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CONVERGENCE OF R&D INTENSITY WITHIN SECTORS

Relatore: Chiar.mo
Prof. Alessandro Sterlacchini

Tesi di Laurea di:
Riccardo Papa

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ABSTRACT

Aziende all'interno dello stesso settore convergono verso un comune valore di *R&D intensity*? Numerose ricerche hanno risposto affermativamente a questa domanda. Tuttavia, usando microdata dallo "*EU industrial R&D investment Scoreboard*" per il periodo 2000-2015, Alex Coad, professore alla Wased Business School di Tokyo, è riuscito ad individuare una persistente eterogeneità dell'*R&D intensity* all'interno dei settori. Nonostante si potesse osservare un processo di *catching-up* (*β-convergence*) nessuna *σ-convergence* veniva individuata. Senza entrambe le condizioni non era possibile parlare di convergenza.

Questa tesi ha come scopo quello di replicare ed espandere lo studio fatto da Coad, usando dati più recenti, in modo da osservare possibili differenze, concentrandosi specialmente sullo studio della *σ-convergence*.

I risultati che sono stati ottenuti confermano quanto individuato da Coad. Se non per alcune sporadiche eccezioni, i dati non mostrano convergenza verso un valore comune di *R&D intensity* per aziende all'interno dello stesso settore.

Un risultato atteso ma che non di meno offre l'opportunità di osservare il comportamento e l'evoluzione delle imprese, permettendo anche a possibili investitori di prevedere le evoluzioni dei mercati.

Keywords: Innovazione, R&D intensity, convergenza tra imprese

INDEX

INTRODUCTION

The ability of a society to better itself, correct what is wrong, and construct the foundation of the future is tied to its progress. Only through innovation is this possible.

Humankind was able to overcome the many problems it faced thanks to new discoveries and technologies. However, it was not until the first industrial revolution that a global understanding of the value of invention became widespread. The scientific approach began to affect the world; researchers examined reality through new perspectives allowing societies to progress.

Innovation became the fuel for economies to boost productivity and efficiency, resulting in the knowledge-based world economy we have today.

The process of innovation is the consequence of a complex interaction of factors, ranging from the significance placed on education to the presence of expert employees in communities.

All of these factors, however, are related to the Research and Development activity. New knowledge is created as a result of efforts undertaken to produce new products, processes or services, or to improve those that currently exist. This can often be risky, but the high rewards might make the risk worthwhile. The most advanced economies are the ones able to promote R&D activities, especially in the private sector.

For many businesses, R&D has proven to be critical. A company can only stay competitive and profitable by developing new products, upgrading old ones, or becoming more efficient. For societies to prosper, large and efficient enterprises are required.

So, how do businesses react when they are up against competitors in the same industry? Is there an unspoken shared objective, or is everything driven by chance? These are two interesting questions to answer in order to have a better understanding of R&D investment trends in various industries and firms.

As a result, the focus of this thesis is on the concept of "R&D intensity convergence." The main goal is to see if companies in the same industry have a tendency to have similar R&D intensity levels.

With a strong belief in the relevance of the subject of this thesis, the first Chapter introduces the basic principles of R&D activities. Then, it would be possible to see how an R&D intensity convergence would affect not only the “economics of innovation” studies, but also how this process could affect the entire research and development process.

The second Chapter will look at the state of R&D intensity in wealthy economies and regions. This would provide an opportunity to examine how R&D activities are carried out in different nations, the change from country-driven to business-driven R&D, and appropriate policies to boost R&D activities, particularly inside enterprises.

In addition, the analysis would look at the proportion of R&D spending in several of the major sectors. This would provide a first indication of which industries are most focused on innovation. Furthermore, a more in-depth examination of how the major sectors conduct their R&D operations would be conducted.

Finally, in the third Chapter an empirical analysis will be carried out in order to ascertain the presence of R&D intensity convergence within sectors.

Convergence has frequently been suggested in previous research. However, a report originally published in 2017 by Alex Coad, and re-published in 2019 as a journal article, looked at microdata from the EU Industrial R&D investment Scoreboard for the years 2000-2015, arguing that there was a lot of variation in R&D intensities among companies in the same sector, and that this heterogeneity persisted over time.

This conclusion was particularly intriguing since it would imply that despite observed catching up behaviour, companies still do not have an optimal R&D intensity target.

After summarizing Coad's study, an explanation of the database used is provided. The 2500 global R&D investors included in the dataset account for 90% of the global business R&D expenditure.

It was then decided to present some of the top R&D investment firms to help comprehend which companies were chosen. The fact that only a few of the top 25 firms are not American and that the majority of them are in the ICT industry was striking.

The further step was to take the EU industrial R&D investment scoreboard and the European Innovation Scoreboard (EIS) dataset and remove problematic data, the reasonable level of R&D was considered to be 30% and the industries with too few companies were left out of the analysis.

The analysis of Chapter 3 aimed at replicating and extending that carried out by Coad, using more recent data. Having the same purposes, the study started by making a descriptive analysis to make some initial assumptions and forecast the possible outcome of the analysis. Then, the focus moved on the σ-convergence test. This test was done by analyzing the evolution of industries' standard errors from the mean and the delta between the final and the initial period. In fact, a positive delta would imply divergence while a negative one would have meant convergence. The ending results were similar to the ones of the original study. Considerable heterogeneity in R&D intensities was observed, differences that did not disappear over time. A closer look was given to a some particularly intriguing cases.

CHAPTER 1: RESEARCH AND DEVELOPMENT

The purpose of this first chapter is to provide some basic concepts in research and development (R&D) and innovation that will be used later in the study.

To begin, some key concepts regarding R&D must be introduced, and the best source of information on the R&D concept is without a doubt the "Frascati Manual," which is available in its most recent version on the Organization for Economic Co-operation and Development (OECD) website (2015).

The next step would be to track how R&D spending changes over time. As a result, it would be required to introduce and focus on the idea of "R&D intensity" and the process of estimating it at both the national and corporate levels.

The third section of this chapter will go through possible R&D inputs (such as R&D expenditures and educational levels) as well as outcomes (Scientific publications, Patents, Inventions).

Finally, in the last paragraph, the thesis's main topic, the 'R&D intensity convergence,' will be discussed. It will be possible to understand how difficult it is to describe and its importance in R&D's industrial research. Some of the ideas discussed in this section will be employed later in the chapters, particularly in the third chapter's statistical analysis.

1.1 WHAT DOES R&D MEAN?

1.1.1 Research and Development Definition

"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" (OECD, 2015, page 44)[1]

The overall acknowledged characteristics of a Research and Development process are its goal of new discoveries based on original thoughts or hypotheses; the uncertainty of the eventual outcome; the planning and budget constraints. In general, R&D and productivity have a positive correlation between them. At the end of the R&D process property rights allow the new knowledge to be freely transferred or traded.

For every R&D process there are five criteria to follow:

- *Novelty:* Aiming at new findings, which can be new advancements in knowledge for the sole academic purpose or to obtain an advantaged position against competitors. R&D processes focus on new knowledge rather than improvements of existing products or processes.

[1] OECD (2015), Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris, https://doi.org/10.1787/9789264239012-en.

- *Creativity:* Based on original, not obvious, concepts and hypotheses that can create or improve existing knowledge. Like an artwork, R&D processes require differentiation but at the same time it must also follow the other criteria.
- *Uncertainty and risks:* Every R&D process carry risks. One comes from the R&D nature as R&D involves uncertainty in final outcome; an R&D project could fail without producing anything useful. The dimensions that are involved comprehend the kind of the outcome, the time required, and the cost. All these aspects cannot be previously determined but can only be predicted during the planning process.

  Another risk is the 'Takeover'. Others could gain technologies from who carried the research activity. This, usually, can discourage companies and funders from engaging in R&D activity. To mitigate this risk public policies granting property rights of research results are enacted.
- *Systematic:* R&D is a formal activity which is conducted in a planned way, keeping records of processes followed and outcomes. This criterion is met when it is possible to identify the purpose of the R&D project and the sources of funding.
- *Transferability and/or reproducibility:* An R&D project should lead to the potential for the transfer of the new knowledge, allowing other researchers to reproduce the results as part of their own R&D activities. This aspect

refers also to negative results, other researchers can verify that there have not been errors. For Marketable outcomes there are various disclosure alternatives that allow intellectual property protection to discourage secrecy.

Even when all of the criteria are met, there still is a thin line between R&D and non-R&D processes, making it difficult to distinguish genuine R&D activity. For example, in the mechanical engineering business, R&D might be classified under the "design and drawing" accounting entry, which also includes routine processes that cannot be considered R&D activities. Another example can be found in the medical industry. Routine blood tests are not R&D, but a particular blood test for patients taking new medications is.

Table 1 shows what should and should not be counted as R&D in a company activity. It is possible to define R&D activities as those that result in long-term improvements and innovations, whereas activities that do not directly affect innovation, even if they are related to it, should not be defined as R&D.

Table 1 - Board line between R&D, innovation and other business activities

Item	Treatment	Remarks
Prototypes	Include in R&D	As long as the primary objective is to make further improvements.
Pilot plant	Include in R&D	As long as the primary purpose is R&D.
Industrial design	Split	Include design required during R&D. Exclude design for production process.
Industrial engineering and tooling up	Split	Include "feedback" R&D and tooling up industrial engineering in innovation processes. Exclude for production processes.
Trial production	Split	Include if production implies full-scale testing and subsequent further design and engineering. Exclude all other associated activities.
Pre-production development	Exclude	
After-sales service and trouble-shooting	Exclude	Except "feedback" R&D (to be included).
Patent and licence work	Exclude	All administrative and legal work needed to apply for patents and licences (delivering documentation as an outcome of R&D projects is R&D). However, patent work connected directly with R&D projects is R&D.
Routine tests	Exclude	Even if undertaken by R&D personnel.
Data collection	Exclude	Except when an integral part of R&D.
Routine compliance with public inspection control, enforcement of standards, regulations	Exclude	

Source: OECD, 2015

It is clear that the research and development process is long and complex, not only to be carried out but even to be classified. So, to ease the studies, it can be divided into three sub-activities: Basic research, Applied research, Experimental development. This division will be presented more deeply in the next section.

1.1.2 Types of R&D

In order to understand the whole R&D process, it is important to identify and understand the three components of R&D.

- <u>Basic Research</u>: *"The experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view"* (OECD, 2015, page 29).

  Basic research focuses on testing hypotheses, theories or laws. The outcomes are frequently published in scientific journals or shared among academics or field experts, rather than being sold or licensed. Basic research results may be prohibited from sharing in some situations for national security considerations.

  Given the lack of a specific goal, academics in universities or the government sector are usually the ones who conduct this type of studies. However, it is still possible to have private companies carrying out basic research activities, focusing on the production of new knowledge that can grant them an edge on competitors without having a clearly defined end goal by stimulating new ways of thinking that can change and improve privates' abilities to deal with problems in the future.

  In some cases, it might be possible to consider the presence of a "directed" basic research, not having a specified end use objective but wanting to improve knowledge in some specific fields. Private enterprise research on energy-saving technology is one example of this classification. Despite the lack of a specified usage, there is an objective that has been underlined, which is to improve energy savings. As a result, it falls under the category of "directed" basic research.

The outcomes of any basic research can then find applications in every field, their only limits are the inventiveness of individuals.

- Applied Research: *"Original investigation undertaken in order to acquire new knowledge. Directed primarily towards a specific, practical aim or objective."* (OECD, 2015, page 29)

  Applied research is done to find possible uses for the findings of basic research or to determine new methods or ways to achieve some practical objectives.

  It is possible to find an actual use for the knowledge to solve practical problems. Given this importance, the results of applied research activities are often protected by intellectual property instruments or secrecy.

  This kind of research requires statisticians and industry experts as studies are usually carried out through the scientific method. Methodology is crucial to not have biased results, by using statistics and data analysis.

- Experimental Development: *"Systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge in order to produce new products or processes or to improve existing products or processes"* (OECD, 2015, page 29)

Experimental development aims to the development of new products or processes by meeting the previously mentioned five R&D criteria.

It is important to not confuse Experimental development with “product development”, which comprehends all the steps from the idea to the commercialization. Experimental development activity consists in the testing knowledge coming from basic and applied research to see its possible uses. It is always possible to consider the production of new knowledge if the R&D criteria are respected even if the activity ends up with negative results.

To summarize, the expected use of the results is the criterion for classifying R&D activities by kind. The dynamic interconnection of the three sub-activities of the R&D process guides the entire innovation process.

Another way to categorize R&D processes is to divide them into groups based on how they are funded. R&D can be conducted with funds from own sources (internal) or from sources coming from external agents (external) (OECD, 2015).

- Internal funds: internal R&D funds represent the amount of money spent on R&D that originates within the control of and are used for R&D at the discretion of the agent carrying out the R&D project.

  To be considered internal funds they must not include funds received from other subjects. So, it might be wrong using the term “own funds” since some might consider public funds awarded to them as "own" but for the literature they are external.

In businesses the internal funds include reserve or retained earnings, sales, raising capital as equity, debt or other instruments.

In public sector, internal funds may include enrolment charges, income from endowments, and other earnings.

- External funds: External R&D funds are the amount of money spent on R&D that originates outside the control of the subject carrying out the R&D process.

  Those are funds received from external entities. In this category we have grants, gifts, and donations.

Given the complexity of the R&D activity, it is frequently difficult to find the exact source of R&D funds. For example, a government research laboratory might provide funds for R&D under a contract to an aerospace firm, which might use part of those funds to purchase R&D from another specialized company. At the same time, the aerospace firm might also use some of its internal funds. So, the identification of the funder(s) is complex (OECD, 2015).

1.1.3 Definition of Innovation

"An innovation is a new or improved product or process (or combination of thereof) that differs significantly from the unit's previous products or processes and that has

been made available to potential users (product) or brought into use by the unit (process)." (OECD/Eurostat, 2018, page 45).[2]

Innovation is the implementation of knowledge and ideas results in the introduction of new goods, services, or strategies. So, the aim of R&D processes is to generate "Innovation", concept that can then be considered as the progress' engine, by not only promoting the creation of new jobs but also changing societies through the improvement and spread of ideas and technologies. Labor productivity increases as a result of innovation activity, leading to a more efficient allocation of resources from which everyone can benefit.

Innovation comes from knowledge-based activities involving the practical application of existing or newly discovered information (data) and knowledge (conclusions derived from data). According to the Utterback (1971) interpretation, any innovation process can be divided into three phases: idea generation; problem solving; implementation.

R&D is only one of several factors that can generate innovation, according to the Oslo Manual of 2018. Yet it is still one of the most significant to which it is given great attention, especially for "breakthrough innovations".

[2] OECD/Eurostat (2018), Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris/Eurostat, Luxembourg, https://doi.org/10.1787/9789264304604-en.

Other activities that can be used to obtain knowledge include market research, engineering operations to improve a process, and data analysis.

Innovation aims to create value, but because its outcomes are unpredictable and heterogeneous, this cannot be guaranteed at the start of the process. As previously mentioned, the existence of this risk is one of the reasons that refrain companies from investing in R&D.

1.2 R&D INTENSITY

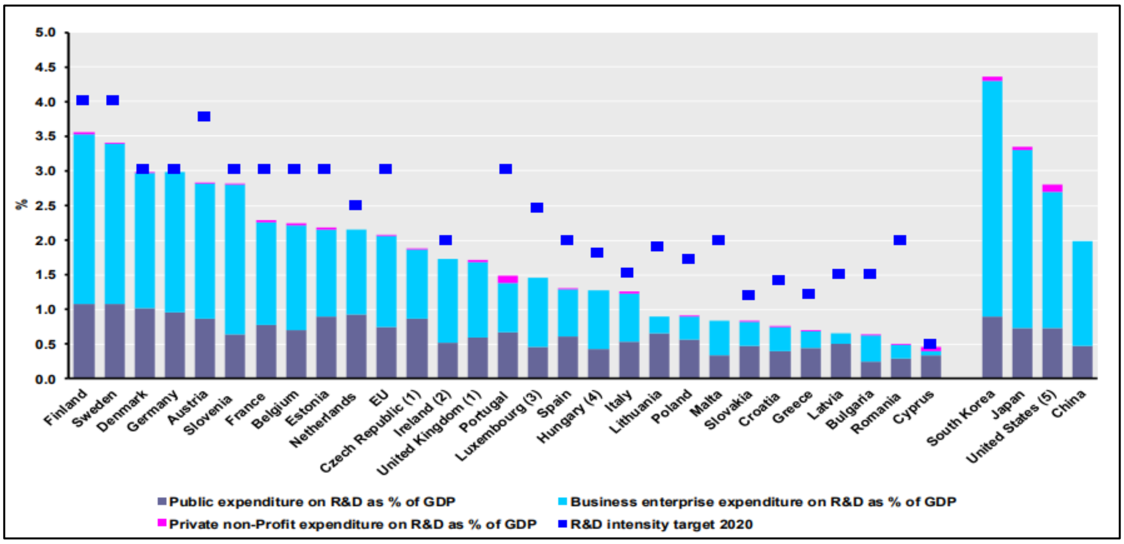
"R&D expenditure permits to understand who conducts and who funds R&D and where it takes place, the level and purpose of such activities, and interactions and the presence of collaborations." (OECD, 2015, page 30).

R&D intensity is defined as R&D spending divided by sales, or value added at a firm level, or by GDP at a county level. The intensity of R&D varies greatly based on many factors, but mainly according to the sector or industry considered. Thus, R&D intensity is still the most used indicator to compare the level of investment in innovation, especially between companies.

Policymakers are interested in the amount of money spent on R&D to determine how to encourage expenditures through incentives and stimulus, as well as to analyse market sector patterns to see which industries are more innovative and efficient. Companies that invest more in R&D are more likely to desire to expand more quickly.

As a result, some governments have set targets for this metric in order to better focus policy decisions and public spending (OECD, 2011).

Figure 1 - R&D intensity broken down by sector, 2012 and R&D intensity targets 2020



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies (September 2014)
Data: Eurostat, OECD, Member States
Notes: (1) CZ, UK: No R&D intensity targets have been set. For CZ a target of 1% is available only for the public sector.
(2) IE: The R&D intensity target is 2.5% of GNP which is estimated to be equivalent to 2.0% of GDP.
(3) LU: The R&D intensity target is between 2.30% and 2.60% of GDP (2.45% was assumed).
(4) HU: The R&D intensity sectoral breakdown does not add up to total R&D intensity.
(5) US: (i) Most or all capital expenditure is not included; (ii) Government expenditure on R&D refers to federal or central government only.

Figure 1 shows how R&D intensity is distributed throughout EU countries, as well as South Korea, Japan, the United States, and China. With a few exceptions, this graph shows how crucial the private sector is in supporting innovation, this is the sector with the highest R&D expenditure levels in each of the countries studied.

The fact that the European countries' R&D intensity plans for 2020 aimed for an overall 3 percent level, an arbitrary amount chosen to be an optimal goal for competing with other countries and more in line with the US level, is also relevant. In 2010, the European Commission proposed the “Europe 2020 strategy” for EU member states, a 10-year strategy for advancing the EU economy by coordinating national and European policies, and one of the five headline target indicators was the mentioned EU R&D intensity level of 3% (objective that has not been reached yet), demonstrating how important this indicator can be in macroeconomic decisions.

It is crucial to note, however, that due to the unpredictability of R&D results, a higher R&D intensity does not always imply better or certain innovation results. Some environmental elements, such as employee education and the value placed on researchers, can have a favourable impact on development as creative individuals are more able to use available knowledge to generate innovations.

1.2.1 Gross Domestic Expenditure on R&D (GERD)

GERD is the gross domestic expenditure on scientific research and experimental development (R&D) and its intensity is computed on Gross Domestic Product (GDP). R&D is carried out by all resident companies, research institutes, universities and government laboratories, etc., in a country. It provides an indication of the level of financial resources devoted to R&D in terms of the share of GDP.

$$GERD\ intensity = \frac{Gross\ domestic\ expenditure\ on\ R\&D}{GDP}$$

Despite its relevance the GERD index has the problem of taking into account the expenditures of both successful and unsuccessful research activities. Hence, a high expenditure value is not always reflected into more innovation. Furthermore, only developed and certain developing countries are able to gather and supply comparable data on a regular basis, making it difficult to compare and track R&D spending variations across countries to have a global picture of the R&D situation (OECD, 2015).[3]

For these reasons, it can be improved by integrating additional variables, both descriptive and analytical, such as the number of researchers as a percentage of the population.

The problems in detecting R&D efforts and effectively accounting for them can be linked to GERD's measuring limitations. Furthermore, R&D spending reflects researchers' pay, which are determined by country average incomes and the importance put on research. So, GERD values are affected by many different

[3] The GERD, like any other social or economic statistic, can only be approximately true. Different components are of different accuracy: sector estimates probably vary from 5% to 15% in accuracy. However, the GERD estimates are sufficiently reliable for their main use as an aggregate indicator for science policy.

factors, both directly and indirectly, but it still is the best way to compare countries' R&D expenditures.

1.2.2 Business Enterprise R&D Intensity

The BERD, or Business Enterprise Expenditure on R&D, is a measure of R&D performance in the business sector. It's the same as the GERD, except it's for the business sector, and it measures R&D spending of the business sector over a set period of time.

The business enterprise sector accounts for the majority of R&D spending and personnel in developed countries. As a result, it's critical to consider the many methods organizations utilize to manage their R&D activities.

BERD is usually estimated through official surveys on the volume and nature of businesses' R&D expenditures. Furthermore, those surveys comprehend some contextual information, such as the number of employees and the main productive activity in order to position the firm in the industry (OECD, 2017).

There are three ways to compute the BERD intensity, each of one can be used to carry different analysis:

- Intensity of Business expenditure on R&D at a country level:

$$BERD\ intensity = \frac{Business\ enterprise\ expenditure\ on\ R\&D}{GDP}$$

- Intensity of Business expenditure on R&D at a sector level:

$$BERD\ intensity = \frac{Business\ enterprise\ expenditure\ on\ R\&D}{Added\ value}$$

- Intensity of Business expenditure on R&D at a company level:

$$BERD\ intensity = \frac{Business\ enterprise\ expenditure\ on\ R\&D}{Sales}$$

1.3 INPUTS AND OUTPUTS OF R&D AND INNOVATION

The various components of the innovation process interact in a variety of ways. To enhance the number of successful innovative activities, a functioning innovation ecosystem is required.

Employment, income, and competitiveness all rise as a result of innovation, as does economic progress.

1.3.1 Innovation Inputs

Innovation's inputs can be classified into five large areas, determining environmental aspects favourable to innovation (institutions, human capital and research, infrastructure, market sophistication, business sophistication). At the same time, innovation's outputs can be put into two sub-groups (Knowledge and technology outputs, creative outputs) (Reis et al., 2021).

Through a ratio between innovation inputs and outputs it is possible to calculate the innovation efficiency ratio, from which it is possible to create the Global Innovation

Index (GII), one of the main indexes used to classify innovation levels between countries.

According to Reis' study, countries can achieve better innovation performance in the GII by using various combinations of input. Richer countries can have a bigger input combinations' portfolio, explaining why successful innovation outcomes often come from high-income/richer countries. It appears that countries with weak innovation ecosystem cannot translate their innovation efforts into product innovation (Reis et al., 2021).

It is essential to include the complete ecosystem when examining R&D and innovation inputs rather than just looking at R&D spending (Mohnen, 2019). For example, the number of researchers per million people, researchers' share of total R&D expenditure (salaries are affected by macroeconomic factors, so this indicator must be weighted), education system investments, high-skilled workers who can adapt to new technologies, collaboration indexes between organizations, and so on are all important factors to consider when studying innovation.

1.3.2 Innovation's Outcomes

"Companies cannot grow through cost reduction and reengineering alone… innovation is the key element in providing aggressive top-line growth, and for increasing bottom-line results" (Davila et al., 2006, page 6).

The innovation process can be described as the transformation of knowledge, produced by research activities, into application, passing through various stages. The goals of the innovation process are different but can be summed up into obtaining technological competitiveness and active price competitiveness (Vaona and Pianta, 2008).

So, according to some experts, innovation always positively affects the society. From it, companies can gain edges in penetrating markets while providing better products and services to clients. Moreover, innovation can give innovators a confident attitude to take risks and obtain results, whether they will get commercialized or not. Having an innovative culture makes growth easier (Henderson, 2017).

Scientific publications and patents can be used to share positive R&D results.

Scientific publications are discussed in scientific journals, making the results of research activities available to the public while renouncing to the discovery's immediate marketability. The main goal of scientific publication are the pursuit and propagation of science.

Patents are a mechanism that gives innovators property rights for a set length of time, allowing them to decide what to do with their creation. A patent is a paper describing an invention while granting property rights to the inventor. The main goal of patents is to encourage knowledge disclosure by giving the opportunity to gain a competitive edge.

A third, more marginal, strategy for dealing with positive R&D outcomes is to keep them secret. It is possible to avoid revealing discoveries in this way. Policies, on the other hand, tend to encourage full disclosure by providing intellectual property protection. This is done because development is made possible by the pooling of many different ideas.

1.3.2 Scientific Publications and Firm's Open Science Strategies

In order to recognize and quantify the progress of research it is possible to use bibliometric indicators, which can show the size, growth, and global spread of research (Meo and Usmani, 2014).

These indicators show the number of scientific research papers that have been published. Scientists collaborate on development by sharing their findings and outcomes from experiments. Furthermore, research publications reflect a country's growth because a robust scientific research environment is a requirement for scientific and economic advancement.

In recent years, a growing number of firms in knowledge intensive sectors participate in open science, a way to promote cumulative knowledge production facilitating the disclosure of discoveries through publications in academic journals (Jong and Slavova, 2014).

Publication of study findings may also provide some indirect benefits. Pharmaceutical R&D laboratories, for example, that encourage employees to publish tend to be more successful in responding to change.

Furthermore, a good research environment is more appealing to scientific communities, providing a competitive advantage in achieving company R&D objectives. Commercially valuable know-hows are frequently found in academic groups where commercialization understanding is lacking. As a result, a corporation that is able to work with academic scholars can receive knowledge from their communities, earning a competitive advantage.

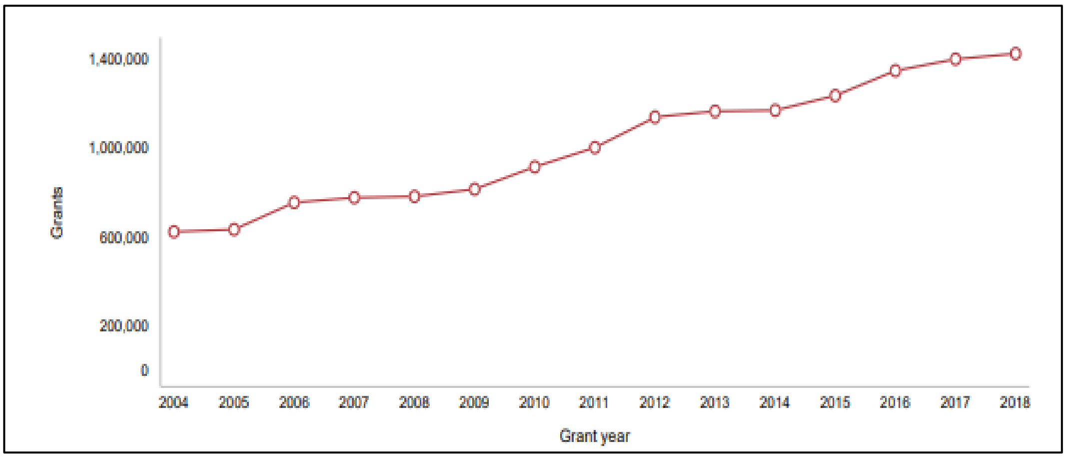
Publishing more and better publications is one strategy to improve a company's academic reputation. This will allow it to attract specialized experts and produce positive and valuable R&D outcomes.

1.3.3 Patents

"A patent is a right granted by a government to an inventor in exchange for the publication of the invention; it entitles the inventor to prevent any third party from using the invention in any way, for an agreed period." (OECD, 1993, page 112)

Patents are important tools for stimulating innovation and improving economic performance. ICT and biotechnology are now the most innovative industries, thanks to scientific and technological advancements. Furthermore, relevant innovation processes are now typically carried out through new research organizations that build knowledge and know-how networks as a result of cooperative agreements between enterprises.

Figure 2 - Patents granted worldwide (1.42 million - 2018)



Source: WIPO, 2019

Figure 2 offers a visual understanding on how the importance of patents have increased worldwide. In just 14 years the number of patents granted worldwide has doubled.

By preventing competitors from adopting beneficial or possibly relevant discoveries, patenting innovations became a tool against rivals. A patent can be a valuable instrument to consider in long-term strategy because patent rights often continue for up to 20 years from the day an application is filed (the length varies depending on the office in which the application was submitted).

A patent is only valid in the country where it is issued, and it is subject to national laws and litigation in national courts. As a result, the patent system must be updated on a regular basis in order to promote a more competitive and innovative environment.

With a working intellectual property protection tool companies can disclosure their discoveries while maintaining a competitive position. At the same time, other firms can work around the innovation to generate a better and more efficient one. In this cycle the one that benefits more is the society, the fostering of R&D leads to the production of better products at lower costs. Furthermore, a working patent system can enhance market entry and firm creation, even a small company can compete with big corporations if it holds the rights of a valuable patent (OECD, 2004).

1.3.4 Inventions

Inventions are linked to innovation; although, while being assumed to be synonyms or at least interchangeable, they are two separate concepts.

Innovation identifies opportunities for improvement, then transforms inventions into goods and services that are sold to customers, creating revenue. Inventions can also be used to have better and more efficient production processes.

Something that has never been manufactured before, or the process of creating something that has never been made before, is known as an invention. To invent is to discover a something new.

Most people seem to believe that inventions are the result of a flash of genius and include great scientific discoveries or technological advancements. Although this is not always the case, many well-known innovations did not involve a major scientific breakthrough nor great technologies, they were created by regular individuals, often working alone or in small groups. The majority of inventions are the outcome of a thorough analysis of a technical problem. It is a legal standard, not a technical standard, that is used to establish patentability.

Innovators use inventions to satisfy society's needs and, most of all, to present commercially successful products. To do that innovators must be creative, presenting something new and viable to the public (Herbert, 2016).

The number of patents granted that are then realized as new products is one method to calculate inventions. In fact, it is possible that a patent awarded will not be commercialized or used. Patenting even insignificant discoveries to slow down competitors has become routine practice, which many argue is harming the innovation process.

1.4 R&D CONVERGENCE

Convergence is a complicated and multifaceted phenomenon with complex dynamics to understand. Talking about R&D convergence, people often assume that long-run convergence demands that: less competitive firms to invest more in R&D than the wealthier businesses; the investments in R&D would lead to innovation and new technologies, enhancing competitiveness.

In the literature, as the many definitions provided by experts demonstrate, there is no clear answer when trying to define convergence. For example:

The Solow model, developed in the mid-1950s by Robert Solow as an extension to the 1946 Harrod-Domar model, it is used by modern economists to study how technological, capital, and labor changes can affect economic growth. The model is founded on the idea that capital accumulation is the driving force behind long-term economic growth.

As a result, according to the Solow model, diverse economies or companies converge to a steady state equilibrium, and growth can only be sustained by introducing technological advances.

The forecast that follower economies or firms will expand faster than advanced economies or enterprises is a key component of this model. Late comers can acquire the most up to date tools without having to invest anything whereas wealthier players must innovate themselves and invest in discovering new knowledge constantly to face competitors.

Another convergence definition is:

"Convergence stands for blurring and gradual breaking down of boundaries between different technologies, which, in turn, brings divers products, markets and industries closer. At a field level, it mostly proceeds through market transactions as new technologies relate and increasingly combine previous distinct and disparate instances" (Tunçalp and Ercek, 2014, page 2).

According to the cited authors, industrial convergence happens when unrelated technologies and industries converge around similar solutions. If firms in an industry tend to employ similar resource/capability compositions, their R&D should converge.

According to a further definition:

"The convergence process has been defined as the escalating and transformative interactions among seemingly different disciplines, technologies, and communities to achieve mutual compatibility, synergism, and integration and thus to create added value to meet shared goals" (Roco, 2016, page 80).

For many years it was possible to observe convergence in different industries. Cars, cellular phones, biotechnology have examples of convergence. In this case convergence is defined as combining knowledge from different fields to produce innovation and inventions by combining different inventions.

Scientific discovery and technological innovation in various fields improve in coherence but in a non-uniform manner (Roco, 2016). This leads to scientific convergence, technology integration, and divergence of knowledge and application into new sectors.

In this thesis the definition of 'R&D Convergence' that will be used is the trend of firms in the same sector to move towards a common "optimal R&D intensity level". The value chosen as a reference is the industry average R&D intensity.

According to Coad (2019)[4] despite observing through statistical tests a catch-up behaviour (β-convergence) by firms with a R&D intensity below the industry's average, it is not possible to say that companies in the same industry converge to a common R&D intensity in the absence of σ-convergence.

- β-convergence: when a negative correlation emerges between the growth of a variable over time and its initial level, there is beta convergence. Coad studied the beta-convergence to observe if *"firms whose R&D intensity is below the industry average will 'catch up' and increase their R&D intensity faster than firms whose R&D intensity is above the industry average"* (Coad, 2017, page 6).

  Beta-convergence is a necessary but not sufficient condition for convergence.
- σ-convergence: in this study, sigma-convergence refers to a reduction in the dispersion of levels of R&D intensity within industries. The presence of σ-convergence results in the decrease, over time, of the standard errors in R&D intensities among firms belonging to the same sector.

[4] The paper on which this thesis work is based, it will be presented in a more detailed way in the third chapter.

CHAPTER 2: DIFFERENCES IN R&D AMONG COUNTRIES AND SECTORS

The purpose of this chapter is to examine how R&D and innovation differ by country and industry.

Countries are encouraging private sector R&D spending to invest in innovation. It appears that in Europe, member states' R&D investments fall short of their potential, lagging behind the United States, Japan, and South Korean levels.

The first section will cover R&D spending by countries and macroregions. There will also be a presentation of the most common government measures to encourage business R&D.

The second section of this chapter will look at the intensity of R&D in various industries, especially the ones that are most R&D intensive (ICT, Pharmaceutical, Automotive, etc.).

2.1 R&D IN DIFFERENT COUNTRIES

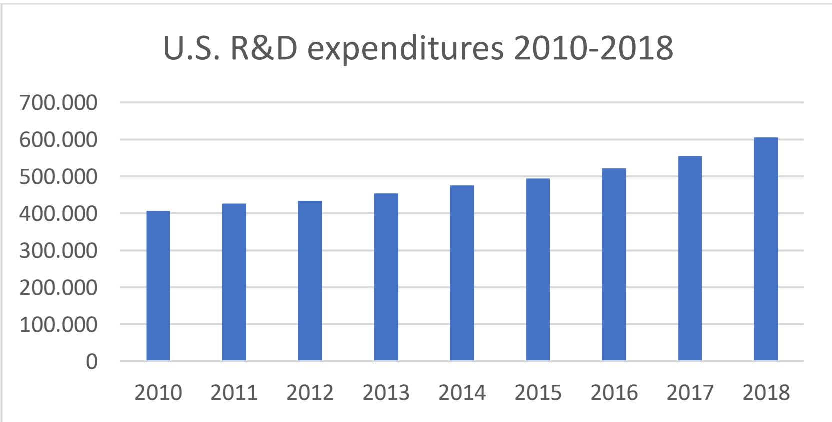
The aim of this first section is to illustrate R&D intensity in countries and the policies promoting private R&D. It offers a brief comparison of R&D intensity between countries and presents some explanations on how globalization affected innovation's transfer between countries.

2.1.1 R&D Around the World

- United States

According to the data from the National Center for Science and Engineering Statistics (Boroush M, 2021) of the United States, as it is possible to notice from Figure 3, the R&D expenditures in the U.S. totaled $606.1 Billion in 2018.

Figure 3 - U.S. R&D expenditures 2010-2018

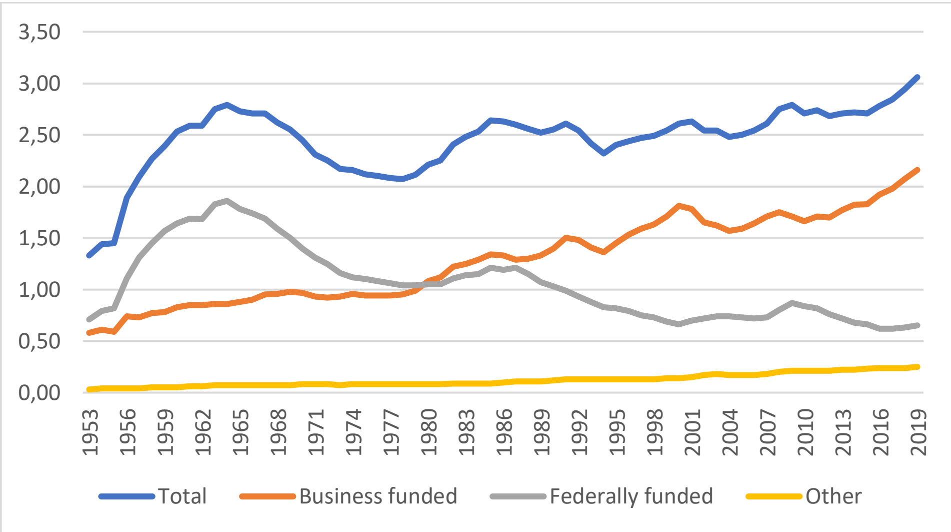


Source: NCSES

The U.S. R&D system consists of the activities of a diverse group of R&D performers and sources of funding. In Figure 3 it is possible to observe the steady and constant evolution of R&D expenditures in the US in the 2010-2018 period, comprehending business, federal government, non-federal governments, higher education institutions, and non-profit organizations expenditures.

The annual increases in US total R&D are due to consistently higher levels of business R&D performance, accounting for about 80% of the increase each year.

Figure 4 - Ratio of U.S. R&D to GDP, by source of funding for R&D: 1953-2019



Source: National Centre for Science and Engineering Statistics (NCSES)

According to Figure 4, adjusted for inflation, growth in U.S. total R&D averaged 3.3% annually over the 2010-18 period, higher than the 2.3% average growth of U.S. GDP.

It is also possible to notice that despite a decrease in federal funds the total R&D expenditure increased due to the increasing expenditure done by business activities. This transition is observable in other capitalistic economies in which companies invest in R&D to maintain their competitiveness. At the same time, governments reduced their investments in R&D by focusing on policy and tax incentives as ways to encourage non-government organizations to invest in R&D.

The NCSES stated that in 2018, U.S. Basic research activities accounted for $101.1 billion (17% of total U.S. R&D expenditures). Applied research was $116.3 billion (19% of the total). Around $388.6 billion were spent in experimental development (64% of the total).

- China

Despite being considered a developing country for many years, China appears to have become one of the main leader economies, along with the U.S. and the E.U. (Dias et al., 2019)

China has become an attractive destination for R&D investments, not only for the low-cost manufacturing, but also because of its excellent R&D laboratories. By attracting foreign R&D investments, Chinese firms had the opportunity to learn know-hows and productions processes directly from competitors. In 2018 it was estimated that around 75% of Chinese R&D expenses were funded by business enterprises (Eurostat, 2018).

Huawei Technologies Ltd is the perfect example of a Chinese company using competitors' knowledge to improve own products and R&D. Established in 1988 as a private high-tech enterprise it soon started to specialize in communications equipment and in a few years became one of the wealthiest Chinese companies. The company's strategy to grow was to adopt existing technologies and improve them with own R&D and cooperation agreement with first-class high-tech companies (Motorola, IBM, Intel, etc.). In just a couple of decades Huawei became one of the biggest high-tech companies in the world, aiming to surpass its historical American competitors.

China has become a major industrial competitor by rapidly expanding in high-tech sectors. The country's planned growth 'Made in China 2025' puts at the centre Research and Innovation policies.

China's spending in R&D as a portion of GDP is higher than in the EU28. R&D expenditure as percentage of GDP in China was reported at 2.19% in 2018, according to World Bank data ($303.59 Billion).

Table 2 - International patent applications by origin (PCT System)

Origin	2018	2019 Estimate
Total	252,775	265,800
China	53,349	58,990
United States of America	56,252	57,840
Japan	49,706	52,660
Germany	19,742	19,353
Republic of Korea	16,917	19,085
France	7,918	7,934
United Kingdom	5,634	5,786
Switzerland	4,576	4,610
Sweden	4,168	4,185
Netherlands	4,134	4,011

Source: WIPO

Table 2 shows that in 2018 China was the second country in patent application to the PCT system and was expected to be number one in 2019, these results are astonishing considering the fact that China's development started less than half a century ago.

According to the 2018 EU industrial R&D investment Scoreboard (Guevara et al., 2018), China's innovation performance growth rate is three times higher than the EU's one. (Dias et al., 2019).

- South Korea

South Korea is one of the world's most innovative nations, this is a surprising result considering that for the first half of the 20th century the country was an agrarian-based Japanese colony.

In just half a century South Korea redesigned its economy and society. This was made possible thanks to the country's outstanding performance in R&D intensity.

According to the "Bloomberg's 2020 innovation index", South Korea was second only to Germany and in 2021 the Asian country became the leading economy in this index's ranking. It is important to state that this ranking is done by comparing various indicators and that South Korea shows the best qualities to combine both government and private R&D efforts.

South Korea has high levels of R&D expenditure (4.64% of GDP in 2018, $80 Billion), highly educated workforce, good and improving innovation framework conditions, large knowledge-intensive and internationally competitive firms, and a strong ICT infrastructure (Korea-EU Research Centre, 2010).[5]

The main South Korean characteristic is its ‘top-down’ innovation system, promoting close collaboration between government, industry, and the academic community (Dayton, 2020).

The Korean system supports the emergence and prosperity of large industrial groups called chaebols. The government pushes the chaebols to invest heavily in R&D while shielding them from competition. Examples of chaebols are companies such as LG, Lotte, and Samsung (Dayton, 2020).

The South Korean institutions promote research and innovation as drivers of national economic and social advance. For this reason, chaebols HQ are often close to universities and research centres, industry R&D and production infrastructure are brought together with local and national universities and research facilities. It is estimated that around 76.6% of Korean R&D is funded by business enterprises (Eurostat, 2018).

[5] “The Europe-Korea Research and Innovation Community was launched in 2019 as a structured platform for collaborations.
The Community aims to promote Korea-EU R&I cooperation through the knowledge exchange on the R&I policy, the match-making events for researchers, and joint calls to support research collaborations and mobility programmes.” The institute was founded by many European research foundations along with the national a private Korean research institute.

- European Union

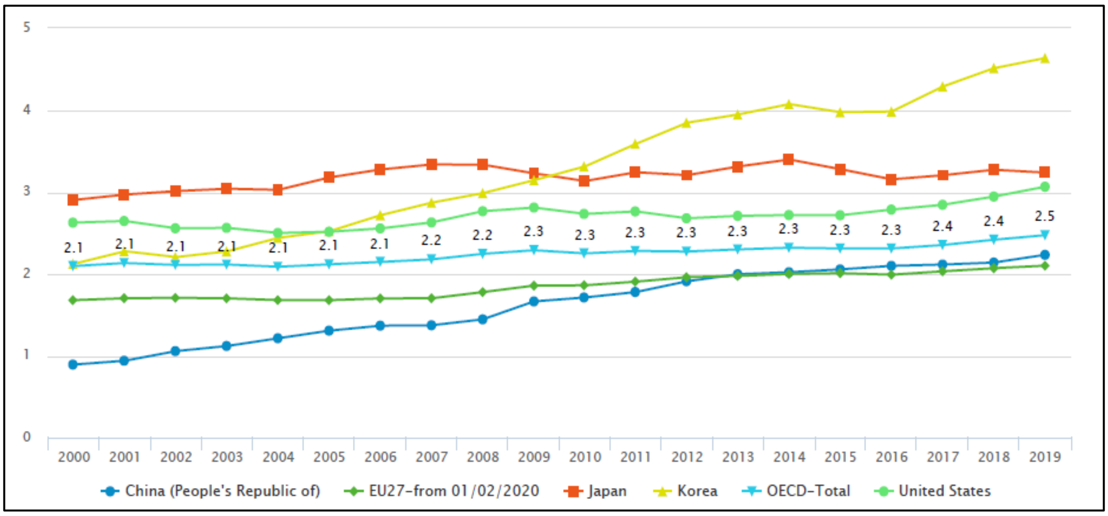
R&D investments improve the lives of millions of European and non-Europeans by solving some of the world's largest societal and generational challenges. The European commission's political guidelines for the period 2019-2024 aim to become the world's first climate-neutral continent. This and other targets are backed-up by a commitment to invest in innovation and research through the European Green Deal investment plan.

The EU is one of the leader producers of scientific knowledge by welcoming researchers from all around the world. However, it is common belief that Europe faces an innovation deficit. Despite an environment promoting new ideas there is a lack of success in diffusing/commercialising inventions. This can be a consequence of a risk-adverse European culture that prevents acceptable levels of investment in the uncertain field of R&D (Eurostat, 2020).

In 2018 the Gross domestic expenditure on R&D (GERD) stood at €294.5 billion in the EU27. An increase of 4.94% on the previous year. It was equivalent to 60% the GERD of the U.S. (Eurostat, 2018).

Figure 5 shows the evolution of GERD done by the countries that invest more in R&D. It is possible to notice the confirmation of the fact that Asian countries like South Korea and Japan were able to become and maintain their position as leader investors. Regarding the EU, in the last decade the Union maintained an overall constant level of investment in R&D but was recently surpassed by China. As it is also possible to notice, almost every country experienced a reduction in R&D expenditure in 2009, it is common to postpone R&D investments in times of crisis.

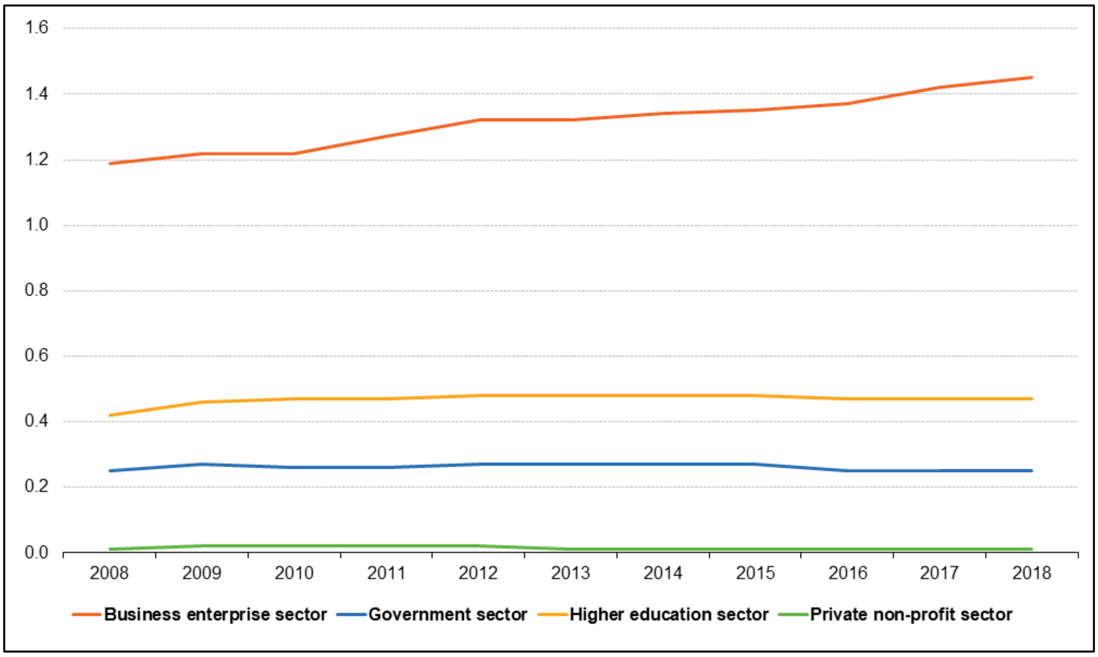
Figure 5 - GERD as percentage of GDP



Source: OECD, 2020

Among the EU member states, in 2018 Sweden, Austria, Germany, and Denmark were the countries with the highest R&D intensities, with values above the 3% goal (Eurostat, 2018). Interesting is the fact that nine member states reported R&D expenditure below 1.00% of their GDP in 2018, each of them joined the EU in 2004 or more recently, with the exception of Ireland. The lowest R&D intensities were recorded in Romania, Malta, and Cyprus (Eurostat, 2018).

Figure 6 - GERD by sector, EU-27, 2008-2018



Source: Eurostat, 2018

Through Figure 6 it is possible to observe how the EU-27's R&D intensity grew between 2008 and 2018 by identifying the share of R&D performed in each of four sectors. As was observable in the US scenario, the main source of R&D intensity is the business enterprise sector rising from 1.19% of GDP in 2008 to 1.45% by 2018 (Eurostat, 2018). The other sectors remained more or less constant through the years.

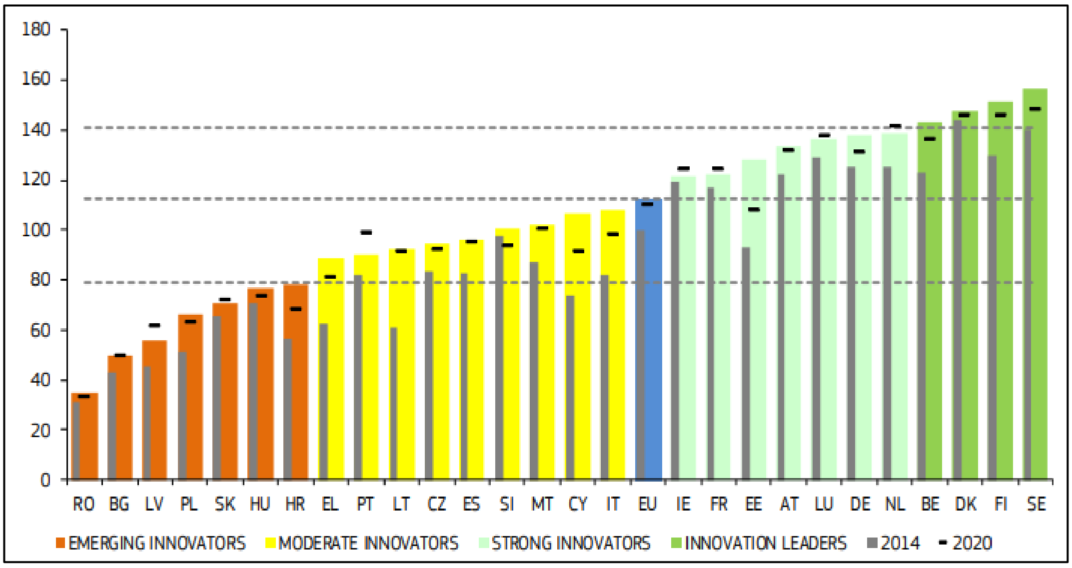
In 2017, almost two thirds of the EU-27 R&D was carried out by the business enterprise sector, this sector usually accounts for the highest R&D spending. The second and third largest contributions came from the higher education (21.9%) and government sectors (11.6%) (Eurostat, 2020).

EU member states with higher ratios of business enterprise expenditure on R&D relative to GDP are the ones that are also able to maintain high overall R&D intensities.

The 2018 Eurostat analysis of R&D expenditure by source of funds shows that more than half (58.9%) of total expenditure within the EU-27 was funded by business enterprises, the rest was funded by governments and foreign funds (Eurostat, 2018). Despite only being partly correlated to the main theme of this thesis (R&D intensity), another interesting analysis of the European innovation situation was done by the European Innovation Scoreboard (EIS), in which it is possible to observe a classification made through a summary innovation index, made as an average of 32 indicators (comprehending R&D expenditures), to divide the EU member states into four performance groups.

Figure 7 shows how countries' summary innovation index changed while also highlighting the countries belonging to each category: *Innovation leaders* (Belgium, Denmark, Finland, Sweden); *Strong innovators* (Austria, Estonia, France, Germany, Ireland, Luxembourg, Netherlands); *Moderate innovators* (Cyprus, Czechia, Greece, Italy, Lithuania, Malta, Portugal, Slovenia, Spain); *Emerging innovators* (Bulgaria, Croatia, Hungary, Latvia, Poland, Romania, Slovakia) (Hollanders H. et al., 2021).

Figure 7 - Performance of EU member States' innovation systems



Source: European Innovation Scoreboard (EIS), 2021

Overall, the performance of the EU innovation system, has improved by 12.5% over the last eight years (2014-2021). Obviously, there are still gaps between each group and country. Yet, it is possible to say that those gaps are closing thanks to a strong cooperation activity and the EU strategies.

By looking at past EIS reports, it is possible to notice that less innovative countries tended to improve their performance faster than more innovative countries. So, it is possible to say that there has been a moderate rate of convergence in innovation performance between member states. This convergence accelerated in the last two years.

2.1.2 The Role of Public Policies for Innovation Support

In a society, both customers and workers profit from innovation. The first have better and less expensive products, while the rest can work in more efficient production lines that require less effort. Technological advancement is critical for improving the environment, promoting a higher quality of life, and maintaining global market competitiveness.

Without incentives, a company would pay all of the costs of discovering innovative solutions, while competitors may profit by copying the idea or waiting until the patent expires. As a result, companies tend to have low R&D investments, indirectly damaging the whole society by slowing down innovation processes. For such reason, policies encouraging research and development should be implemented.

Business strategies change periodically, and government policies should be adopted to stimulate industrial innovation and improve the capabilities of national innovation systems (Knoll, 2003).

According to the Nicholas Bloom (2019) paper published in the Journal of Economic Perspective, it is possible to identify five policies that can effectively drive innovation (Bloom et al., 2019):

I. Tax incentives for R&D – Tax subsidies and grants seem to be the most effective way to increase innovation along with productivity. Tax incentives for R&D can take various forms leaving firms to decide which

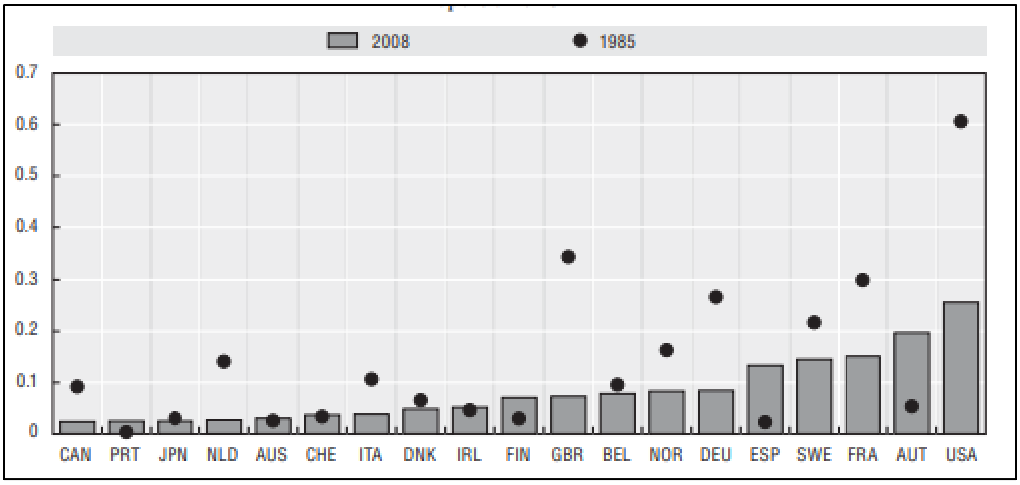
R&D activities to fund. They can be expenditure-based (tax credits, tax allowances and payroll withholding tax credits for R&D wages), or income based (taxing income derived from R&D capital) (Westmore, 2014).

Studies seem to find that tax incentives are effective in long-run R&D activities. Yet, it seems to vary with the design of the incentive, incremental tax credits can sometimes be more effective than volume-based tax credits (Westmore, 2014).

II. Government financed business R&D – Direct government funding of private R&D can have different modes and vary significantly in the way it is administered (Westmore, 2014). In this category it is possible to identify grants, loans, loan guarantees, or procurement contracts, though each may have different goals. Loans can support business R&D focused on the needs of civilians.

According to 2014 OECD data (Figure 8) it appears that direct government funding has been decreased in favour of R&D tax incentives, as it was mentioned before. A shift that shows, along with the data presented in previous sections, how the relevance of private enterprise R&D activity increased in less than half a century.

Figure 8 - Government financed business R&D (portion of GDP)



Source: OECD, 2014

R&D processes often have a multi-year horizon, and the investment decision is difficult to reverse once the project is commenced (Westmore, 2014). Hence, the effectiveness of R&D policies can be undermined if they are "unstable" (Westmore, 2014).

III. Patent protection – Patent rights temporarily grant the holder the ability to limit others from using an invention in exchange for the innovation being made public. It is possible to believe that a working patent tool can incentive businesses to invest in R&D to gain an edge on competitors.

IV. Other policies – Some policies may indirectly affect business' R&D:

Promote free trade: Opening trade can generate innovation by increasing competition, allowing innovation to spread faster and dividing its cost over a bigger market (Shu and Steinwender, 2018).

Support skilled migration: Covering R&D costs cannot be enough if there are not enough scientists to do the research. For this reason, it can be useful to adopt policies with the goal of attracting researchers, allowing more high-skilled immigrants into the country (Hunt and Gauthier-Loiselle, 2010).

Train workers in STEM fields: Another way to increase the number of researchers in the long term is to invest in training them domestically by promoting certain fields, Science, Technology, Engineering, and Math.

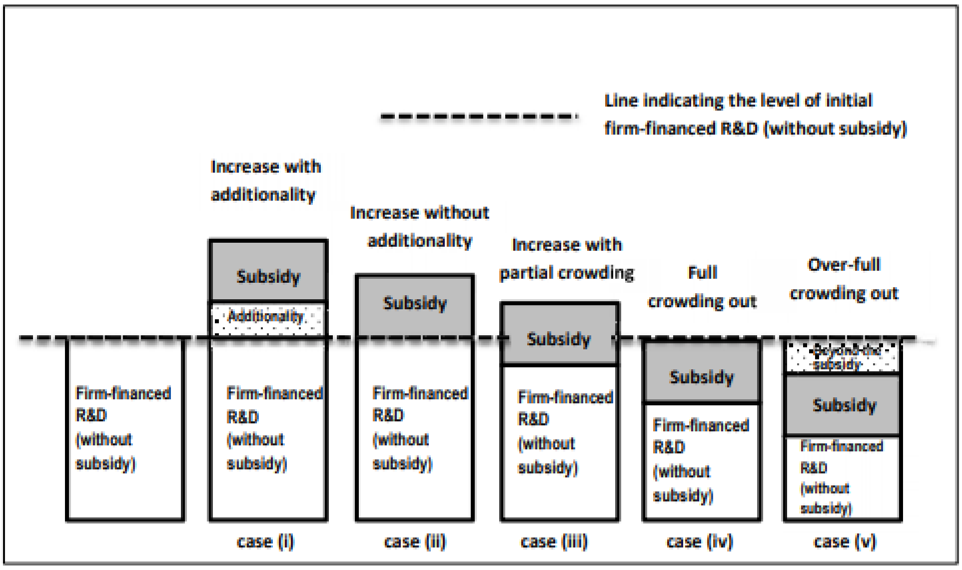
2.1.3 The Additionality Effect

"Conceptually, additionality is a determination of whether a proposed activity will produce some "extra good" in the future relative to a reference scenario, which we refer to as a baseline. In other words, additionality is the process of determining whether a proposed activity is better than a specified baseline...A baseline is a quantified amount of good or harm produced by the behaviour of the actors proposing and affected by the proposed activity in the absence of one or more policy intervention" (Gillenwater, 2012, page 3)

Numerically, additionality can be defined as the net positive difference that results from economic intervention. $A = I_{in} - I_{rc.}$ Where A is the additionality, I_{in} is the impact of the intervention, and $I_{rc.}$ is the impact of a reference case.

Additionality is strongly linked to government initiatives. The additionality impact in R&D studies refers to a larger R&D investment than the baseline and the subsidies combined (D'andria et al. 2017). This can be shown in Figure 9, which shows both the additionality impact and the crowding out effect that can occur when a company receives a subsidy. Because the R&D investments are above the baseline value, the first three examples generate positive externalities.

Figure 9 - Possible outcomes of fiscal policy intervention on business R&D expenditure additionality



Source: European Commission, 2017

The additionality effect, case (i), is evaluated ex post the observation of an activity affected by policy intervention. Clearly, in the presence of R&D additionality or positive externalities, the policy may be considered a success, and a good business environment emerges in which corporations are willing to invest more than the baseline in order to achieve greater results.

Case (ii) can still be considered a neutral result. In this case firms neither increase nor decrease their R&D expenditures and an overall increase in investment is observable.

Case (iii) is to be considered a borderline situation in which there are positive externalities as the subsidies are still encouraging an investment level higher than what it would have been without them. However, the policy is not really working, as companies invest less, they would have invested without the policy, covering their loss in expenditures with the subsidy.

Problems arise in the presence of full/over-full crowding out effects, cases (iv)(v), in which companies can reduce their R&D investments by the same or even a higher amount than the one of the subsidies. In this case there can be a bad business environment and a lack of innovation culture in which companies take advantage of the policies generating negative externalities.

2.1.4 The Globalization's Effects

"It took 1,000 years for the invention of paper to spread from China to Europe. Nowadays, in a world that has become more integrated, innovations spread faster and through many channels" (Aslam et al., 2018)

Globalization has increased the spreading of knowledge and technology across borders. Even the post-World War II Italian miracle is an example of how developing economies can enhance innovation and production in a short period of time by strengthening international ties.

Globalization helps spread technology around the world by making it simpler for countries to acquire foreign knowledge, increasing international competitiveness, which encourages companies to invest in R&D.

Globalization looks to be beneficial to everyone's inventiveness. Emerging economies can use efficient technology to produce more at a cheaper cost, allowing them to close the gap with industrialized economies. At the same time, by combining competitors' technology with their own, leading economies can benefit from each other's innovation.

Obviously, spreading innovation alone is insufficient; the ability to assimilate foreign knowledge and expand on it necessitates scientific and engineering expertise. As a result, countries must continue to invest in education, human resources, and domestic R&D.

The number of domestically published articles that have institutional affiliations from other countries or economies is referred to as international collaboration.

Transnational corporations (TNCs) have also played an important role in adapting and strengthening global R&D, particularly in developing countries. Globalized businesses can transfer technologies and decentralize R&D. TNCs are responsible for a significant portion of worldwide R&D activity due to their financial resources. The technological intensity of products and services has increased significantly in the global economic environment, making technology a key competitive factor. Furthermore, facing global competition necessitates faster adaptability and distinction from competitors, necessitating faster innovation. R&D costs are increasing as a result of these factors. As a consequence, TNCs have discovered a way to save costs by partnering with laboratories all over the world, particularly in developing nations where salaries are low, even for scientists. Collaboration with developing countries, on the other hand, has mutual benefits, allowing them to get up-to-date technology and catch up with more developed economies. (United Nations, 2005).

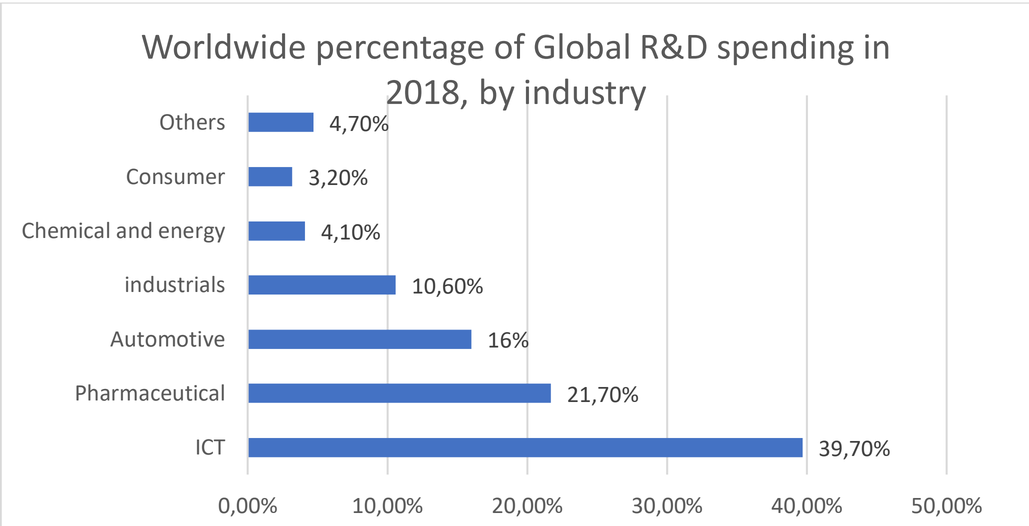
2.2 R&D AMONG SECTORS

The levels of R&D intensity in the major economic sectors will be presented in this paragraph. The R&D of leader sectors will be highlighted. It would be possible to have a first look at the heterogeneity of firms' R&D intensity within sectors, which will be examined more thoroughly in the R&D convergence statistical analysis.

The majority of R&D spending appear to be concentrated in just a few industries, those in which competitivity through innovation is a key factor: automotive, ICT, and pharmaceuticals.

Figure 10 shows the global percentage of global R&D investment by industry in 2018. As can be seen, the sectors with the largest R&D expenditures are those that require a continuous innovation process in order to sustain competitiveness, accounting for roughly 76 percent of total R&D spending across all businesses. Despite the most known industries (chemicals, automotive, pharmaceutical, and ICT) there are three other sectors that must be identified.

Figure 10 - Worldwide percentage of Global R&D spending in 2018, by industry



Note: In 2018, about 22.5% of global R&D spending was made by the computing and electronics industry (2018 global R&D expenditure = $1.395.744.000.000, OECD)
Source: Statista, 2021

The "industrials" sector includes businesses that manufacture physical things, such as machineries, to sell to other businesses across all industries. The "consumer" sector reflects consumer products production. The "other" industry is a collection of all other small industries that, while not having huge R&D spending individually, can be considerable when combined.

2.2.1 Automotive

According to a PWC paper published in 2020 (Foltz et al. 2020), carmakers' R&D costs have risen significantly along with the development of electric, connected, and autonomous vehicles. Cars are becoming more expensive as they are adapted to changing customer's preferences and expectations, environmental regulations, and technological disruption.

Research and development in this industry is focusing on implementation of ICT and other digital technologies in vehicles.

The future of automotive invention seems to focus on 4 aspects (Noor, 2019):

1. Electric: Worldwide environmental regulations have tightened in recent years. Each country has a plan to ban diesel and gas cars in just a few decades. So, car manufacturers are studying electric motors and batteries to present affordable and efficient hybrid and electric cars to the public. Moreover, companies like Tesla surpassed in value historical firms like Ford in just a decade, highlighting the potential of the electric cars market.
2. Autonomous: U.S., China and Japan seem to be the leaders in the development of self-driving cars. This technology would allow more efficient transportation while at the same time reducing human errors.
3. Interconnected: Vehicles are increasingly being equipped with built-in network capacity. It has become essential for cars to connect with smartphones and web application to offer comfort to the users.

4. Shared: It appears that the higher maintenance car costs and the will of new generation to act against climate change has led people to adopt a ride-sharing philosophy. Car manufacturers have decided to invest in car-sharing services proving that the car industry is experiencing a unprecedent change.

Car manufacturers are nowadays focusing on five emerging digital technologies which are researched the most (Foltz et al., 2020):

- Artificial Intelligence (AI) – Development of simulations, calculating optimal component design and packaging; Electronic Control Unit (ECU) configuration, more accurate cars.
- Virtual, augmented and mixed reality – Virtual testing, optical evaluation of interior and tools using mixed-reality.
- Blockchain – Technology that aggregates data and verifies that everything works correctly.
- Product lifecycle management – Use of tests and digital tools to offer better and long-lasting products.
- Additive manufacturing – Cheaper and personalized production.

2.2.2 ICT

Nowadays, information and communication technologies are everywhere. In most OECD economies ICT industries account about a quarter of business R&D expenditures (OECD, 2017).

ICT innovation is important because it directly influences the rate of digital transformation of the economy, improving firm productivity across industries and contributing to the economic growth of nations (Koutroumpis et al., 2020). ICT's start-ups are now seen as the most promising firms for economic development. Such activities are strongly linked to scientific activity and scientific progress (Koutroumpis et al., 2020). The ICT industry, especially electronic components, had the greatest source of opportunity renewal while semiconductors and electrical equipment had high opportunities for innovation (Koutroumpis et al., 2020).

ICT can be divided into two subcategories:

- *Hardware*

Hardware and ICT are two of the sectors that are driving global R&D. Most firm-level studies show that investment in ICT and hardware is positively correlated with productivity as they can affect other sectors' efficiency (Álvarez, 2016).

This could explain why developing countries still face a challenge of closing the productivity gap with rich economies, which instead invest a lot in hardware's R&D. The hardware R&D can be divided into various subjects, such as:

- Communication systems.
- Control systems.
- Imaging and signal processing.
- Power conversion.
- Microelectronics and nanostructure.

Moreover, each of these subjects comprehend a large number of research topics.

The R&D in electronics does not stop in developing new products to sell to customers but it also concerns coming up with innovative and more efficient production processes, affecting all the other modern sectors.

- *Software*

As a result of innovation and software engineering innovation, new software is introduced to the market on a regular basis.

To function efficiently and to attract potential customers, today's businesses and organizations must employ software. Banks, for example, offer online banking services that allow customers to access their accounts and accomplish things that they could only do in person a few years ago.

Furthermore, software development might focus on providing product customization to provide each client with the greatest experience possible.

Today's software R&D comes from traditional labs and small start-up companies. According to "Reuters", leading enterprises have started spending less on R&D of physical products like gadgets, investing more in software and IT services instead (Auchard, 2016).

Best-in-class software companies are allocating more to R&D than ever before, spending more than 20% of their revenues on R&D to as much as 40% to 50% when expanding beyond their core products (Ahlawat et al, 2019).

2.2.3 Pharmaceutical

New drugs are always produced on the market, there is the need for better drugs with fewer side effects at acceptable costs. The pharmaceutical R&D is constantly increasing and improving, the pharmaceutical industry is always innovating.

Pharmaceutical R&D is funded from a complex mix of private and public sources (OECD, 2019). Governments tend to support basic and early-stage research through direct budget allocations, research grants, publicly owned research institutions and higher education institutions.

In 2016, governments of 31 OECD countries with shared data collectively budgeted about $53 Billion for health-related R&D but it is possible to believe that if there are added tax incentives the value could be even higher. The pharmaceutical industry spent approximately $101 Billion on R&D across OECD countries in 2016 (OECD, 2019).

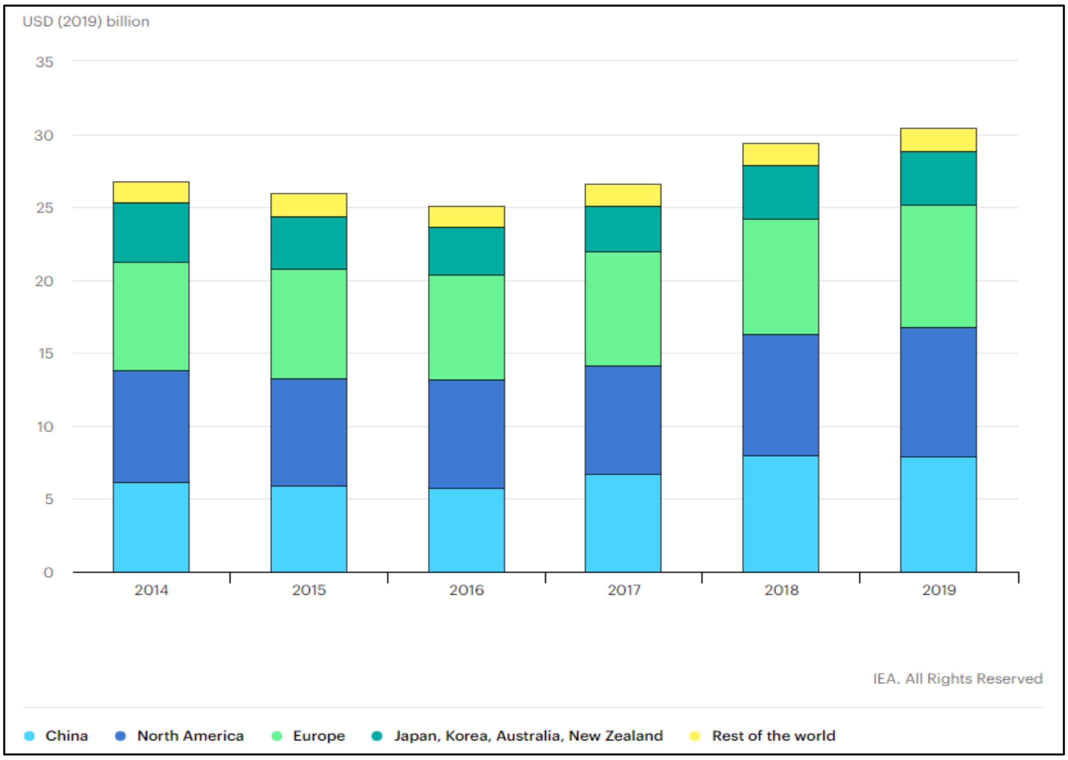
The pharmaceutical industry is one of the most R&D intensive, spending on average nearly 12% of its gross value added on R&D.

2.2.4 Energy Production

Research and development activity in the energy sector is essential to achieve a wide variety of societal and policy goals. Efficient technology is crucial in determining economic prosperity, environmental quality and national security (Runci and Dooley, 2004).

Energy R&D should consider the demand management and conservation, and the impact of policy instruments, such as price, physical and legal controls, technical improvements, and education, on energy demand (Munasinghe, 1990).

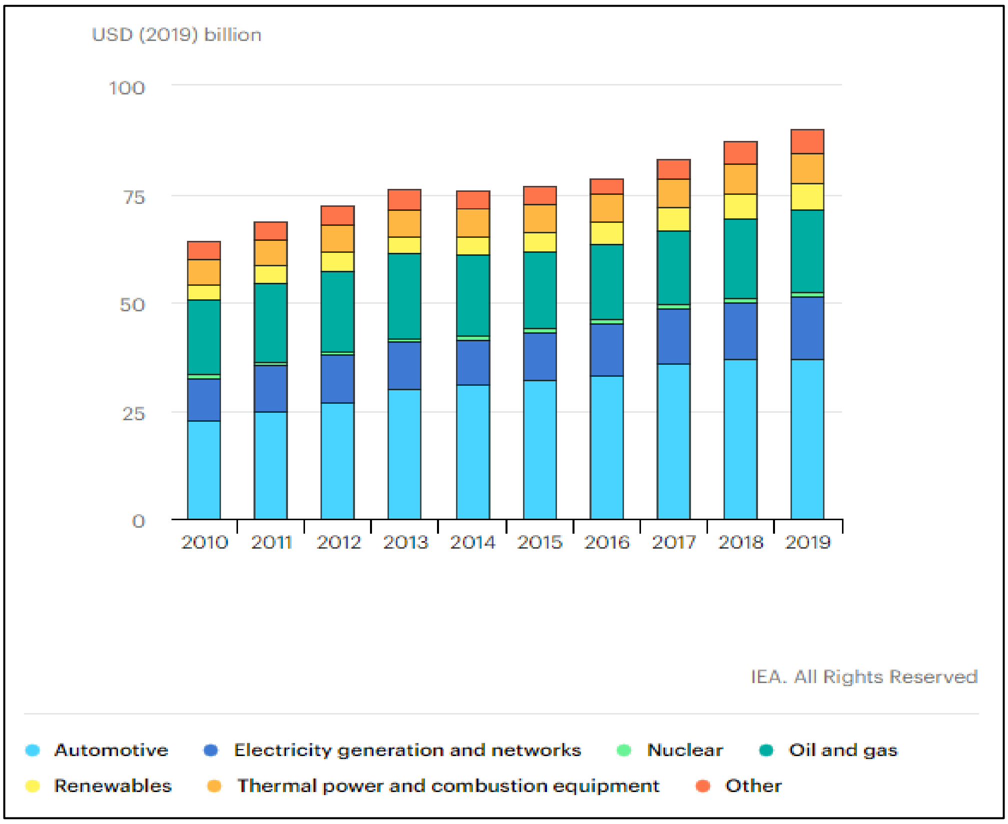
Figure 11 - Spending on energy R&D by national governments, 2014-2019



Source: International Energy Agency (IEA)

According to Figure 11 and from the data of the international energy agency (IEA) government energy R&D spending grew by 3% in 2019 reaching $30 Billion, this increase is mainly due to the EU and the US alongside with the steady spending in China (IEA, 2020).

Figure 12 - Global reported corporate energy R&D spending selected sectors, 2010-2019



Source: IEA

As it is shown by Figure 12, energy R&D mainly focuses on low-carbon energy technologies development. Around 80% of public energy R&D spending was in fact on focused on energy efficiency; carbon capture, utilization and storage (CCUS); renewables; nuclear; hydrogen; energy storage and cross-cutting issues such as smart grids.

According to IEA data, it is possible to notice that automakers are the companies that continuously increase their spending on energy R&D in the production of energy efficient and electric vehicles.

CHAPTER 3: R&D CONVERGENCE WITHIN SECTORS

This Chapter starts with a presentation of the study that inspired the idea for this thesis. Then, an empirical analysis is performed to test whether there are converging R&D intensities within sectors. After describing the data base, section 3.3 focuses on some leading companies in terms of R&D expenditures while section 3.4 is devoted to the above-mentioned analysis.

3.1 THE ALEX COAD'S STUDY

The inspiration for this thesis research is the Alex Coad's 2019 paper "Persistent heterogeneity of R&D intensities within sectors: Evidence and policy implications", published in "Research Policy". Research that was previously published in 2017 with the same title in the "JRC technical reports" of the European Commission, wanting to answer to the question: Do enterprises in the same industry converge toward the same R&D intensities?

Coad acknowledged the need of innovation in establishing high-productivity jobs in today's economy in his work. Examining microdata from the EU industrial R&D investment scoreboard (EIS) for the years 2000-2015, Coad observes a persistent and large amount of heterogeneity in R&D intensities among firms in the same sector.

The author then analyses the convergence behaviour through the use of σ-convergence and β-convergence tests. His conclusions are that, overall, firms in the same industry do not converge to a common R&D intensity.

Scholars have noticed that within industries, European firms are not less R&D intensive than their US counterparts (Coad, 2019) but they are still lagging behind their potential. It appears that the European R&D intensity gap might be related to a lower number of high-tech enterprises as opposed to a bigger share of low- and medium-tech firms. Few young prominent inventors in Europe are quickly expanding to become leaders of newly developed high-tech industries, this could close the gap with the United States. Another reason could be the difficulties in stimulating existing firms to increase their R&D investments within their sectors. One component that seem to heavily influence Business R&D seems to be the industrial structure of a country (Coad, 2019).

Academics have considered the first route to be the main cause, suggesting to the EU to adapt its industrial structure and increase economic activity in the high-R&D-intensive sectors (Coad, 2019).

Using EIS data, which will be discussed in the next section, Coad (2019) investigates the existence of heterogeneity in R&D intensity among enterprises in the same sectors from 2000 to 2015 looking at the possibility of enterprises' R&D intensity to converge over time, a study that has never really been done using microdata.

According to the literature on R&D investment, firms are unable to calculate the optimal R&D investment level, because of uncertainty of future benefits of R&D. R&D investment decisions are not taken rationally, companies follow rules of thumb, aiming for a target R&D intensity. The fixed percent of sales is something that is usually done, 10% is a reasonable sort of number in high-tech industry (Coad, 2019).

The presence of uncertainty surrounding the optimal level of R&D investment can lead firms to follow a second rule of thumb, pursuing the same R&D intensity as that of its rivals in the same industry. Given imperfect information on firm behaviour and performance, firms in the same sector are benchmarked against each other to ensure that their performance remains competitive (Coad, 2019). A sector R&D intensity target can reduce uncertainty surrounding decisions, simplifying strategic decisions. Even investors may use this benchmark to predict which firm would have an advantage over others in time, this puts a pressure on firms in the same industry to pursue the same sector-level performance targets (Coad, 2019).

Coad's paper then presents its hypothesis:

1. Firms in the same industry will have the same R&D intensity.

   "Industries are characterized by never-ending turmoil and creative destruction" (Coad, 2019). The outcome in this first hypothesis may only happen after a long period of time, as firms with different starting points and situations converge. Given the R&D intensity formula: $\frac{R\&D\ investments}{Sales}$, to increase the value firms would never cut sales on purpose. Instead, they would have to boost R&D investments a process that might be part of a long-term strategy which can be modified during the period and for this reason being problematic to make forecasts. So, if the gap between firm's R&D intensity and industry's R&D intensity is positive the firm will increase its R&D investment, if the gap is negative, the firm may reduce R&D.

2. Firms in the same industry will converge to a common R&D intensity.
    a. Firms whose R&D intensity is below the industry average will 'catch up' and increase their R&D intensity faster than firms whose R&D intensity is above the industry average (β-convergence). However, this condition is necessary but not sufficient for convergence.
    b. The variation in R&D intensity among firms in the same sector will decrease over time (σ-convergence).

To test these hypothesis, Coad's paper proceeds by doing a descriptive and parametric analysis where the gap trend is studied through panel data.

According to the research, there is a considerable heterogeneity in R&D intensities between industries and among firms in the same sector and those differences do not disappear over time. Instead of having firms with the same behaviour as their industry competitors a persistent heterogeneity is observe (Coad, 2019). According to the author, his results offer a new point of view regarding firms' innovation activities patterns.

He continues by stating that his findings might have an impact on industry structure policies. R&D intensity appeared to vary, with some firms in low-tech industries showing high R&D intensity and others in high-tech industries showing low R&D intensity. He suggests that policymakers should not solely focus on encouraging new firms to enter high-tech sectors in order to improve aggregate R&D intensity, but they should also encourage existing firms to expand their R&D within their sector.

As stated from the beginning, the objective of this thesis is to replicate and continue Coad's study and look whether there are any differences in the results by using more recent data from the EIS database.

3.2 DATABASE DESCRIPTION

The data that will be used come from the EU Industrial R&D Investment Scoreboard. The Scoreboard views private R&D trends from the global 'corporate' perspective, and as such, complements analysis based on R&D data collected by international and national statistics offices. The most recent data (2019-2020) have been collected by Bureau van Dijk – A Moody's Analytics Company under supervision by Petra Steiner, Vivien Schulz, Annelies Lenaerts, and David Pérez Vicente (EIS, 2016-2021). This data source contains information on several thousand of the world's largest R&D investing companies, and together the firms included in the Scoreboard account for about 90% of the total expenditure on R&D by business firms worldwide (Hernandez et al., 2016).

The official EU Industrial R&D Investment Scoreboard has been published annually since 2004 by the European Commission (Directorate-General for Research and Innovation and the Joint Research Centre). The 2020 edition of the Scoreboard comprises the 2500 companies investing the largest sums in R&D in the world in 2019/20. The Scoreboard data, taken from companies' latest published accounts, comprise key indicators on the 2500 parent companies and more than 800 thousand subsidiaries that enable assessing companies' economic and innovation performance. The 2500 companies, based in 43 countries, each invested at least €34.7m in R&D for a total of €904.2 billion. The 2020 Scoreboard total R&D is equivalent to approximately 90% of the world's business-funded R&D. The sample includes 421 companies based in the EU27, accounting for 21% of the total R&D in the sample, 775 US companies (38%), 309 Japanese companies (13%), 536 Chinese (13%) and 459 from the rest of the world (15%).

Previous analyses of Scoreboard data, which were used by Coad in his paper, include Cincera and Ravet, 2010; Garcia-Manjona and RomeroMerino, 2012; and Montresor and Vezzani, 2015. The individual waves of the Scoreboard were merged using the Bureau Van Dijk company-level identifiers, to obtain an unbalanced panel dataset which, in the latest available version, covers the period 2000-2020. However, some datasets are not available anymore or are not comparable with the latest. For these reasons, the study will focus on the 2013-2019 period, with some descriptive analysis using data from 2004.

While many papers in the literature focus on just one country at a time, using data from that country's statistical office, an advantage of the EIS dataset is that there is data on many countries. Furthermore, due to the way the database is constructed, virtually all firms in the dataset have positive R&D, not suffering from statistical problems due to a large number of zero values for R&D. Of central interest to the study is the reporting of a firm's annual total R&D expenditure and sales for each available year t, which is reported by the company's headquarters. Other variables, relating to firm performance, used to understand businesses' situation, are net sales, total employment, capital expenditures, market capitalization, and operating profits. Other controls include years, regions, and Industry Classification Benchmark (ICB) industries. R&D intensity is defined as the ratio of R&D expenditures to sales.

Data are cleaned to remove negative values of sales or R&D investment and other corrections were done to have a more consistent sample. Before performing statistical estimations, data were cleaned by removing observations of non-positive net sales and removing observations where the R&D intensity is negative or is greater than 30% of sales.

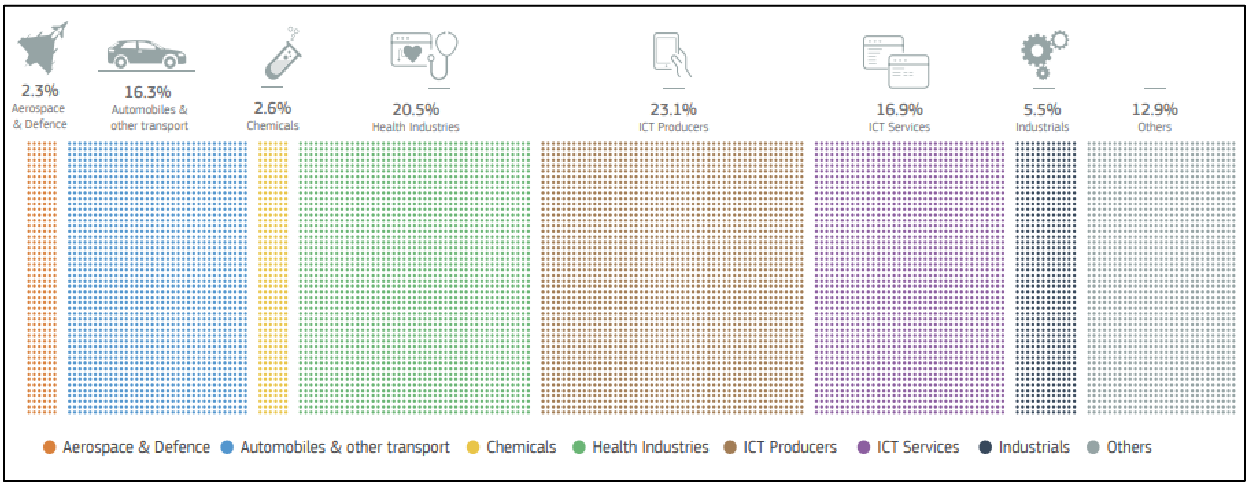
3.3 INDIVIDUAL COMPANIES R&D

This section will treat the levels of R&D investments in some big companies.

Big companies and organization have more resources to spend in R&D, moreover it is easier to find data on them than on small companies or start-ups.

As it will be possible to notice, most of the companies with high levels of R&D investments are the ones working in ICT (Amazon, Apple, Alphabet, Samsung, Huawei, Facebook, etc.). The three industries with higher R&D expenditure are the ones discussed in the previous chapter: ICT, automotive and pharmaceutical.

Figure 13 - R&D investment sectors of the 2500 companies, 2020



Source: EIS, 2021

Based on the EIS database, Figure 13 shows the sectors in which companies with higher R&D expenditure operate. As it was obvious, the three main sectors (ICT, Health, Transportation) amount for 76.8% of the 2,500 companies total R&D expenditure, and ICT alone accounts for 40%.

An important characteristic to notice is the fact companies with higher R&D expenditure are often from the United States or from East Asian countries (China, South Korea, Japan) while among the European countries only Germany seems to have companies with high levels of R&D.

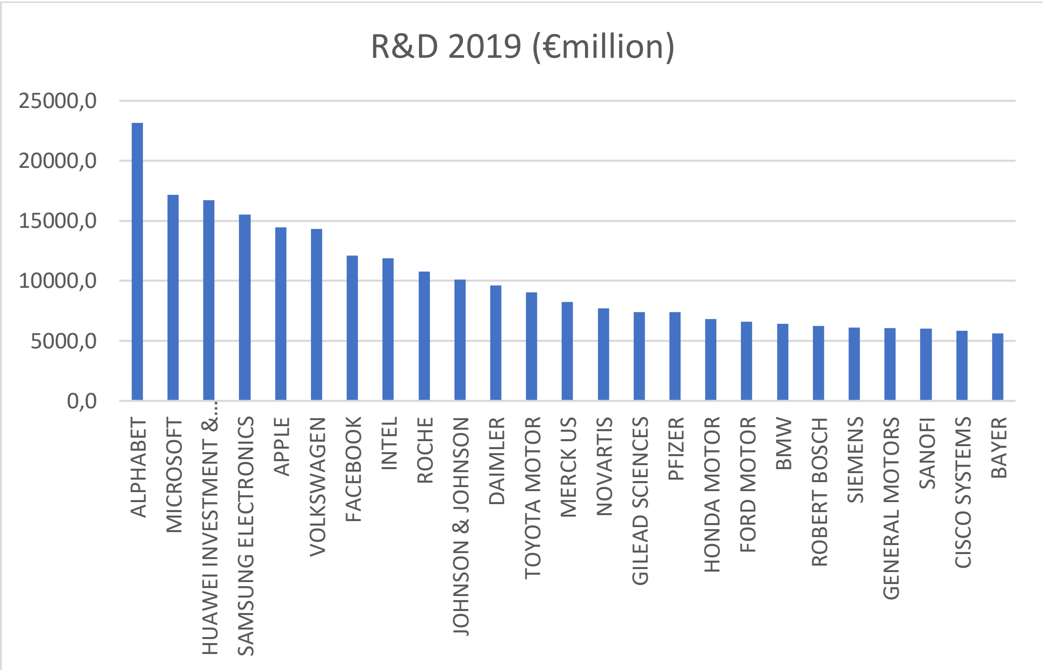
R&D intensity have significantly increased over the past 40 years, surpassing marketing expenditures in many companies.

According to the EIS (2020), in the top 15 R&D spenders the majority had an R&D intensity above 10% or close to this value, which confirms that successful companies spend a lot in R&D to maintain their position.

By using the EIS (2020) data it appears that among the top 2,500 R&D spenders the R&D intensity shows that the top 10 companies with higher R&D intensity are the ones that can be accounted for 16.16% of the total R&D intensity of the 2,500 companies, the top 25 account for 27.78%, and the top 100 are the ones responsible for 51.94% of R&D expenditure of the main group of firms, defining a great polarization of R&D expenditure.

3.3.1 <u>R&D by Company</u>

Figure 14 - Top 25 R&D spenders 2019



Source: EIS, 2020

Figure 14 is based on the EIS database and shows the R&D expenditure of the top 25 companies with higher R&D expenditure. It comes by no surprise that it is possible to notice firms operating in the already mentioned three main fields.

This next part will present some of the top R&D spenders, their expenditures and the projects that are spent on. Data and explanations come from the 2021 Nasdaq report and refer to the year 2020 and to the first months of 2021 (Bajpai P., 2021).

- **Amazon (AMZN), $42.74 billion**

Amazon is one of the company that invest more in R&D. Amazon's Security and Exchange Commission (SEC) filing shows an expenditure of $42.74 billion in the fiscal 2020 (11.1% of net sales) on ‘technology and content’, in 2019 the expenditure was of $35.93 billion.

During 2020, 2,244 patents were granted to Amazon, the majority of which were in high-tech such as artificial intelligence (AI), machine learning, and computer vision as the core of its ventures—be it cloud computing, voice-based virtual assistant, cashless Go stores, drone deliveries or robotic warehouses.

- **Alphabet (GOOG, GOOGL), $27.57 billion**

Google’s 2004 founders’ IPO letter read, “Our business environment changes rapidly and needs long term investment. We will not hesitate to place major bets on promising new opportunities. We will not shy away from high-risk, high-reward projects because of short term earnings pressure.”

Despite changing the company’s name, the philosophy is still the same, and a high stake of revenues are invested into R&D initiatives.

Alphabet spent $27.57 billion on R&D, which is equivalent to 15.1% of its revenue of $182.57 billion during the fiscal 2020. The company’s R&D sending has more than doubled since the fiscal 2016.

1,817 patents were granted to Alphabet in 2020. The main investments are in developing AI and AI-enabled devices and software.

- **Volkswagen, $14.5 Billion**

Volkswagen is one of the European companies that invest more in R&D and has been present in the top 10 investors rank for a long period.

Given the size of the company it comes with no surprise that its high R&D spending. The company wants to develop reliable convenient cars. R&D focuses on improving cars' connectivity, automation, construction, and use of light materials. In 2018 it filed a massive 7639 patent applications for employee inventions.

- **Huawei, $22.04 billion**

Huawei is a leading global provider of information and communications technology (ICT) infrastructure and smart devices. During the fiscal 2020, it spent around $22.04 billion on R&D. Its R&D spending constituted 15.9% of its total revenue. Huawei is one of the world's largest patent holders. 2,761 patents were granted to the company was in 2020. Overall, Huawei has more than 100,000 active patents across 40,000 plus families. The number of people working in R&D at Huawei is around 105,000, which is more than half of its total workforce.

The core values driving Huawei's R&D are growing in the industry, working together, and sharing values. Huawei has become partner with major industry players to innovate in emerging fields such as cloud computing, 5G, and the Internet of Things (IoT).

- **Microsoft (MSFT), $19.27 billion**

Microsoft's R&D studies a spectrum of technologies, tools, and platforms focusing on three interconnected ambitions: Reinvent productivity and business processes; build an intelligent cloud platform; and to create more personal computing.

The company's R&D spending has increased along with its revenues, Microsoft's policy is to maintain an overall allocation around 13% over the years.

During the fiscal 2020, the company reported an R&D expenditure of $19.27 billion.

During 2020, Microsoft Technology Licensing LLC (MLT) was awarded 2,905 patents, the fourth highest globally. MLT is a subsidiary that manages the company's patents and technology transfer activities. In addition to its main R&D operations, the company runs Microsoft Research, which is one of the world's largest corporate research organizations and works in close collaboration with top universities around the world.

- **Apple (AAPL), $18.75 billion**

Apple has conventionally deviated from the thought that relates innovation to the amount of spending on R&D. The company's founder, Steve Jobs, never saw innovation as a process linked with R&D expenditures, but rather with the people in company, how they are managed and what they can give to the company.

In 2020 Apple spent $18.75 billion on R&D, around 7% of its net sales. The company recognizes the importance of R&D investments as a process to reach future growth and competitiveness in the marketplace, and to the development of new and updated products and services.

- **Samsung, $18.75 billion**

The South Korean Conglomerate Samsung is the largest non-U.S. spender on R&D. Samsung spent $18.75 billion in fiscal 2020, which constituted 9% of its sales. 6,415 patents were granted to Samsung during 2020, placing at the second spot. However, Samsung is the world leader with 80,577 active patent families as cumulative patent holder.

The company's R&D aims at shaping the future with innovation and intelligence. R&D focuses on AI, data intelligence, robotics, next-generation communications & visual technology, and security. Samsung operates three levels of R&D organizations, the first is a business unit development team that works on market ready technologies with a 1–2-year outlook, the second is the research institute that develops mid-to long-term technology with a 3–5-year outlook, and the Samsung Advanced Institute of Technology that develops core technology as seeds for future growth engines.

- **Johnson & Johnson, $9.7 Billion**

Johnson and Johnson is a company working in the pharmaceutical field and by looking at its R&D statistics it is one of the top investors. In 2018 the company invested $10.8 billion in R&D (higher than the value reported in the EIS.

Like other pharmaceutical companies, Johnson & Johnson has to deal with expiring patents. Whenever a patent expires, other companies can produce similar drugs and bite off large chunks of the market. To remain competitive, Johnson&Johnson's

R&D tech expenditures are aimed at new and better technologies and products. Sometimes, this means buying stakes in companies. In 2018, Johnson & Johnson spent around $1 billion buying company stakes. It bought shares in Arrowhead, a company working on a hepatitis B drug. Together with an upfront payment of $175 million, this got J & J the global rights for the drug *(Source: The 2018 EU Industrial R&D Investment Scoreboard).*

- **Facebook (FB), $18.45 billion**

According to Facebook, its "business is characterized by innovation, rapid change, and disruptive technologies." During the fiscal 2020, it allocated $18.45 billion equal to 21% of its revenue towards R&D spending. Facebook R&D focuses on AR/VR, AI, blockchain and cryptocurrencies, data science, computer vision, machine learning, cyber security, natural language processing, and more.

3.3 EMPIRICAL ANALYSIS

3.3.1 Statistical Tools

R&D intensity: The focus of this analysis will be on how R&D intensity values have changed and change over time. This concept is defined in the dataset as the ratio of annual R&D spending to annual revenue.

Industry average R&D intensity: Coad (2019) uses this as a reference value, stating, *"Convergence is investigated with reference to the industry average R&D intensity."* (Coad, 2019, page 8). The average will be calculated for each industry and for each year to serve as a standard for comparing the behaviors of different intensities along a different level of R&D intensities.

Standard deviation from the mean: The standard deviation from the mean is a method for determining how data is distributed by evaluating how much each observed value deviates from the mean. This is frequently represented by a Normal distribution, in which values are symmetrically dispersed both over and under the average value and are centered around the mean.

Standard error: The standard error is the value that is used to measure convergence. The formula to get the standard error is the ratio between the standard deviation and the square root of the number of observations. The standard deviation of the mean is a measurement of how far sample means differ from the population mean.

The difference between the standard deviation and the standard error is the fact that the first is a descriptive statistics defining the degree of variability from the individual data values to the mean. While the standard error estimates how far the sample mean is likely to be from the population mean.

3.3.2 The Analysis

Datasets analyzing the 2500 businesses investing the most in R&D in the globe for each year since 2000 are available from the European Commission. Alex Coad used the same datasets in his study (2019), in which he examined the possibility of R&D intensity convergence between enterprises in the same industry.

Despite the large amount of data, samplings are not always consistent, and data from some years is no longer available. The fact that in some years were considered less than 1000 companies (for example in the 2005 dataset) made it difficult to compare variations between years for each sector.

As a result, the thesis' major analysis is based on the time period from 2013 to 2019, when the sampling size was consistent. Some may consider a 7-year period too short to obtain satisfying results but all the conclusions that are going to come out from this analysis will be compared with the Coad's ones, giving a continuity to his project.

In order to replicate and continue Coad's study, the analysis was based on the variable "R&D intensity", defined as the ratio between R&D expenditures and Sales during a time t.

The datasets classified the 2500 businesses into 38 industries. Some of them, though, only had a couple of enterprises in them. So, in order to have a consistent and meaningful analysis, only sectors with at least 30 enterprises in each year were considered.

To avoid considering problematic data, the next step was to select a range of R&D intensities. For example, it is usual in the pharmaceutical sector to have high R&D intensity levels just for the first year of business; this would create a problematic discontinuity that would have led in biases. The companies had a maximum level of R&D intensity equal to 30%.

The sectors presented in Table 3 were found to be suitable at the conclusion of these screenings:

Table 3 – List and brief description of the examined sectors

Aerospace	*Huge sector comprehending five markets, from military and space to commercial aviation;*
Automotive	*Industry comprehending a wide range of companies involved in all the step of producing and selling of motor vehicles;*
Chemicals	*Companies in this sector produce industrial chemicals by converting raw materials into a large variety of products;*
Construction	*An industry consisting of a wide range of companies involved in the mining, quarrying, and processing of raw materials used for both heavy and building construction;*
Electrical equipment	*A fragmented sector producing electrical components and products both for other companies and for public consumers;*
Food production	*A huge sector comprehending companies working from the production of general food, confectionery to beverages;*
General Industrials	*Sector including companies that manufacture and distribute capital goods to other industries;*
Health equipment	*Industry comprehending manufacturers of health care equipment and medical products;*
Industrial engineering	*Sector comprehending companies involved in long-rage planned activities, from robotics to the development of new systems in industries;*
Personal goods	*Industry regarding the production of products designed for the general public;*
Pharmaceutical	*Companies having as core business the discovering, development, production and selling of drugs or other medications;*
Software	*Includes businesses concerned with development, maintenance, and publication of software products;*
Hardware	*Industry focusing on the production of communications equipment, technology hardware, storage and peripherals and electronic equipment, instruments and components.*

Throughout the 7-year period, the total number of companies analyzed was always over 1,600. For each of the investigated years, Table 4 indicates the number of enterprises present in each sector. Each year, the number of firms changed, but in most of the cases the variations were small, posing no problem for the rest of the analysis.

Electrical equipment, industrial engineering, and, most significantly, the hardware sectors are the ones that experienced a higher loss of enterprises through the years. Among these three sectors, the fact that big businesses can buy out smaller competitors to obtain patents and know-hows could be a reason of the number of businesses changes. This, along with the database's construction, which only considers the 2500 businesses with higher R&D spending, might have been the main reasons for the decreasing number of firms.

The disappearance of a large number of businesses could also be a regular phenomenon influenced by market changes and firms' reclassifications.

The highlighted industries are the ones with more than 100 companies in each year. Having a bigger sample gives the opportunity to generalizable conclusions.

Table 4 - Number of firms by sector

SECTOR	2013	2014	2015	2016	2017	2018	2019
Aerospace	51	55	51	49	51	50	44
Automotive	143	150	146	161	151	146	146
Chemicals	136	130	119	122	128	129	129
Construction	72	71	65	67	66	61	65
Electrical equipment	239	226	215	237	237	226	222
Food producers	59	58	50	56	54	50	51
General industrials	91	95	75	92	90	81	75
Health equipment	86	96	81	85	83	80	86
Industrial engineering	208	198	181	198	190	187	187
Personal goods	47	46	48	51	46	46	44
Pharmaceutical	169	165	154	171	183	185	178
Software	243	238	213	228	225	243	238
Hardware	302	290	256	257	250	230	220
TOTAL	**1846**	**1818**	**1654**	**1774**	**1754**	**1714**	**1685**

The analysis begins by calculating the average R&D intensity value in each of the sectors studied for each year. As the hypothesis focuses on companies' converging behavior towards the industry average R&D intensity, this is the reference value.

Table 5 - Average R&D intensity by sector

SECTOR	2013	2014	2015	2016	2017	2018	2019	Trend	AVERAGE
Aerospace	5,27	5,29	5,07	4,92	4,65	4,45	4,61	Decreasing	4,89
Automotive	3,62	3,94	4,22	4,27	4,31	4,57	4,79	Increasing	4,24
Chemicals	3,38	3,50	3,61	3,52	3,48	3,47	3,62		3,51
Construction	1,90	1,70	1,94	1,96	1,85	2,09	2,24		1,95
Electrical equipment	7,03	6,57	7,28	7,34	6,99	7,49	7,60		7,18
Food producers	2,04	1,98	1,27	2,25	2,62	2,98	2,89	Increasing	2,29
General industrials	3,01	3,23	3,19	3,40	3,42	3,37	3,74	Increasing	3,33
Health equipment	9,13	8,09	7,89	8,47	8,62	8,73	9,13		8,57
Industrial engineering	3,53	3,70	3,71	4,15	3,88	3,81	3,83		3,80
Personal goods	2,90	2,65	2,73	2,73	2,89	3,17	3,23		2,90
Pharmaceutical	11,55	11,01	11,03	11,06	11,73	11,89	11,66		11,41
Software	14,54	15,21	14,93	14,79	14,88	15,35	15,48	Increasing	15,56
Hardware	12,14	11,76	11,50	11,63	11,45	11,03	11,44	Decreasing	11,56

The standard deviation could then be calculated, yielding standard errors for each year in each industry. The standard errors would represent the deviations from the average means.

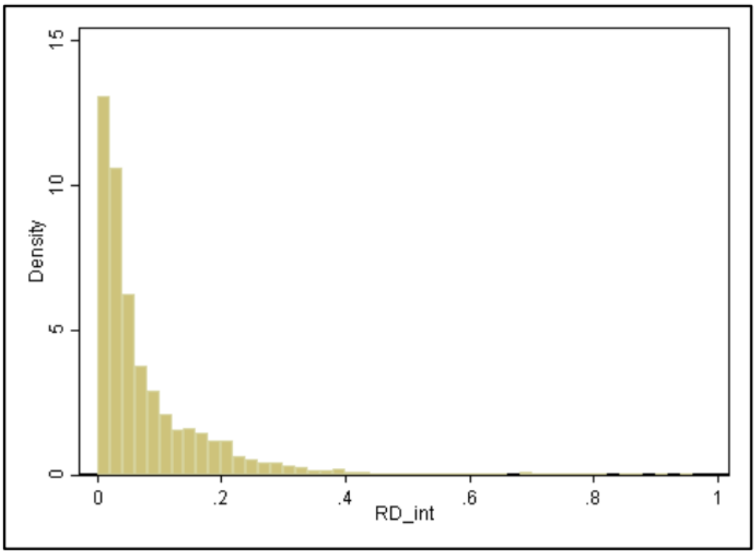
The standard error trend study was compared to Coad's sigma convergence study, which sought to reduce the variance of firms' R&D intensities by comparing the variance from the individual standard error from the mean in the initial period with the one in the final period.

A decrease in the absolute value of standard error from the mean indicates convergence, whereas an increase in the value indicates heterogeneity and divergence.

3.3.3 Descriptive Analysis

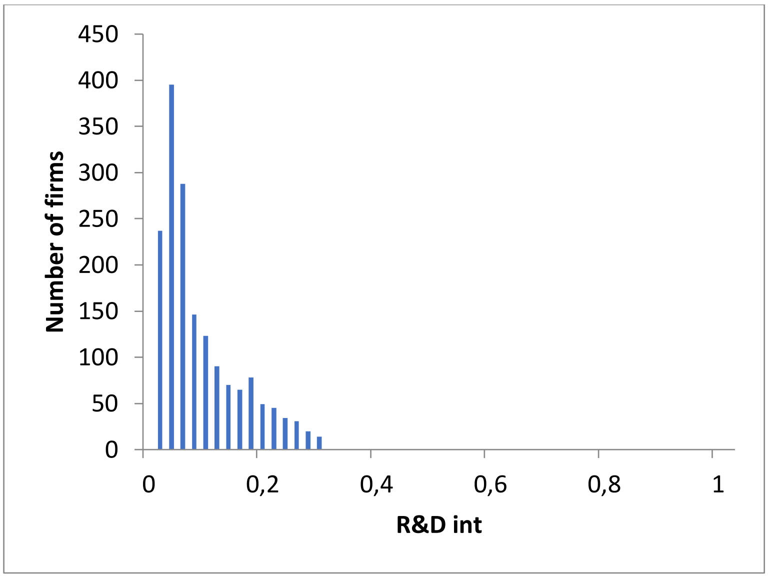
The investigation began by comparing older data with that available in the new scoreboards in order to replicate and update Coad's analysis.

Figure 15 - Distribution of R&D intensity across firms (2015)



Note: Coad's results: histogram of the distribution of R&D intensities of firms in 2015

Figure 16 - Distribution of R&D intensity across firms (2019)



Note: Histogram of the distribution of R&D intensities of firms in 2019

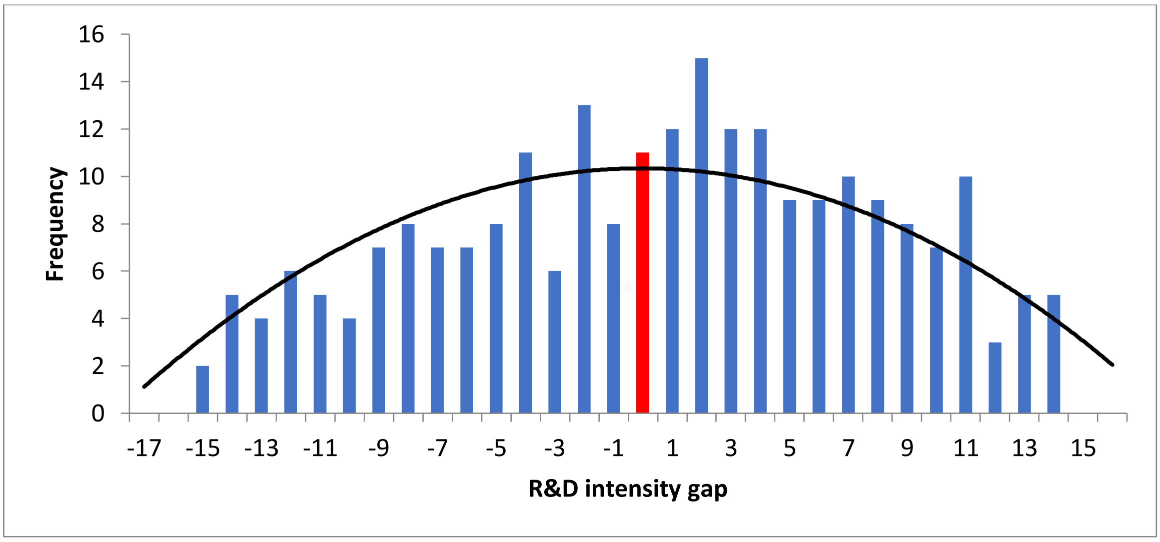
Figures 15 and 16 show that R&D investment amounts are evenly dispersed throughout a broad spectrum

Figure 15 shows the results obtained by Coad, whereas Figure 16 is done using the most recent EIS data. As it is possible to notice, the distribution of R&D intensities remains skewed and heterogeneous. In four years, it is not possible to notice significant changes.

From this comparison it is possible to conclude that R&D intensities are distributed across a wide support and firms do not concentrate around any particular 'optimal' amount of R&D investment. Despite having a great number of companies with R&D intensities close to the sample mean (around 8%) there is considerable heterogeneity. As Coad said, this result can perhaps be explained by firms having heterogeneous innovation capabilities.

Figure 17 shows the Software sector's R&D intensity gap in 2019, the last available year. This first analysis was based on the software sector because it is one with the highest number of firms and with the highest average R&D intensity through the 7-years period.

Figure 17 - R&D intensity gap distribution in the software sector in 2019



Note: The red histogram represents the frequency of R&D intensity gap=0

The R&D intensity gap was calculated by subtracting the individual value for each company from the sector's average R&D intensity in 2019.

The histogram shows that there is lots of heterogeneity in R&D intensities, even between firms in the same industry, the same results found by Coad. While it is possible to notice a normal distribution, with a peak where the firms' R&D intensity is close to the industry average (R&D intensity gap close to 0), the wide distribution of values-suggests that there is lots of heterogeneity in R&D intensities within the software industry.

Given the interesting result the same study was done on the other industries with at least 100 companies in them, the ones that could grant a more robust analysis.

As it is possible to observe, not every industry has a normal distribution. In some cases, like in the automotive, chemicals, industrial engineering, and electrical equipment sectors, the peak of the distribution is not on the zero value, showing that companies in these sectors do not tend towards an R&D intensity equal to the average R&D intensity of the industry. Instead, it is possible to observe that some values tend to be very far from zero, highlighting a strong variation.

Other sectors, such as the hardware and pharmaceutical, show a distribution similar to a normal, but even in these cases it is not possible to consider the average R&D intensity as an 'optimal' goal. Especially in the pharmaceutical, very few companies have an R&D intensity gap equal to zero, and a lot of heterogeneity is found.

Figure 18 - R&D intensity gap distribution in the automotive sector in 2019

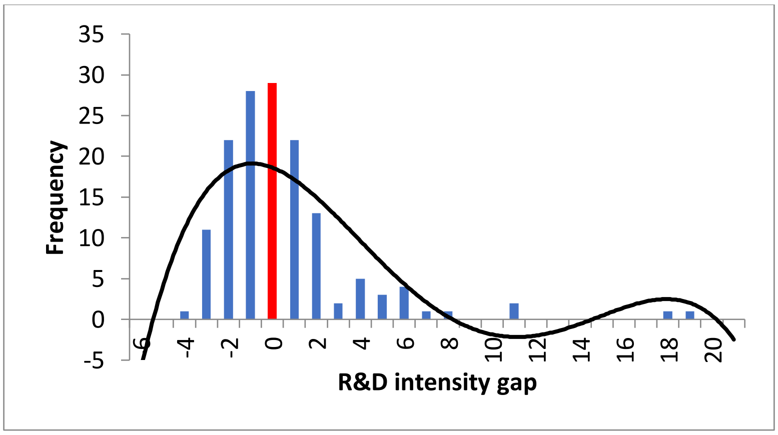


Figure 19 - R&D intensity gap distribution in the hardware sector in 2019

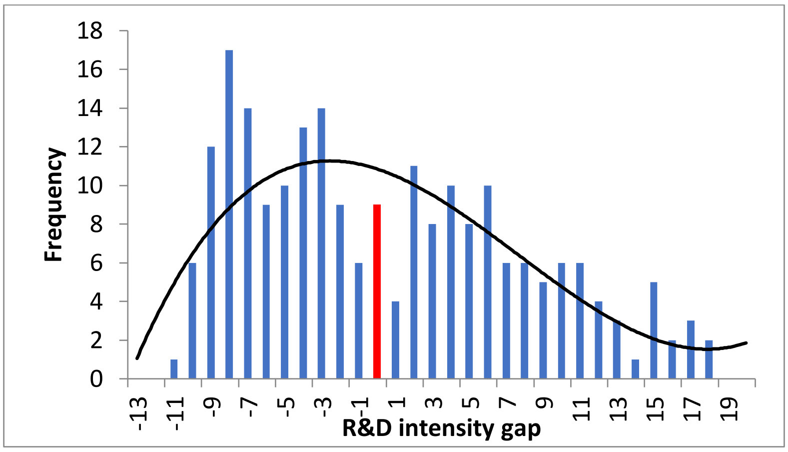


Figure 20 - R&D intensity gap distribution in the chemicals sector in 2019

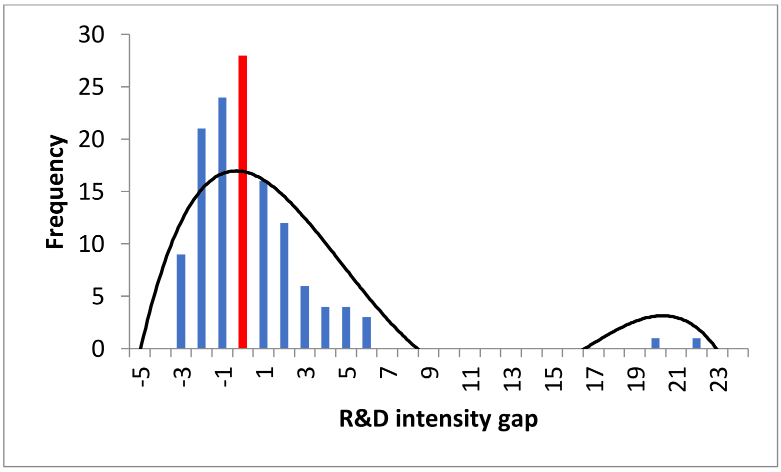


Figure 21 - R&D intensity gap distribution in the industrial engineering sector in 2019

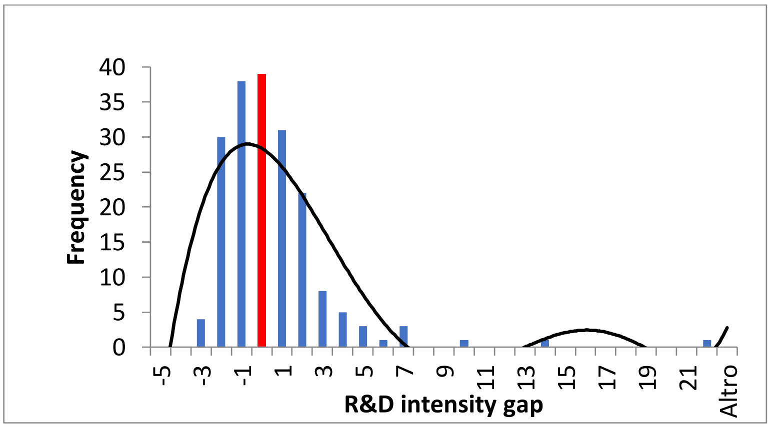


Figure 22 - R&D intensity gap distribution in the pharmaceutical sector in 2019

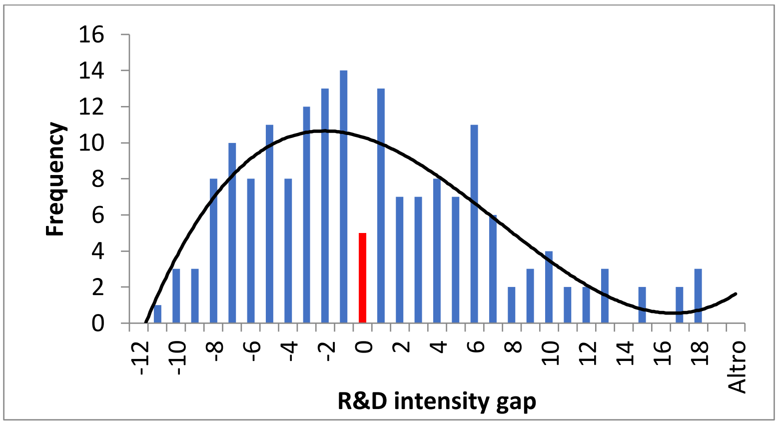
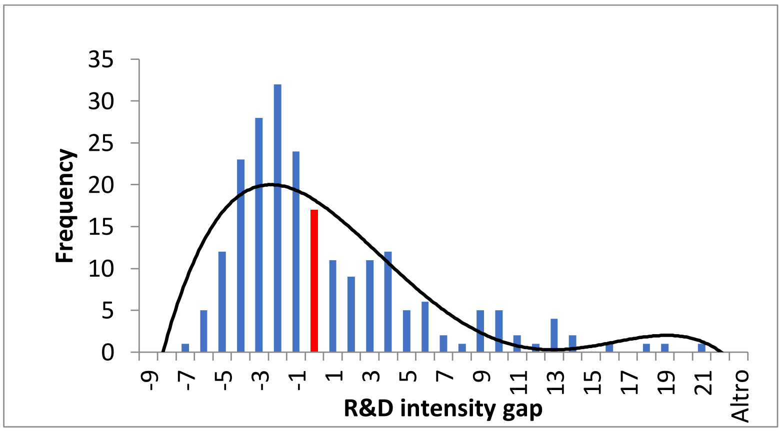


Figure 23 - R&D intensity gap distribution in the electrical equipment sector in 2019



3.3.4 <u>Preliminary Study: Line Plots of R&D Intensity of Leading Firms in the Same Sector</u>

This section examines three distinct industries to see if the leading firms in each of them have converged on a common R&D intensity throughout the years. This research is a continuation of Coad's descriptive analysis. Coad examined four different industries: Pharmaceuticals, Software, Industrial engineering, and

Hardware. Due to the lack of new data that could have been utilized to improve Coad's results, the Hardware industry was excluded.

The "leading firms" chosen are the same ones that Coad selected. Those are the ones with the highest total sales in 2015. The investigation focuses on determining whether or not there are interactions and interdependencies amongst the leading firms.

Obviously, the results obtained in this first descriptive study might be different from the outcome of the whole industries' analysis. In fact, as it will be shown, while the leading firms in the pharmaceutical sector increase their divergence the whole industry experienced a converging trend (see Section 3.3.5).

There is no evident convergence to a common R&D intensity when looking at the trend in the following figures. There is still a lot of heterogeneity that hasn't gone away since 2015. This casts doubt on the possibility of a shared value convergence.

The Industrial engineering sector (Figure 24) is showing a long-lasting divergent trend, with companies catching up to one another but still maintaining a differentiated trend.

In the Software industry (Figure 25), the opposite is true. Many of the selected companies have seen a decline in R&D intensity since 2015, and in 2019 some of them have converged on a common level, a finding that was not observed in the whole industry' analysis.

Although there is some convergence in the Pharmaceutical sector (Figure 26) the fact that some corporations, such as Astrazeneca, have increased their R&D intensity in recent years while others have maintained their levels highlights the existence of diverging behavior. The R&D intensity of AstraZeneca remains about double the R&D intensity of Bayer during the entire studied period.

However, this is an interesting sector in which big shifts in R&D activity are more usual than in other industries.

Figure 24 - Top 8 companies in industrial engineering

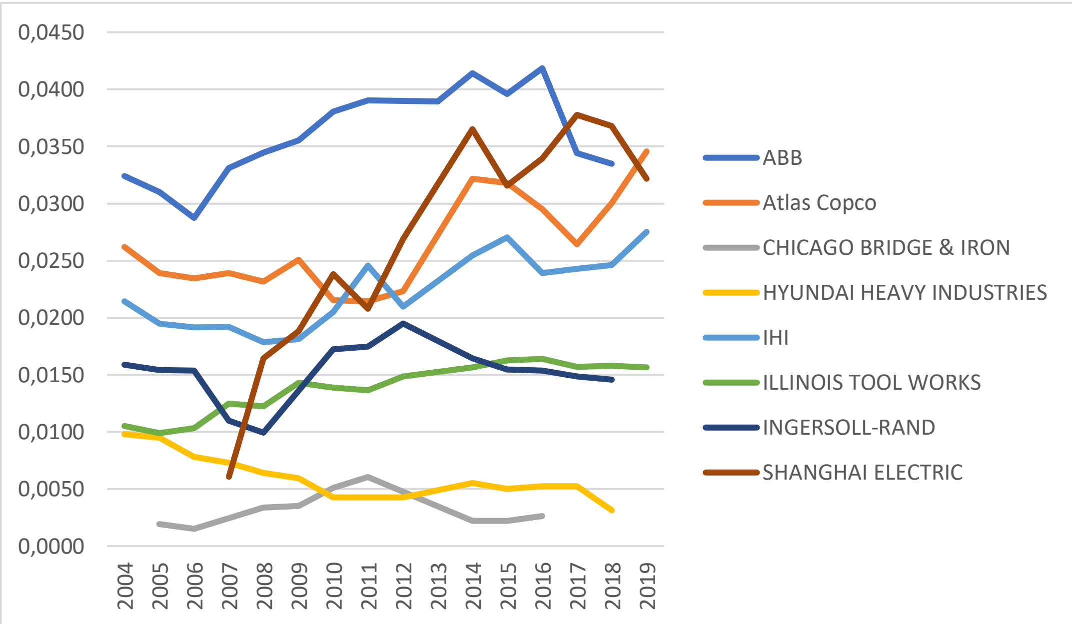


Figure 25 - Top 8 companies in software

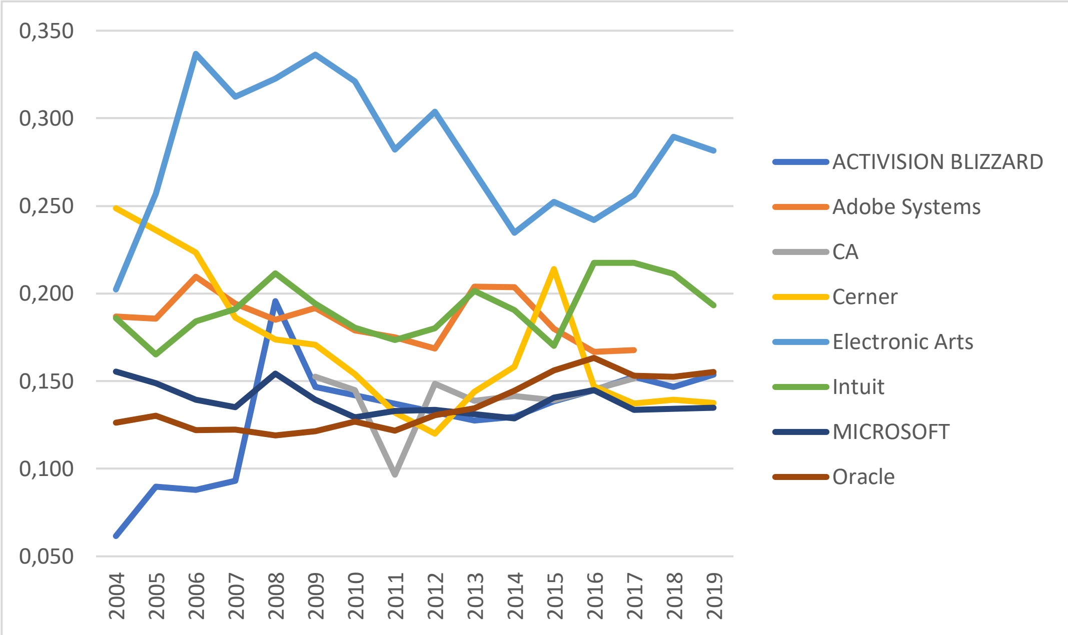
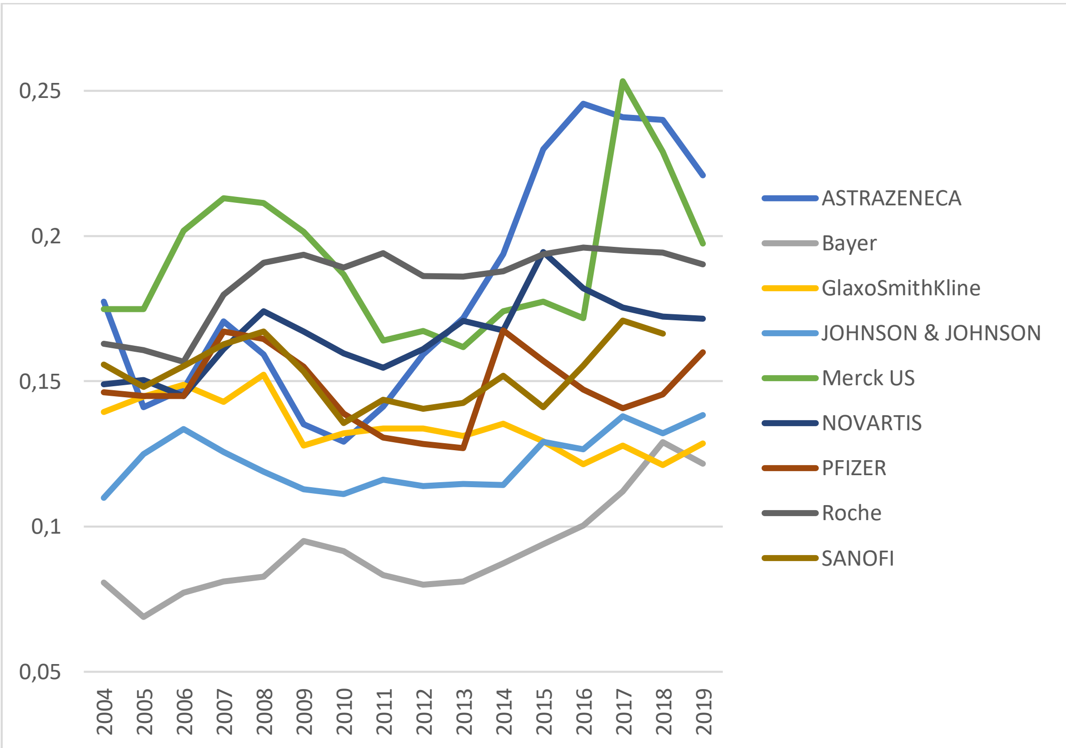


Figure 26 - Top 9 companies in Pharmaceutical



3.3.5 Analysis of sigma-convergence within the whole sectors

While the previous evidence allowed for some preliminary considerations, a more in-depth analysis was conducted to confirm the presence of divergence and heterogeneity.

The research was carried out by looking at the evolution of standard errors in each sector. This would be equivalent to Coad's core sigma-convergence test. A decrease in standard errors would reflect a general decrease in each firm's divergence from the mean, leading in convergence.

According on the observable results in Table 6, no significant reductions in standard errors emerge. This means that the companies in these industries do not have convergent behavior.

Table 6 - Standard errors by sector and differences between 2019 and 2013

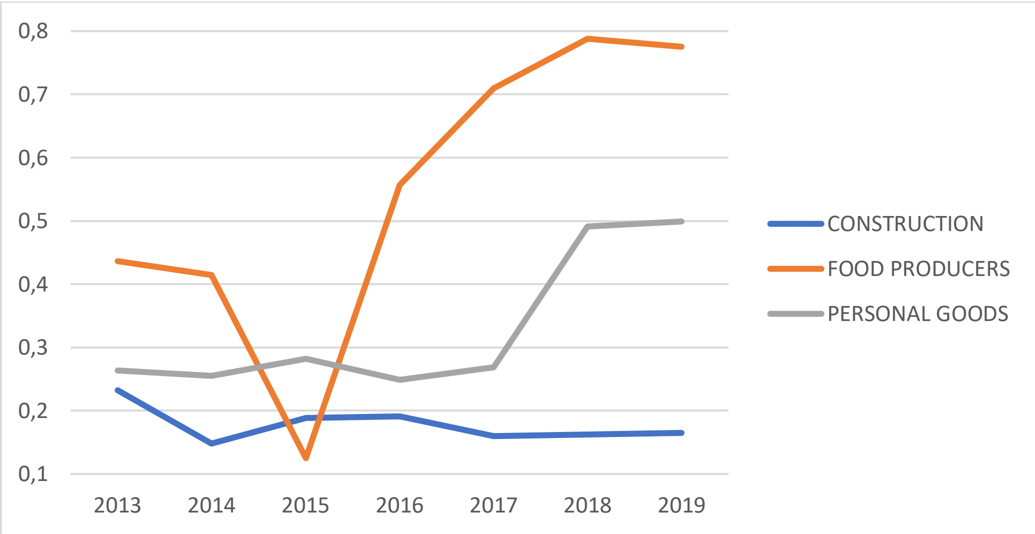
Sector	2013	2014	2015	2016	2017	2018	2019	Change 2019-2013
Aerospace	0,446	0,463	0,438	0,416	0,426	0,412	0,453	0,007
Automotive	0,178	0,221	0,312	0,230	0,258	0,274	0,279	**0,101**
Chemicals	0,247	0,246	0,246	0,223	0,272	0,298	0,290	**0,042**
Construction	0,232	0,148	0,188	0,190	0,160	0,162	0,164	-0,067
Electrical equipment	0,369	0,321	0,377	0,361	0,326	0,360	0,346	-0,023
Food producers	0,436	0,414	0,124	0,557	0,709	0,787	0,775	**0,339**
General industrials	0,358	0,354	0,364	0,293	0,314	0,264	0,293	-0,065
Health equipment	0,597	0,462	0,495	0,582	0,582	0,585	0,597	0
Industrial engineering	0,191	0,221	0,214	0,254	0,223	0,212	0,205	0,014
Personal goods	0,263	0,254	0,282	0,248	0,268	0,491	0,499	**0,236**
Pharmaceutical	0,549	0,507	0,540	0,486	0,504	0,483	0,485	**-0,063**
Software	0,467	0,487	0,515	0,472	0,479	0,482	0,475	0,008
Hardware	0,437	0,423	0,443	0,449	0,466	0,472	0,497	**0,060**

Note: The industries are highlighted in: Yellow: considerable increase in divergence. Red: unexpected behaviour from low R&D sectors. Green: noticeable converging behaviour.

However, there are a few interesting things worth investigating more. Based on the levels of their average R&D intensities in 2019, the industries were divided into four groups. The ‘General industrials’ industry was excluded from this analysis because the enterprises in this sector are too varied to produce statistically significant results.

The first group is shown in Figure 27. The industries considered are construction, food producers, and personal products, all of which have an average R&D intensity of less than 3%. Despite having low R&D, the data shows a significant growth in standard errors in the food producers and personal products sectors, while the construction sector has maintained a low level of standard error over time, with some convergence. This result was expected to be the same for alle three industries. Companies in these sectors were expected to be focusing on marketing competition rather than R&D competition, with little to no increase in R&D intensities.

Figure 27 - Standard errors trend in industries with low average R&D intensity (R_{int}<3%)



However, the “Food producers” and “Personal goods” industries greatly increased their divergence. This outcome was unexpected and necessitated further investigation. An increase in divergence in low R&D intensity sectors would most likely indicate the presence of companies with increasing R&D intensities or new firms entering the market with high R&D intensities. The research proved that it was a combination of the two possibilities.

Four companies are mostly responsible for the increase in divergence in the "Food producers" industry, KWS (German); Sakata seed (Japanese); Vilmorin (French); Aviagen (English). Companies that focus on bio engineering on agricultural products to produce long-lasting and better vegetables and fruits, as well as avian breeding to give rise to better chickens. These are examples of businesses with high R&D intensity that generate deviation. These firms entered or returned in the EIS database in 2016, with R&D intensities ranging from 8% to 26%, resulting in an increase in standard errors.

It is important to note that the average growth of R&D intensities in the “Personal goods” sector declined from 2016-2017 to 2017-2018. However, as new companies entered the dataset with a high level of R&D intensity, the standard deviation increased, resulting in increasing divergence, the new companies with the highest R&D intensities are: Farfetch (English-Portuguese), Huami (Chinese), Kingnet (Chinese).

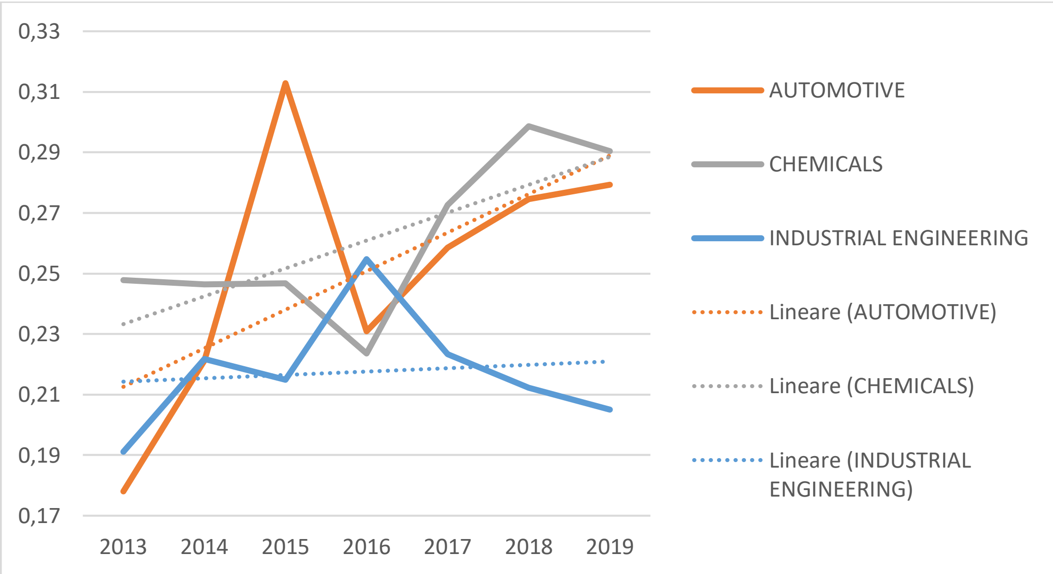
New companies include those that make high-tech wearables (smartwatches), those who work in high-fashion e-commerce, which necessitates better web services, and those that build network games and computers.

The second group, as shown in Figure 28, includes companies with a low-medium average R&D intensity ($3\% < R_{int} < 4.5\%$). The sectors analyzed are those with a large number of companies in the sample. Standard error is increasing in the automotive, chemicals, and industrial engineering industries, with the automotive and chemicals industries experiencing a faster growth. This result indicates that divergence processes are taking place in these industries.

By analyzing the automotive sector, it appears that the increase in the standard error seems to be correlated with the growing interest in electric cars and interconnected car components. Such technology shifts resulted in a more competitive market where car manufacturers and other linked companies struggles to improve their position.

According to the data, the R&D investments increased during the 7 years among the automotive companies. Yet, the increasing R&D intensities led to higher intensity gaps, resulting in an increasing divergence from the mean.

Figure 28 - Standard errors trend in industries with low-medium average R&D intensity (3%<R_{int}> 4.5%)

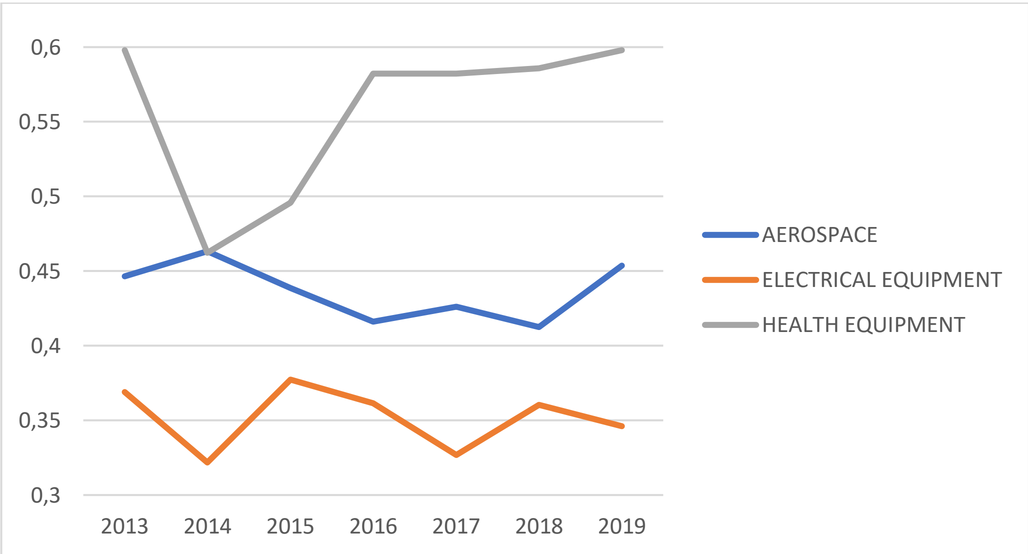


The third group, shown in Figure 29, considers the industries in which a medium-high average R&D intensity (4.5%<R_{int}<9%). The three sectors are Aerospace, Electrical equipment, and Health equipment. Despite being a medium-high R&D intensity group, all these industries show little R&D intensity's competition. There is no real sign of divergence but neither of convergence.

The electrical equipment industry showed some converging trend. This was not unexpected, knowing how companies are affected in their expenditures by the market situation.

The sole notable exception occurred in the health equipment sector in 2014, when the standard error dropped but quickly reverted to its prior level. All activities relating to people's health, as will be explained for the pharmaceutical business, might suffer unexpected shifts in R&D spending to meet individuals' requirements.

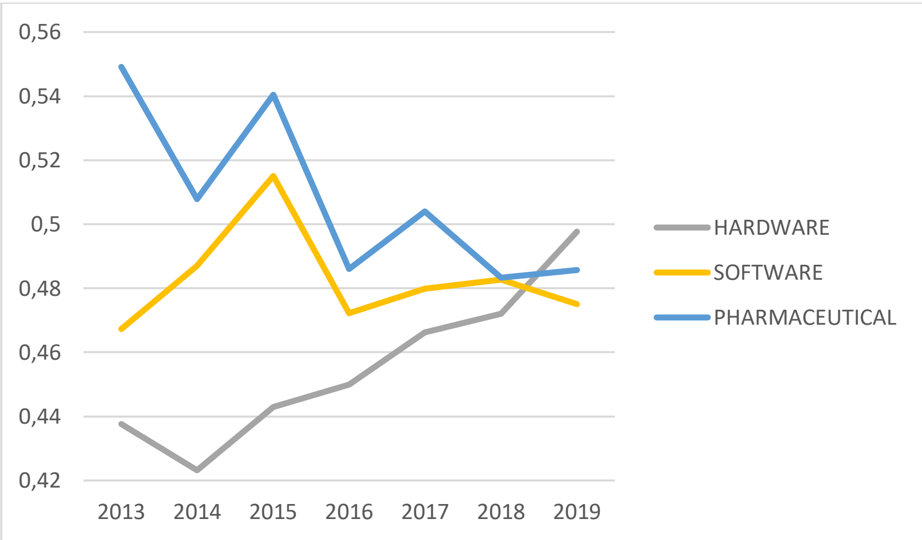
Figure 29 - Standard errors trend in industries with medium-high average R&D intensity (4.5%<Rint>9%)



Finally, the fourth group consists of industries with a high average R&D intensity (R_{int}>9%), figure 30. The three industries studied are hardware, software, and pharmaceuticals.

It is natural to find high levels of standard errors in the pharmaceutical sector because it is the most R&D intensive. However, it is important to analyze the pharmaceutical sector's behavior. Unlike the software industry, which has seen a nearly constant trend and the hardware sector, which has experienced an increase in divergence, the pharmaceutical industry has been through what looks to be real convergence.

Figure 30 - Standard errors trend in industries with high average R&D intensity (Rint>9%)



When comparing the results to the descriptive analysis, which revealed a divergence in the top 10 companies in each sector (see Section 3.3.4), it seems that the convergence should mainly be caused by an increase in R&D intensity by companies that had lower R&D intensity. When comparing data from 2013 to 2019, it appears that companies with low R&D intensity increased their expenditures closing the gap with the average R&D intensity. At the same time, companies with high R&D intensity in 2013 decreased their investments closing the gap with the average R&D and explaining the converging trend. Moreover, companies that are boosting their R&D intensity outnumber those that are decreasing it.

However, it is important to state that the Pharmaceutical market is unique. Companies in this industry may decide to invest differently each year depending on the need for new drugs (see the nowadays example of vaccines) making it hard to have smooth data over short periods. Hence, its convergence must be taken with caution, depending upon the years under consideration.

CONCLUSIONS

The aim of this thesis was to stress the importance of Research and Development investments, by focusing on the R&D intensity concept, both in country and industry analysis and, most of all, in business studies.

Although the globalization process should provide every economy with similar opportunities, the second Chapter has highlighted quite different R&D performance across countries, which could be explained by a variety of reasons, such as a strong presence of large companies and high-tech industries, and a high level of human capital.

Then, the study started to focus on the main subject, the R&D investment among companies. The introduction of industries and their R&D expenditures was essential for the analysis at company level. Three business sectors were cited multiple times: ICT, Pharmaceutical, and Automotive. Among these three, the ICT sector is without doubt the most important when considering R&D. All the other sectors that were then considered had something to do with ICT. Software and Hardware have entered every field and digital technologies are in the everyday life of individuals and businesses.

By replicating and expanding Coad's study, which stressed the persistence of firms' heterogeneity in terms of R&D intensity, it was possible to observe that even in the period 2013-2019 it is still not possible to observe convergence. There is considerable heterogeneity in R&D intensities, even among firms in the same sector. These gaps do not disappear over time.

According to the analysis, among the 13 examined sectors, 9 experienced an increase in the standard errors of R&D intensities (with respect to the sectoral means) during the 7 years considered. The only converging trends have been observed in the construction, electrical equipment, and pharmaceutical industries.

The first one is a low R&D intensity sector; thus, large R&D intensity variations are not common, and a converging behaviour might have been expected. Companies in this sector do not require constant innovation to be competitive and convergence could be the natural consequence.

The electrical equipment industry is a medium-high R&D intensive sector. A converging behaviour may not have been expected. However, this is a fragmented industry producing both electrical components and finished products especially for other firms as well as consumers. Hence, a converging trend might reflect a change in the demand of electrical equipment, leaving less margin for R&D investments.

The last converging industry is the pharmaceutical one. This sector is one of the most unpredictable when considering R&D intensities. New companies tend to have a high R&D intensity, having to spend a lot in R&D in comparison to their sales. At the same time, existing companies can deeply change their R&D expenditures in short periods, depending on the demand for new drugs, making it an unstable industry. However, it would be interesting to keep observing the sector to make deeper analysis on longer periods.

As already mentioned, Coad's analysis found no evidence of σ-convergence and the work done in this thesis largely supports the same conclusion. R&D intensity fluctuations are common in each business, from the least to the most R&D intensive. The fact that, in a couple of decades, many Chinese firms entered the scoreboard is another indicator of the fact that not having convergence does not necessarily imply the formation of oligopolistic R&D environment within industries. As explained in the first chapter, innovation does not always lead to successful outcomes and R&D expenditures are only one part (even if one of the most important) of the many elements affecting innovative processes.

With the right innovative culture every firm would have the opportunity to gain edges on competitors. However, as it was found, there is no optimal level of R&D intensity to seek, and every company is left to decide its own level of R&D investment.

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