&D intensity and company's profitability. They found negative relationship for low levels of R&D investment, positive with medium levels and negative with high levels of R&D investment. This suggests existence of optimal R&D intensity levels.

Research carried out by Ehie & Olibe (2010) showed the anecdotal evidence of companies reducing R&D expenditures following major economic disruption does not have support in the data. The authors have also found that generally firms that invest heavily in R&D have a higher likelihood to be profitable. They also reviewed results of Osawa and Yamasaki (2005) factors inhibiting linkage between R&D investment and company value, concluding the lack of a definite output measure for R&D, time lag effect and absence of proper indices for R&D make it difficult to accurately account for the overall effects of R&D investment over time. Ehie & Olibe (2010) found positive relationship between R&D and market value for both, manufacturing companies and service based companies, however they show that on a general sample of companies, manufacturing companies are more involved in R&D than service companies.

Xu & Jin (2016) provide an insight into a segment of technology industry, namely Chinese internet of things companies over the period from 2011 through 2013. Their results are conforming to the overwhelming literature finding first lagged phase of R&D investment to have a positive impact on company performance, however suggest a negative overall relationship of R&D and company performance. They argue this might be due to the emerging nature of the segment.

Chen *et al.* (2019) examine Taiwan's semiconductor industry and provide an outline of relevant literature focusing on high-technology companies and show a predominant consensus on positive relationship between R&D and company value among such companies. They acknowledge previous research has found R&D to be a key metric when examining high-technology companies and despite the overall expected positive effect, excessive R&D might be harmful to the company. In their own analysis they examine the impact of R&D intensity on return on assets and find that R&D intensity has a negative link to the current business performance, however lagged value of R&D intensity shows with a disproportionately larger positive effect. They also conclude positive correlation of firm size and business performance, arguing the size of the company having positive effect through allowing for larger R&D investment and thus increasing the observed positive effect.

Chapter 3

Methodology

3.1 Alternative Measurement Approach R&D Index

In order to examine and determine the methodology to be used in this analysis, it is of key importance to first address the problematic of R&D expenditures reporting, as especially among technology companies this may produce severely unreliable data. Barth (2000) points out overall mismatch between reporting research and companies' practices, while Tou *et al.* (2019) address the problematic of R&D among technology companies specifically.

They examine new concept of R&D reporting pioneered by Amazon and provide further insight into the companys practice to not even report these expenditures as R&D and rather uses 'technology and content'. Despite this being an anomaly, crucial lessons can be learned from the approach. Tou *et al.* (2019) comment on the uncertainty what is and what is not included in Amazon's R&D expenditures, since allegations were made accusing Amazon of including routine technological maintenance in this category. Other companies have also been questioned regarding their standards when it comes to R&D expenditures and thus serious doubt has been shed upon the reported values in technology industry. Tou *et al.* (2019) also point out specifics of Amazon's approach to R&D, such as user-driven innovation. Since the reporting standards of Amazon became part of public debate, several other companies were questioned regarding their standards on reporting R&D.

On the other hand, Abrahams & Sidhu (1998) concluded that capitalized R&D expenditures are value relevant for Australian companies with high R&D

intensity, thus supporting the notion of new concept in R&D endeavor presented by Tou *et al.* (2019).

To avoid contamination of the data by potential mismatch in reporting, alternative measurement approach R&D index has been employed to derive a proxy measurement to R&D intensity. The index has been constructed by employing principal component analysis, relying on reported R&D intensity (reported research and development expenditures incurred in given year with no capitalization compiled from income statement item and accompanying notes as a fraction of total sales), fraction of intangible assets to total assets and lastly ‘typical value‘ for R&D intensity as a fraction of operating costs among 3 groups of data collected, sorted into ‘high‘, ‘medium‘ and ‘low‘ R&D intensity companies. The first principal component capturing 87 percent of variation has been used as the proxy measure.

This approach provides a more reliable metric to examine R&D effects on company value, however invalidates testing one of the hypotheses set out in the proposal, as to the composition of the new proxy variable.

3.2 Companies with Open and Closed Cycle Product Development

For the purpose of this thesis, companies at hand were sorted into two basic categories - those with open cycle product development and those with closed cycle product development.

The distinction has been made based on the predominant nature of products or services provided by a given company. Test to which the companies have been subjected to in order to determine to which of the two categories shall they belong was formulated as follows:

(i) If the company provides information on the spendings which may be classified as development on already released products, it will be assigned to the ‘open cycle‘ category if such expenses account for at least 10 percent of the overall R&D expenses, otherwise it will be assigned to the ‘closed cycle‘ category.

(ii) If the company does not provide information on such spendings, product portfolio has been examined, it will be assigned to the ‘open cycle‘ if the usefulness of the product portfolio is highly dependent on substantial continuous development, otherwise it will be assigned to the ‘closed cycle‘ category.

In the second case, typical aspects differentiating the two categories were taken into account. Fan *et al.* (2009) provides a valuable insight into the differences and competition between companies providing ‘shrink-wrap‘ software and software as a service. The general notion of hardware companies predominantly belonging to companies with closed cycle product development, since once a product is released, only software for such product can be updated, physical alterations would constitute a new product release. There is also a differentiating factor in prevailing monetization method among software providers, since ‘shrink-wrap‘ software is typically paid for in a one time payment, whereas software as a service tends to be paid for on a repetition basis. It is notable, however, that even typical ‘shrink-wrap‘ software on the consumer market is slowly making its way into the subscription model sphere, as more and more companies see a potential in this type of monetization. This has historically been the case only for licensed corporate customers on the business to business market.

Since the potential candidates for suitable companies have been pre-selected with sufficient representation of both categories, the final distribution of companies represented in the sample was approximately 60 percent of companies with open cycle product development and 40 percent companies with closed cycle product development.

3.3 Formulating Approach

Due to the nature of problem at hand, an empirical analysis of panel data has been performed. In construction of the model, traditional approach to R&D contribution to productivity growth has been examined and approach discussed at length in Griliches (1979) has been used for inspiration. Together with direct application in Griliches (1980), Griliches (1998) and also Cockburn & Griliches (1988), these models have been used to create the general idea of the model at hand and transform theoretical concept of R&D impact on company value into empirically observable analysis.

In a more modern application, Xu & Jin (2016) employ a model using directly observable variables for the regression, not following the original concept of augmented production function. Similarly, Kim *et al.* (2018), Chen *et* *al.* (2019) or Postula & Chmielewski (2019) also employ models without direct linkage to augmented Cobb-Douglas production function with explanatory variables mostly directly observable within the companies' annual reports.

Coccia (2002) and Bowns *et al.* (2003) provide frameworks for modeling R&D performance in public sector, which in its existing state cannot be utilized on private companies due to vast differences in reporting and measurability of goals of research.

Nawrocki (2015) presents empirical analysis built on Spearman rank correlation coefficient to relax some of the traditional assumptions required for analysis. Doffou (2015) presents an improved model for company valuation (without employing R&D) and provides valuable insights into the mechanics of technology company valuation.

Empirical panel data analysis in the form of a regression with a proxy for company value as dependent variable has been chosen. For independent variables a set of R&D predictors has been selected complemented with a set of control variables constructed from companies' financial reports. Following further testing (F test rejecting the null hypothesis, Lagrange Multiplier Breusch Pagan test rejecting null hypothesis, Hausmann test rejecting null hypothesis and Chow test not showing poolability issues) and in accordance with reasoning presented in Postula & Chmielewski (2019), fixed effect estimation has been employed.

$$y_{it} = \alpha + X_{it}\beta + u_i + \epsilon_{it},$$

where y_{it} is the company value, X_{it} are the independent variables, u_i is a fixed effect omitted from the regression and ϵ_{it} is the error term.

3.4 Selection of Variables

First, response variable had to be chosen. Since the goal of this analysis is to provide insights into the impact of R&D expenditures on company value a variable reflecting company value had to be chosen. Research Postula & Chmielewski (2019) suggests using EBITDA or market capitalization, and they argue that EBITDA is an advantageous choice since it is based on historical data following standardized reporting, thus allowing for true display of the impacts of R&D expenditures on company's performance. On the other hand, Kim *et al.* (2018) advocate using a measure reflecting market value instead of book value of the company, since it encompasses the perception of the market and intangible value of the company. Finally, Grandi *et al.* (2009) suggests additional information included in the stock market valuation, since expected benefits are also included in the variable and argues under the assumption of effective markets, market capitalization can be used as an effective proxy to underlying company value. Additionally, he builds on Griliches (1981) suggesting the expected value of intangible capital created by research and development is also captured in the stock market valuation of the company, since this translates into expectation of future cash flows.

Book value of the company is also not suitable, since R&D does often not meet capitalization criteria and even if it did, such analysis would simply show that the increase in the book value of the company is indeed correlated with the capitalized R&D expenditures, as they are added to intangible assets. Thus, natural logarithm of market capitalization has been selected as response variable. Market capitalization has been calculated as retrieved share price data multiplied by the number of shares outstanding.

For R&D, Alternative measurement approach R&D index has been employed and several potential forms have been conceived. R&D intensity computed as R&D divided by total assets is largely used in the existing literature (e.g. Xu & Jin, 2016, Kim *et al.*, 2018 or Chen *et al.*, 2019) as independent variable and since it provides the independence from firm size and introduces comparability of results, measures based on this variable have been composed. Similarly to findings of Hall (2007), Chan *et al.* (2001) argue that a R&D intensity measure reflecting past R&D investments is beneficial, however due to the fast depreciation of intellectual property and constant competition in the segments, this approach was not used.

Simple R&D intensity, determining R&D as a portion of total sales (**rndip**), showing the direct relationship between R&D and company value.

The square of R&D intensity (**rndip_sq**), isolating any non-linear effects of R&D on company value while also providing basis to determine potential diminishing returns.

Two comparative measures of R&D expenditures to the R&D expenditures of current segment leader for the given year in terms of total sales. Absolute R&D intensity measure compared to the segment leader (**rndl**) has been calculated as the absolute value of R&D expenditures of given observations divided by the absolute value of R&D expenditures of the current segment leader, effectively providing a percentage value showing what fraction of total

R&D compared to the segment leader did the given company have. This variable provides insight into the competitive dynamics between the market leader and the remaining part of the segment, since it shows how beneficial it is for companies to match or even surpass the leader in spendings.This two variable provides insight into the competitive dynamics between the market leader and the remaining part of the segment, since it shows how beneficial it is for companies to match or even surpass the leader in spendings. Similarly, relative R&D intensity measure compared to segment leader (**rndlr**) has been constructed, taking a fraction of the R&D intensities of the given company and the segment leader. This variable compares the relative R&D intensity of a given company and a segment leader, thus showing whether it is beneficial to employ the same distribution of costs (or rather focus R&D to the relative same extent) as does the segment leader.

Since it has been clearly shown in existing literature there is a lagged effect to R&D expenditures, all of these variables were also utilized in their first and second lagged form.

As for control variables, those describing total assets and its movement reflect substantial amount of information effecting company valuation as perceived by the stock markets. Abrahams & Sidhu (1998), Nawrocki (2015), Kim *et al.* (2018), Chen *et al.* (2019) all include some form of asset based predictor to account for the size effect of the company and trends associated with it (in case of the growth rate term of the variable). The necessity for such control variable is shown in Griliches (1998), since it may be used as a proxy input to Cobb Douglas productivity function. The total assets variable has been included in the form of its natural logarithm (**lntas**) and as a year on year growth rate (**tasg**). Remaining control variables were employed based the model presented by Kim *et al.* (2018) - accounting for leverage (**lev**) calculated as total debt divided by total assets and return on assets (**roa**), calculated as net income divided by total assets.

3.4.1 Model and Expectations

The initial model (undoubtedly over-specified and subject to further elimination of R&D related independent variables) thus stands as follows.

$$lnmcap_{it} = \beta_0 + \sum_{l=0}^{2} \Big(rndip_{it}\beta_{1l} + rndip\_sq_{it}\beta_{2l} + rndl_{it}\beta_{3l} + rndlr_{it}\beta_{4l} \Big) +$$

$$+ lntas_{it}\beta_1 + tasg_{it}\beta_2 + lev_{it}\beta_3 + roa_{it}\beta_4 u_i + \epsilon_{it},$$

where in addition to already mentioned l is the lagged term of given variable.

With respect to previous research, direct impacts of R&D intensity and R&D intensity squared in the same year are expected to either be statistically significant and overall negative, or statistically insignificant, as R&D expenditures performed in the same year have low chance of impacting the performance of the company and since the progress on R&D is usually kept secret, stock markets do not have additional information during the year to adjust their expectations for future benefits of such R&D investment.

It is also expected for both of the R&D intensity measures compared to the segment leader not to be statistically significant in the same year, following similar logic as above. Since the results of R&D investments are expected to be seen with a delay, it is to be expected the results of competitiveness to be seen at the same time.

In past studies the results as to which lagged values were shown as statistically significant and the signs of their respective coefficients. Although challenged by Madsen (2006), the general notion of diminishing returns and marginal effects of R&D expenditures having an inverted U shape function is predominantly accepted among the academic literature. Therefore it is expected to examine similar behavior in this dataset and all its subsets.

Based on the aforementioned it is expected for the companies with open cycle product development to manifest higher overall R&D expenditures (in terms of intensity) and potentially also higher marginal returns to R&D expenditure. This expectation is based on the predominant nature of markets where companies with closed cycle product development operate, facing comparatively high operating costs and often tend to operate on comparatively lower margins, thus rendering the portion of R&D of total sales lower.

It is also expected for the natural logarithm of total assets to be a statistically significant predictor for company value, since naturally larger companies in terms of total assets are benefited with respect to company market value. Additionally, as has been shown beforehand, R&D expenditures do benefit from economies of scale and this effect may partially manifest in increasing the coefficient of this company size variable, since the model does not provide a mechanic to accommodate this effect in another way.

The model will be further experimentally reduced to its effective form, where only a part of the R&D independent variables will be kept.

Chapter 4

Data

4.1 Data Consideration

To perform the analysis outlined above, data collection criteria had to be set. Due to the aforementioned, it was of key importance to collect data with regard to the companies' respective sub-segments in order to reflect the competitive landscape in which they are participating. Further, the limitations of R&D reporting and consistent sub-segmentation of the technology market by respective companies do not allow for a reliable division of financial information and valuation indicators into single-segment divisions of a given company. Since it is crucial to attribute specific portion of each recorded balance sheet and income statement item to a segment, large multi-segment companies with broad product portfolios ranging through segments with various R&D intensity requirements had to be excluded.

Additionally, size of the company to be included in this analysis had to be considered since, as described above, economies of scale have a substantial impact on R&D mechanics and as noted by Salgado *et al.* (2018), small and medium-sized technology based companies face specific challenges regarding R&D. As mentioned before, the interest of this analysis lies specifically in large, multinational trend-setters driving innovation in the industry. Thus, only major players with substantial history in their respective field were considered for the dataset. Since market capitalization has been identified as a dependent variable for the model, only publicly listed companies were considered for the sample, since private companies do not have a reliable source of externally provided market value in every given point of time.

Time period for data collection has been chosen to be years 2013-2018.

Lower boundary was chosen to ensure relevance of the data collected in the fast paced environment of technology companies, yet to also provide sufficient time dimension of the data. Upper boundary was selected to ensure data availability from public sources, as at the time of data collection, 2019 financial data was not yet available.

4.2 Data Collection

The data were collected from annual reports, specifically balance sheets, income statement and their respective accompanying notes (10-K reports or analogous with standardized specifications were chosen), which are publicly available on the investor relations web pages of the companies or on respective stock exchange web page. Share prices were retrieved from Yahoo! finance.

4.2.1 Items Recorded

- **Currency of financial report** - Currency used in financial statements.
- **Total assets** - Lump-sum of all assets presented on the balance sheet.
- **Intangible assets** - Total reported intangible assets in the report.
- **Total liabilities** - Lump-sum of all liabilities presented on the balance sheet.
- **Equity** - The book value of equity presented on the balance sheet.
- **Sales** - Total sales value reported on income statement.
- **Operating costs** - Total reported operating costs.
- **EBIT** - Earnings before income tax reported on income statement.
- **Profit** - Profit for the given year reported on income statement
- **R&D** - Research and development expenditures, recorded as all R&D expenses incurred in the given year (i.e., real R&D expenses for the given year) compiled from income statement item and accompanying notes.
- **Outstanding shares** - Total number of shares outstanding used for market capitalization in combination with share price in given time period.

- **Year** - Financial year for which the data was retrieved.
- **Open cycle** - Dummy variable for the identified nature of R&D continuity in the given company (determined through thorough inspection of product portfolio and given products and services post-release R&D intensity).
- **Share price currency** - Currency used in listed share price.
- **Share price** - Average listed price per share from 1st November to 31st December (only using days for which price is available) of given year. This range for averaging has been chosen after the data from annual reports has been collected and showed the majority of them report values ending in December. To avoid introducing bias to results with post-publication market price changes (as observed in Doukas & Switzer, 1992), it was determined to choose a close date prior to earliest possible release of these financial statements. Additionally, retaining the same time period for all companies instead of appropriating the range to average over 2 months preceding date to which financials are reported has been chosen to ensure consistency of the data and all of the companies are impacted by potential overall market fluctuations in the same manner.

The data were recorded in the form of panel data with the indices of company identifier and year. Only data available throughout the whole sample period were chosen to be used for further analysis.

4.2.2 Segment Assignment

After thorough inspection of each company during initial data collection, suitable segments to cover companies who are direct competitors have been identified and companies which fit into one of the segments were kept, discarding the remainder of the companies. Companies were divided into software and hardware companies, with the requirement of at least 90 percent of their business falling into the category and then sub-segmented further along. No distinction as to consumer oriented and business oriented companies has been made, since overwhelming majority of the companies examined had a varying mixture of the two.

Alongside determining appropriate segment, each company was inspected and attributed either to a group of companies with an open cycle product development, or with a closed cycle product development. This distinction has been done based on the typical intensity of R&D required following a certain product release, with majority of companies which design and manufacture physical products being categorized as companies with closed cycle product development.

General consumer electronics companies had to be excluded, due to the presence of significant overlaps among various segments, since majority of observed general consumer electronics brands fell into the category of large multi-segment companies with product ranges covering substantial part of hardware category, often even overreaching into other industries than technology. Notebook manufacturers had to be discarded with similar reasoning. Smartphone segment, which perfectly fulfills the direct competition condition had to also be excluded, since the most forefront companies do not provide sufficient data granularity to extrapolate their smartphone divisions from their financial reports (and additionally, due to the spread of their business focus, appropriating market capitalization portion of their respective businesses to this division would undoubtedly introduce additional imprecision). Additionally, due to high concentration in this market, remainder of the companies (some of which are private, thus ineligible for the data set) do not present a representative sample.

Software companies were divided among internet companies and deployed software companies, following the nature of majority of their business. Companies which provide stand-alone software were categorized as deployed software companies, regardless of their typical monetization method and update intensity. Companies whose products or services overwhelmingly rely on cloud based services were categorized as internet companies.

Finally, hardware companies were distributed among semiconductor, accessorial semiconductor and networking equipment companies. The distinction between semiconductor companies and accessorial semiconductor companies has been made based on their position in the market and their respective dependency on the available technology. Companies were classified as semiconductor companies if their core business focuses on manufacturing or designing processing units in the form of high-density integrated circuits (e.g. Intel, AMD, Nvidia or Qualcomm), whereas they were classified as accessorial semiconductor companies if their business closely related to semiconductors as defined above, however did not compete directly against players in the market (e.g. MSI, Gigabyte or Supermicro). These segments were selected due to their distinct nature with low overlap across each other and low contamination of companies operating in these segments with products from other segments with different R&D requirements and mechanics.

Out of initial list of 849 potential companies for the analysis, data was collected about 141 companies and only 62 companies were suitable candidates for further analysis based on aforementioned limitations. Thus a total of 846 observations has been collected with 372 eligible for further investigation.

4.3 Data Description

Original data included 5 currencies of financial statements, namely US dollar (USD), New Taiwan dollar (TWD), South Korean won (KRW), euro (EUR) and renmibi (also called Chinese Yuan) (CYN). As for the share price data, neither CYN nor EUR were present, however in addition to the remaining ones, Hong Kong dollar (HKD was also present).

After performing adjustments as described in methodology, 1st quantile, median, mean and 3rd quantile of chosen variables for the whole sample is shown below.

Table 4.1: Descriptive statistics (1)

	1st Quantile	Median	Mean	3rd Quantile
R&D intensity	0.059	0.076	0.090	0.107
R&D intensity squared	0.003	0.006	0.012	0.012
R&D % of leader	0.053	0.143	0.265	0.359
Leverage	0.376	0.452	0.484	0.671
Total assets growth	0.997	1.098	1.173	1.264

The following table shows means of the same variables separate for each of the examined segments.

Table 4.2: Descriptive statistics (2)

	Hardware	Software	Semiconductor	Accessorial	Networking equipment	Internet	Deployed
R&D intensity	0.097	0.078	0.128	0.101	0.065	0.059	0.100
R&D intensity squared	0.014	0.009	0.025	0.014	0.004	0.006	0.012
R&D % of leader	0.281	0.238	0.28	0.295	0.257	0.209	0.270
Leverage	0.475	0.499	0.481	0.497	0.431	0.451	0.553
Total assets growth	1.111	1.278	1.213	1.099	1.049	1.488	1.050

Based on the tables presented above we can conclude the data shows less significant differences between hardware and software technology companies than what was expected, mainly regarding their R&D intensity metric (since before the data collection, it was hypothesized software companies would have significantly higher overall spendings on R&D than their hardware counterparts). This held true for both, the used metric of R&D intensity as reported and for the alternative measurement approach R&D index. The square of R&D intensity follows the general pattern of R&D intensity and does not provide any conclusive additional information on its own, since no obvious anomalies have been discovered.

Interestingly the variable measuring portion of R&D spendings of a given company to the market leader in given segment had mean values between 20 and 30 percent, combined with percentile data showing the majority of companies in each field spend on R&D only approximately one-fourth of the R&D spendings of the market leader. This trend provides an invaluable insight into the data, since it speaks to the concentration of R&D expenses among very few companies. Such results were to be expected among the hardware companies, however were surprising when manifesting the same tendencies among the software companies, since unlike among hardware companies, software companies in the sample most often do not present direct competition to each other in the same way hardware companies do, since they usually do not provide perfectly substitutable products (among internet companies, other factors than technological advancement are often differentiation factors among the companies when majority of the market is not captured by a single company, while among deployed software companies it is also common for clear market leader in a specific category to emerge and assume the position of a business standard).

Leverage among the companies is an important indicator as to its effect on market value of the companies, however as a standalone metric does not provide conclusive information about most of the segments in the dataset, since it has little relation to R&D, which is the point of interest of this analysis. It is however worthwhile to note the largest fluctuation within one category (hardware or software) is between internet companies and deployed software companies, where the propensity to financing with equity is clearly visible among internet companies.

The total asset growth variable shows substantially higher values for semiconductor and internet segments, which can be explained for the semiconductor segment by recent growth of application for high density microcircuits accompanying the growth of the market of internet of things, including this technology into multitude of applications in both, consumer markets and business markets. Since the internet of things uprise is only captured in the semiconductor segment among the data collected (majority of the companies designing and manufacturing accessorial semiconductors for the internet of things market is either part of a large conglomerate including general consumer electronics, or do not have public data available for the duration of the time frame chosen for the analysis), it is natural other segments among do not capture this growth. As for the internet companies, the growth may be partly explained by a selection bias, as leading companies were selected and since the market of internet companies is constantly growing being lead by the major players, this may explain the nature of this variable. Additionally, since many of the internet companies may use a combination of in-house cloud services and outsourced ones, growing in terms of user base may warrant switch towards increasing portion of services provided in-house, thus making new procurement a necessity.

Table 4.3: Descriptive statistics (3)

	Software					
	Min	1st quantile	Median	Mean	3rd quantile	Max
EBIT margin	-0.973	0.067	0.220	0.171	0.308	0.806
Profit margin	-0.971	0.027	0.170	0.124	0.239	0.809
ROA	-0.266	0.018	0.071	0.060	0.112	0.305
	Hardware					
	Min	1st quantile	Median	Mean	3rd quantile	Max
EBIT margin	-0.162	0.049	0.139	0.150	0.256	0.528
Profit margin	-0.214	0.035	0.116	0.123	0.208	0.605
ROA	-0.212	0.043	0.090	0.096	0.143	0.372

Table above showing several performance indicators show trends in accordance with intuition, since software companies strongly dominate hardware companies in the upper quantiles. It is to be expected for software companies to have lower both, cost of good sold for products captured in the EBIT margin and profit margin statistics (as i.e. shrink-wrap software companies have very slightly scaling cost with additional sales and this feature penetrates to some extent the whole category), as well as fixed costs in terms of manufacturing equipment captured in the return on assets statistic.

Chapter 5

Results

5.1 Final Model Derivation

The all-encompassing model depicted in the methodology did perform poorly as expected, showing virtually no significant variables due to obvious over-specification. Through a series of comparative testing insignificant and inconsistent variables regarding R&D were dropped.

The relative R&D intensity measure compared to the segment leader (**rndlr**) has beed dropped in favor of the absolute R&D intensity measure compared to the segment leader (**rndl**), since the latter provided significantly more explanatory power to the model and showed consistent significance at least at some lagged values compared to the relative one.

No unlagged variables regarding R&D showed statistical significance as predictors to either market capitalization, or market capitalization growth in most of the tested models. When significant at 5 percent, R&D intensity with no modifiers showed with negative coefficient. Either comparative R&D measure with respect to market leader did not show as significant in any sensible model tested. The square of R&D intensity was also insignificant. This is in line with existing literature, where unlagged R&D intensity either presented itself as insignificant, or with a negative coefficient (depending on the choice of response variable and other model specifications), which follows the intuition of R&D expenses hurting the company during the process of development and benefiting it after the results have been implemented. This relationship held true for both, companies with open and closed cycle product development, showing there is no difference in the delay which it takes for the R&D expenditures to affect company's market value.

In the first lagged term, both R&D intensity and R&D intensity squared were kept for the final model, dropping the comparative measure to the market leader, which did not present a significant variable across the models. This is not in line with expectations, since it contradicts the hypothesis of constant competition in the segments. This might be explained by the overall low means of this variable and obvious concentration of large portion of R&D among few largest companies, as discussed in the data section.

In the second lagged term, neither R&D intensity, nor R&D intensity squared were found to be significant, which contradicts some of the existing literature. This may be explained by the selection of the companies and segments, most of which operate in a very innovative and fast-paced environment, diminishing the effect of past efforts in favor of the ones currently competing on the markets. Additionally, it may also be caused by the choice of dependent variable, since the stock markets may have a tendency to discount aging information in an expedited manner, mainly when regarding R&D spendings.

These findings were consistent across the sub-samples examined and no major deviations in the explanatory power of different lags were discovered. Remaining terms were kept in the model irrespective of their significance to avoid spurious correlation and misspecification of the model.

Thus final model this analysis will rely on consists of the following variables:

- **lnmcap** - Natural logarithm of market capitalization.
- **lntas** - Natural logarithm of total assets.
- **tasg** - Growth rate of total assets.
- **roa** - Return on assets.
- **lev** - Leverage.
- **rndip_lag1** - Proxy for R&D intensity in the first lagged term.
- **rndip_lag1_sq** - Proxy for R&D intensity squared in the first lagged term.
- **rndl_lag2** - Absolute R&D intensity measure compared to the segment leader.

$$lnmcap_{it} = \beta_0 + lntas_{it}\beta_1 + tasg_{it}\beta_2 + roa_{it}\beta_3 + lev_{it}\beta_4 +$$

$$+ rndip\_lag1_{it}\beta_5 + rndip\_lag1\_sq_{it}\beta_6 + rndl\_lag2_{it}\beta_7 + u_i + \epsilon_{it}$$

5.2 Whole Sample Results

Results from the regression on the overall sample are shown in the table below.

Table 5.1: Empirical results (1)

Variable	Coefficient	Std. Error	Significance level
Intercept	-5.636	1.537	0.000
lnctas	1.251	0.069	0.000
crndi_lag1	17.394	4.888	0.001
crndl_lag2	-1.329	0.336	0.000
crndi_lag1_sq	-40.151	15.370	0.010
lev	0.094	0.504	0.853
ctasg1	-0.257	0.239	0.284
roa	0.105	0.0957	0.913
R-squared		0.685	
Adj. R-squared		0.663	

Natural logarithm of total assets shows as statistically significant, following the intuition of larger companies being valued at higher prices than smaller ones. This effect is potentially amplified by the perceived stability of technology companies by the stock markets, putting higher value on size of the company and the expectation of continuity. The coefficient exceeding 1 supports the fact technology markets tend to result in a monopolistic or oligopolistic competition, thus making market share a significant determinant of value of the company (as market share is present in the model, total assets may fulfill the role of a proxy in this situation).

The first lagged term of R&D intensity follows expectations, as it is statistically significant with a positive coefficient. This suggests the direct impact of R&D intensity is positive, which corresponds to the expectation set out at the beginning of the analysis and existing literature. Negative first lagged term of R&D intensity squared is also statistically significant and in accordance with previous research. These two coefficients combined support the thesis of R&D expenditures having diminishing returns at a given level of total sales.

To find out at what point the R&D intensity begins to have a diminishing return according to the model run on our dataset, we can take a derivative of the simple quadratic equation and find its root.

$$\frac{\partial}{\partial x}\Big(- 40.150x^2 + 17.393x\Big) = 0$$

$$x = 0.2166$$

Such high R&D intensity is at the level of 96th percentile of the data used for this analysis and we can explain this inconsistency in two parts. Firstly, since there are no representative companies for such high R&D intensity, there are no observations which could show the negative effect of such high R&D intensity and the ultimate need to either reduce other costs to accommodate such expenses, or to increase overall sales, which is also beyond the information used in this model. Secondly, as discussed beforehand, significantly higher technological advancements of a single company, which may warrant such high R&D intensity, would likely result in a technology which would have very limited uses, due to unprepared infrastructure for manufacturing and general implementation, as well as limitations arising due to compatibility with other segments of the technology market. In addition, due to inherent managerial limitations to R&D expenditures, as it is not selected randomly across the companies, this might also be the effect of unavailable opportunity for increasing the level of R&D intensity at the same level of effectiveness as the current one. Thus this model only captures the undertaken R&D intensity, which may have already utilized vast majority of the available research opportunities.

The second lagged term of absolute R&D intensity measure compared to the segment leader is also statistically significant, with a negative coefficient. This result contradicts the hypothesis that companies in the technology industry need to strive to match the market leader in absolute value of R&D expenditures. Potential explanation may resolve around economies of scale, since this measure compares the absolute value of the R&D expenditures rather than R&D intensity itself. Since the market leaders in terms of total sales might utilize economies of scale and distribute their R&D expenditures accordingly, whereas companies with smaller market shares might not have this opportunity, manifestation of excessive R&D in absolute values might be an indication of mismanagement among companies with smaller market shares, thus also carrying a decrease in company value. This observation also may suggest a stronger link to R&D effectiveness, which may vary heavily among not only segments, but also individual companies, rather than raw R&D expenditures. Another explanation for this phenomenon may be a difference in managerial strategy, where companies in the same segment of the technology industry may have different propensity to uncertain innovation and different corporate governance rules for approving uncertain projects to be undertaken. Chiesa *et al.* (2009) stress the importance of performance measurement in R&D. Systems such as proposed by Archer & Ghasemzadeh (1999), Franco-Santos *et al.* (2007), Farrukh (2000) or Coffin & Taylor (1996) may be an example of such rules. If this were the case, it may be argued that quality of such ruleset would have a stronger impact on company value (since R&D investment would be undertaken for projects with higher positive expectations) and as this model does not have any means to account for such relationship, success rate of R&D undertakings would impact this comparative variable negatively.

Surprisingly, unlike in some of the existing research, neither leverage, asset growth nor return on assets shows statistical significance. This might be caused by the fact other variables capture the impact on market value such manner these variables do not provide additional insight. Leverage and return on assets may have lower importance with respect to market value due to the nature of technology industry, where often start-ups with low profitability exhibit substantial valuations and leverage might have a two-fold impact on the valuation of these companies, since on one hand it burdens the company financially, however on the other manifests reliability of the company, indicating financial institutions and third parties were willing to provide financing for the company. This is supported by the fact that to the authors best knowledge, none of the selected companies were in any form of immediate financial distress.

Asset growth impact may be hindered, since despite the fact it shows the trends in company's growth, the absolute value is already captured in the model and among companies in the sample most negative asset growth was not correlated with a distressing event, as it rather reflected strategical sales of subsidiaries with minor impact on the core business.

5.3 Results for Companies with Open Cycle Product Development

Results for the regression on a subset of data only including companies with open cycle product development are shown in table below.

Table 5.2: Empirical results (2)

Variable	Coefficient	Std. Error	Significance level
Intercept	-5.610	4.258	0.192
lnctas	1.153	0.181	0.000
crndi_lag1	29.678	8.938	0.001
crndl_lag2	-0.623	0.632	0.327
crndi_lag1_sq	-81.306	25.156	0.002
lev	1.014	0.730	0.169
ctasg1	0.890	0.711	0.214
roa	-1.791	1.413	0.209
R-squared		0.611	
Adj. R-squared		0.592	

Generally the results follow the intuitive expectations presented prior to the analysis, as the second lagged term of absolute R&D intensity measure compared to the segment leader is no longer statistically significant and first lagged term of R&D intensity manifests a substantially higher coefficient than the model encompassing the whole data set.

Identical discussion as above applies for the coefficient of the natural logarithm of total assets, as it also manifests a statistically significant coefficient greater than 1, suggesting stock market preference towards larger companies.

Larger coefficient for the first lagged term of R&D intensity suggests higher R&D intensity benefiting companies with open cycle product development disproportionately more than the overall technology industry companies in the sample. Such result was to be expected after examining the surprisingly low mean R&D intensity among software companies, which stand for the majority of companies with open cycle product development. Since higher levels of R&D intensity in such environment may provide additional indication of company's specialization and market it is operating on, it is possible the increased value for the coefficient for the first lagged term of R&D intensity captures different valuation of companies operating in very close, yet distinctive environments from the point of view of the stock markets.

In contrast, larger negative coefficient for the first lagged term of R&D squared suggests the R&D intensity is going to have a steeper concave curve with respect to returns in terms of market value. This contradicts the original hypothesis of companies with open cycle development having overall higher returns to R&D intensity and a higher point at which the returns begin to diminish. It is however in line with the adjusted expectation following the data examination, since it provides insight into why the segments dominated by companies with open cycle product development manifest lower R&D intensities than companies with closed cycle product development. Additionally, we may employ the same method as above to determine the optimal R&D intensity value as formulated by this model.

$$\frac{\partial}{\partial x}\Big(- 81.306x^2 + 29.678x \Big) = 0$$
$$x \approx 0.1825$$

As described above, the value is substantially lower than the one manifested in the model on the whole sample following our adjusted expectation. This result is at the level of 91st percentile of the companies with open cycle product development subset, which despite being a lesser extreme value than the one at the whole sample level, still remains more of an outlier. Similar argumentation as to why does the mean value (0.0786) differ by more than a factor of two applies. The effects described above may be complemented by the nature of companies with open cycle product development, since despite the need for constant development following given product release, overall expenses for this development might constitute a lower portion of the overall expenses the company is facing when compared to companies with closed cycle product development when developing a new product. This effect may be an important distinction, since generally companies in the sample with open cycle product development either provide products and services in a continuous manner with little to no completely new releases, or simply add products to their existing portfolio, while generally maintaining the existing products, thus this effect would still be present. We can therefore conclude that contrary to expectations technology companies with open cycle product development have lower threshold for positive returns from R&D expenditures compared to the whole sample, however in line with expectations do have higher marginal effect of R&D intensity on company value compared to the whole sample.

Finally, the loss of significance for the second lagged term of absolute R&D intensity measure compared to the segment leader may have similar reasoning as larger coefficients for the first lagged terms of R&D intensity, since it may be attributed to the predominant nature of the markets on which companies with open cycle product development operate and general lack of imminent direct competition when it comes to their product portfolios. Since often the companies have different development goals, low explanatory power of such comparative measure is intuitively understandable.

5.4 Results for Companies with Closed Cycle Product Development

Results for the regression on a subset of data only including companies with closed cycle product development are shown in table below.

Table 5.3: Empirical results (3)

Variable	Coefficient	Std. Error	Significance level
Intercept	-4.445	1.182	0.000
lnctas	1.203	0.056	0.000
crndi_lag1	-19.773	8.177	0.019
crndl_lag2	-1.740	0.325	0.000
crndi_lag1_sq	159.493	46.209	0.001
lev	1.403	0.613	0.026
ctasg1	-0.145	0.160	0.371
roa	4.655	0.958	0.000
R-squared		0.710	
Adj. R-squared		0.699	

This subset employs the most statistically significant variables of the three described in results. Natural logarithm of total assets follows the same interpretation as in previous sections and shows market preference towards larger companies in terms of valuation, which corresponds to the expectations.

First lagged terms of R&D intensity and R&D intensity squared, both statistically significant, show inverted signs opposed to the expectations and previous results. This shows convex shape of the R&D intensity impact on market value of the company. We may again employ a simple quadratic equation composed from the two coefficients and examine its positive non-trivial solution.

$$159.493x^2 - 19.773x = 0$$

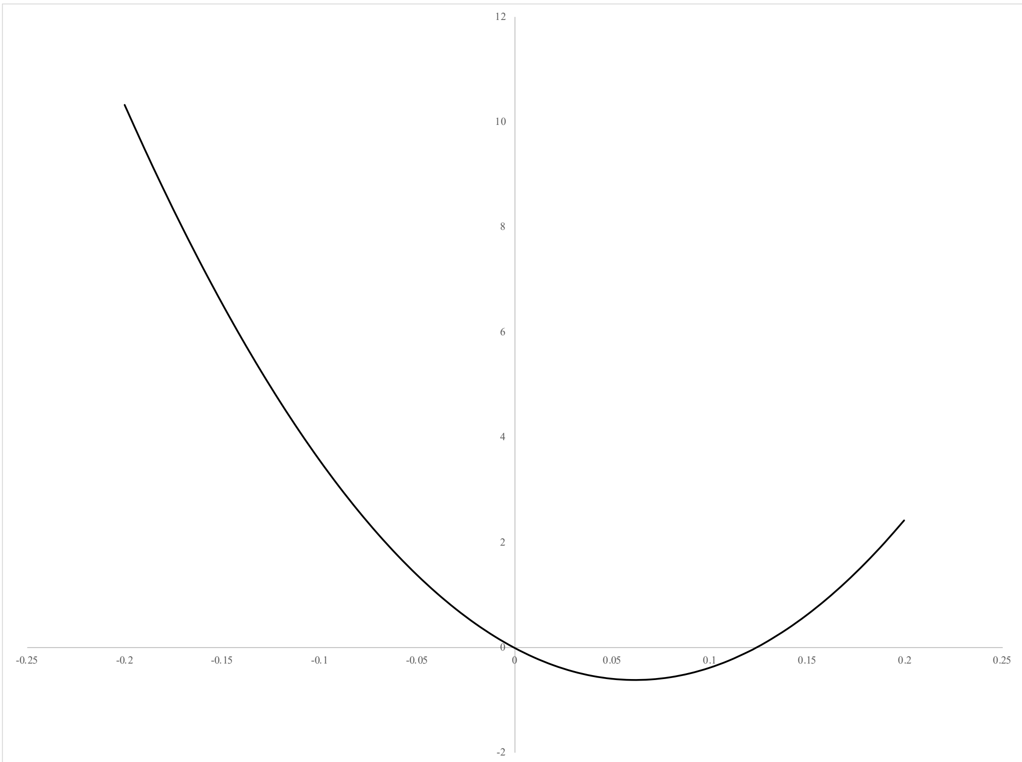
$$x = 0.1240$$

These results alone would suggest the impact of R&D on company value among companies with closed cycle product development is negative up till the point at which R&D intensity exceeds 0.1240 and is not subject to diminishing returns. When however confronted with the fact this result corresponds to the 87th percentile of the sample with none of the companies being market leaders in either sales or company value, it is clear the relationship does not manifest such effects in reality. Additionally, we can find the global minimum of the function in order to determine the marginal effect of R&D intensity.

$$\frac{\partial}{\partial x}\left(159.493x^2 - 19.773x\right) = 0$$
$$x \approx 0.0620$$

This indicates marginal effects change at this level, which corresponds to 38th percentile of the subsample. For better understanding of the relationship we may examine the plot of the quadratic expression with the information range from 1st to 3rd quantiles in the data is 0.05179 - 0.10430.

Figure 5.1: U-shape relationship



Thus we can clearly see that approximately half of the data (38th to 87th percentile) experience positive marginal effect of R&D intensity on company value, despite R&D intensity having overall negative impact on company value. Despite the coefficients not being in line with expectations and existing literature, such interpretation conforms with the overall research and indicate positive relationship between marginal R&D intensity and company value for majority of the sample. The 37 percent of the sample experiencing negative relationship of marginal R&D intensity and company value may reinforce the notion of R&D having a level of uncertainty present and may indicate failed projects among companies with lower R&D spendings. This observation is however not conclusive, since strong correlation between companies having failed projects in a given year and companies with low R&D intensity would be required to be present. Another possible explanation is insufficient spending resulting in sunken costs, as a required threshold of R&D intensity is not met to provide the benefits associated with it. This hypothesis, however, is also inconclusive, since R&D intensity does not reflect the overall R&D expenditures directly, thus making a clear link between R&D intensity and sufficiency of technological advancement cannot be conclusively shown.

The second lagged term of absolute R&D intensity measure compared to the segment leader is also statistically significant and as well as in the case of the whole sample, negative. This can be interpreted similarly as before, however furthering the notion of economies of scale. Combined with the information about the relationship of R&D intensity and company value, it can be easily seen the positive effect of the increase in R&D intensity in this model is at least to some extent compensated by the negative effect of this comparative measure. This reinforces the notion of diminishing returns to excessive R&D intensity and contradicts the original expectation of the positive effect of attempting to match the industry leader's R&D expenditures. Additionally, coefficients of these variables also suggest the need for effective R&D spendings, rather than excessive ones and similar argumentation as above can be applied.

On this subset, leverage is also statistically significant and has a positive coefficient exceeding 1, thus suggesting stock markets disproportionately benefit more leveraged companies to less leveraged ones. A potential explanation for this phenomenon may be positive aforementioned signaling or operational indicators of successful technology companies focused in part in manufacturing increasing this ratio, thus making it a statistically significant positive predictor.

Lastly, return on assets is statistically significant and has a substantially positive coefficient. Due to the nature of this sub-sample, which includes companies resembling traditional industries, natural interpretation of this coefficient is its utilization as a proxy to company's efficiency, as higher return on assets in combination with the preference towards more leveraged companies indicates higher returns on equity. Such interpretation can only be applied to the sub-sample of companies with closed cycle product development as to how it was constructed, due to its comparatively higher dependency on physical assets.

Chapter 6

Case study

6.1 Scene Setting

The history of semiconductor industry dates back to the beginning of the 19th century, when an Estonian-German physicist, Thomas Johann Seebeck discovered one of the thermoelectric effects of semiconductors, later named the Seebek effect (Seebeck, 1895) Early after that, the first true semiconductor effect has been observed by Michael Faraday in 1833, who discovered changes in conductivity in materials attributed to temperature changes (Busch, 1989)

The basis these observation provided rose into semiconductor theory and with the development of p-n junction (Karl Ferdinand Braun, 1874) more commonly known as a diode (specific form of a diode), originally intended to be used as radio receiver, and later with the development of transistors in 1947, allowed for the first computers with transistor CPUs (Central Processing Units) to be built. Since the development of MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) and integrated circuit, computer processor technology has been focusing on improving the technology to its current state, however there has been no substantial move away from the general framework of the silicone-based microprocessors. To date, to the best authors knowledge, the most transistors present on a single CPU is on AMD EPYC counting almost 40 billion transistors (AMD 2019).

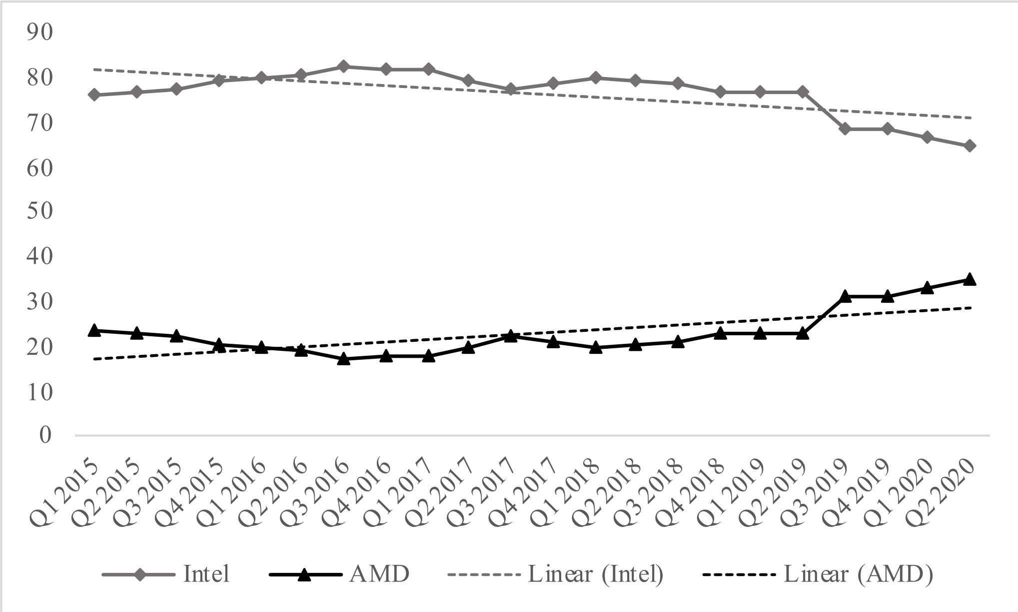
The previous two paragraphs may seem to be completely irrelevant, nevertheless when one realizes how mechanically simple and yet technologically complicated the 'brains' of the machines we use every day are, it makes one appreciate the extent to which R&D is a crucial inseparable part of the semiconductor industry.

In this case study we are going to focus on a duopoly in the semiconductor industry, Intel and AMD. These two companies are best known for their computer CPUs and have virtually no competition on the general playing field - there are other designers of CPU products, mainly Qualcomm in the smartphone industry and ARM focusing on processors with RISC (Reduced Instruction Set Computing) architecture typically found on single board computers, such as Raspberry pi. If we were to examine the relationship between AMD and Intel on the CPU market in more detail, we would face a challenge to attribute revenues and investments into this specific segment for both companies, as CPU design and manufacturing is by far not the only part of the respective businesses. Since AMD's acquisition of ATI, AMD, among other, simultaneously takes part in another duopoly on the consumer GPU (Graphics Processing Unit) market. This may be a strategic decision, since both Intel and AMD also design and manufacture CPUs with integrated graphics processors on board (typically used in computers with lower requirements on graphics processing power). Intel, on the other hand, also operates on the computer memory and storage market, computer networking market and develops commercial software. It is, however, without a doubt the core focus of both companies is on the CPU and chipset market, which places them into the position of direct competitors.

6.1.1 R&D Spendings and Product Market Performance

There have been dramatic changes in the dynamics of this duopolistic competition on the CPU market in recent years following the release of Ryzen brand of processors by AMD. The development of market share for x86 CPUs worldwide is shown below. In this section we are going to examine R&D expenditures of the companies leading up to this market disruption.

Figure 6.1: x86 computer CPUs market share development



It can be clearly seen the market share reacts to the release of Ryzen brand of processors by AMD. It may also be argued the full effect does not show in this chart due to potential contracts with notebook manufacturers, pre-built computer manufacturers and mainly data center customers. Since these business to business sales are usually pre-planned, longer time frame would be necessary to show the effect to the full extent. Upon inspection of the overall reported R&D data by the companies, shown in table below, it is however apparent the R&D expenditures reported by the companies do not show any sudden overwhelming dominance in this regard by AMD.

Table 6.1: R&D spendings comparison

	R&D spendings (USD bil.)		
	AMD	Intel	Nvidia
2013	1.2	10.6	1.3
2014	1.1	11.5	1.4
2015	0.9	12.1	1.3
2016	1.0	12.7	1.5
2017	1.2	13.0	1.8
2018	2.4	13.5	2.4

As discussed beforehand, these values do not necessarily fully reflect the R&D efforts of the companies in the field of CPUs, as both of the companies also undertake R&D efforts in other fields. On the other hand, when taking into account CPU market is the main market for both of the companies, the

R&D expenditure data clearly show a significant difference. Additionally, respective data for Nvidia have been added, as it is the competitor to AMD on the GPU market. We can clearly see that even when not taking AMDs R&D expenditures into consideration, Intel spent approximately tenfold the amount on R&D compared to AMD (if we include Nvidia's R&D budget, the figure rises to twelve to fourteen fold). This provides strong indication that factors other than R&D investments themselves play a crucial role in company's success. Managerial decisions might be one of the explanations, as AMD focused on different approach to performance increase of their products than Intel did. In June 2017, Intel went as far as to mark Ryzen processors as 'glued together' on their press workshop. Another possible explanation might be focused on the binary nature of R&D successes, virtually concluding AMD 'got lucky'.

To elaborate on the differences in R&D investments among the companies, we might also examine the reported R&D intensities of these companies (shown in table below).

Table 6.2: R&D intensity comparison

	R&D intensity (R&D % of total sales)		
	AMD	Intel	Nvidia
2013	0.23	0.20	0.32
2014	0.19	0.21	0.29
2015	0.24	0.22	0.27
2016	0.24	0.21	0.21
2017	0.23	0.21	0.18
2018	0.38	0.19	0.20

The data shows there is no significant difference in R&D intensity between the two companies, since for each year prior to the release of the Ryzen technology, the difference does not exceed 3 percentage points (13 percent). Such difference is well within the margin error caused by the improper association of R&D reported purely with the CPU market.

As a result, these findings may be perceived as a reinforcement of the notion of importance of correct targeting of R&D investments. Managerial decisions and corporate governance nuances allowing for better projects to be pushed forward by the company seem to be a significantly more important predictor of the success of a company than R&D investment values themselves. On the other hand, the notion of a company simply 'getting lucky' surely cannot be discarded and under the assumption of constant conditions, company with higher budget allocated to R&D faces a higher potential for successful R&D projects. As this case study has been carried out on a market with arguably one of the highest requirements for constant innovation and no significant competitors to disrupt the long existing duopoly of AMD and Intel have been identified, it also supports the theory of minimum threshold of knowledge for a company to be competitive in such field to be very high.

Chapter 7

Conclusion

Technology companies are highly reliant on constant R&D endeavors, as their success is dependent on furthering technological advancement in some way. Simultaneously, technology companies are a diverse group competing on a multitude of markets with different parameters. In this analysis we have examined the marginal effects of R&D expenditures on company value among technology companies. We observed the differences in marginal effects of R&D intensity on company value between technology companies with open and closed cycle product development and have examined the competitiveness in absolute R&D expenditures between companies in the same segments.

If taken at face value, results of this analysis show clear connection between R&D expenditures and company value among technology companies and are mostly conforming with existing academic literature. Empirical findings for the whole dataset and all its subsets show no significant variation in lag of predictors among groups of technology companies. It was shown there is a significant difference in the relationship of R&D and company value between technology companies with open and closed cycle product development. The empirical analysis suggests positive marginal returns to R&D expenditures intensity beyond the point at which R&D expenditures are undertaken by majority of the companies examined, including market leaders, thus reinforcing the notion of other limitations being at play. The results also show surprising relationship between R&D spending relative to the market leader for a given segment, contradicting the expectation of a competition within segments to reach the most advanced technology with the most absolute amount spent on R&D. Contrary to the expectations the analysis also shows U shaped returns in terms of company value to R&D intensity among technology companies with closed cycle product development, however when interpreted within the manifested limitations of R&D investment opportunities, the results reinforce the overall consensus on the diminishing nature of marginal R&D investment.

The main shortcoming of this analysis is the small sample size in the cross-sectional dimension of the data. There is vast space to further the research in the direction proposed in this thesis, although it would be necessary to develop a reliable method to extrapolate partial data (including company market value) from multi-segmental technology companies to accommodate each observation in a specific segment. Another option would be to reclassifying the segmentation employed by this analysis and finding different categorization in which selected companies would be direct competitors. There is also an opportunity in examination of segments of technology companies separately employing metrics specific to the given segment which would provide deeper insight into the given segment.

Chapter 8

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