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Understanding the Drivers of Regional Economic growth: An exploration of R&D, Human Capital, and Technological Advancement.

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Index

Abstract

Comprendere i fattori che guidano la crescita è più importante che mai in un'era in cui la performance economica è costantemente monitorata e analizzata. La mia tesi di laurea è divisa in due sezioni principali ed esamina le complesse relazioni tra le varie variabili economiche e il loro impatto sulla crescita: una revisione della letteratura accademica sulle variabili di interesse e un'analisi empirica con metodi di correlazione e regressione per convalidare i dati storici. Il tema principale è l'interazione del prodotto interno lordo (PIL) con la ricerca e sviluppo (R&S), l'istruzione terziaria, le TIC, con un piccolo focus anche sulle disparità regionali in Europa. L'obiettivo è fornire una comprensione completa di come queste variabili influenzano la crescita economica. Inoltre, utilizzando metodi rigorosi e empirici, l'obiettivo è di supportare le affermazioni storiche. L'obiettivo della tesi è colmare la discrepanza tra i dati della realtà e le prospettive teoriche al fine di chiarire le disparità economiche presenti. Le intuizioni che vengono fornite sono sia accademicamente rigorose che pratiche, fornendo informazioni utili a coloro che esercitano influenza sulla politica che mira a promuovere lo sviluppo economico. Il progetto di politiche economiche efficaci richiede una comprensione dei determinanti del PIL pro capite, e questa tesi, attraverso un'analisi approfondita e test empirici, contribuisce a tale comprensione. In conclusione, la tesi mira a rapresentare un esempio di ricerca accademica che combina teoria ed empiria per affrontare questioni economiche rilevanti e attuali.

Introduction

In an era where economic performance is closely monitored and analyzed, understanding the factors that drive growth is more important than ever. My degree thesis delves into this area by examining the complex relationships between the various economic variables and their impact on growth. This study is meticulously divided into two primary sections: the first part reviews the extensive academic literature regarding the variables of interest, while the second part focuses on empirical analyzes aimed at validating historical data through correlation and regression methods. The central theme of this thesis revolves around the gross domestic product (GDP) and its interaction with research and development (R&D), tertiary education, information and communication technology (ICT), and an exploration of regional disparities within Europe. Specifically, my empirical results concentrate on GDP per capita to provide a nuanced understanding of economic performance across regions. The purpose of the study is to provide a comprehensive understanding of how these variables influence economic growth and to validate historical claims through rigorous empirical methods. By examining differences in regional GDP and economic performance, the thesis aims to shed light on existing economic disparities and the factors contributing to these differences. This study is scientifically significant as it bridges the gap between theoretical frameworks and real-world data, offering insights that are both academically rigorous and practical. By validating literature sources with empirical data, the thesis not only contributes to academic knowledge but also provides valuable information for policymakers aiming to promote economic development. Understanding the determinants of GDP per capita is fundamental to designing effective economic policies, and this thesis aims to contribute to this understanding through detailed analysis and empirical testing.

CHAPTER 1

1. GDP

GDP, the abbreviation of Gross Domestic Product, is a basic measure of the overall size of a country's economy[1], according to Eurostat, the Statistical Office of the European Union. Its predecessor, gross national product (GNP), was initially developed in the 1930s to help America get out of Great Depression by Simon Kuznets. At the time, government lacked comprehensive data on the state of the economy, making it difficult to know wheter policy responses were working or not. Furthermore, the Marshall Plan or the European Recovery Program is also mentioned as one of the factors that facilitates the development and widespread use of GNP (Coyle, 2014; Bos, 2008). This plan was intended for post war reconstruction in Europe. Nevertheless, GDP was not totally accepted. Soviet Union used a different measure of economic progress: the net material product, which included physical goods but excluded services. When the Soviet Union collapsed in 1991, gross "national" product was replaced by gross "domestic" product, basically the GDP we're talking about. An important difference between these two indicators is that GNP attributes the earnings of a multinational company to the country where the company is owned and where its profits are ultimately received. GDP is also used to compare and rank countries around the world (Fioramonti, 2013). With GDP, profits are attributed to the country where the factory is located and resource extraction occurs, even if the profits leave the country. So, unlike the GDP, GNP does not separate where the output is produced. This indicator is extensively employed by analysts, politicians, journalists, businesspeople and societies at large as a universal measure to assess economic performance and well-being, as well as to appraise the efficacy or shortcomings of governmental economic

[1] GDP Definition by Eurostat: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Gross_domestic_product_(GDP)

strategies, and even the societal advancement and progression of a nation (European Commission et al., 2009; Costanza et al., 2009). GDP serves as a fundamental metric for assessing the size and health of a nation's economy and it encompasses the total value of goods and services produced within a country's borders over a specific period, typically annually or quarterly. It's the total gross value added of all resident institutional units involved in production, plus any product taxes and minus any product subsidies: it is used as an overall measure of production. But not all productive activity is included in GDP. For example, unpaid work (such as that performed at home or by volunteers) and black-market activities are not included because they are difficult to measure and value accurately. Furthermore, GDP fails to incorporate the depreciation of capital assets used in production, such as machinery and infrastructure[2]. When depreciation is deducted from GDP, the resulting figure is termed Net Domestic Product (NDP). Additionally, GDP is equal to the total of primary earnings distributed by resident producer units, as well as the sum of the final uses of products and services (all uses except intermediate consumption, to avoid double counting), measured in purchasers' prices, less the value of imports of goods and services. Therefore, it can be an be defined as 'market value' of the finished goods and provisions that are produced or manufactured locally or nationally in any country within a specific period. GDP informations are gathered from different sources, such as surveys to business, export and import information gathered from customs documents and extrapolations (Landerfeld, Seskin & Fraumeni, 2008).

[2] Measuring GDP: https://www.imf.org/en/Publications/fandd/issues/Series/Back-to-Basics/gross-domestic-product-GDP

1.1 GDP Literature

On the 7th of December 1999 the U.S. Commerce Department declared GDP "one of the greatest inventions of the 20th century." Taking a step back, in order of time, Johan Norberg, a Swedish author and historian, was also in favor of using GDP as a state's economic goal, stating that increasing wealth (through increasing GDP) will enable people to do the things they want, such as reducing the working hours and investing more. Basically, he stated that GDP growth correlates with happiness. He was overall very skeptical towards the alternatives of the GDP. He argued that the use of different index instead of GDP would not bring any new knowledge to us, but rather reduce it, as we would become less aware of currently available economic measurements like unemployment rates. He stated that GDP does not guide people in what they do, but rather tells them what they can do. In addition to this, since the 1970s, numerous alternatives and or complement indicators have been proposed and developed. However, none of these indicators can match the mainstream use of GDP. It is said that these alternative indicators are not yet a perfect indicator to measure the welfare[3]. Other famous economists such as Richard Stone, first recognized GDP as a crucial measure of economic activity but, once understood its limitations in capturing the intricate interdependencies within an economy, he believed that traditional methods of GDP estimation often oversimplified economic dynamics, overlooking the complex relationships between sectors. Stone utilized input-output tables to provide a comprehensive understanding of economic activity ("The Input-Output Relation in Production and Distribution", 1951). He emphasized the significance of incorporating complex sectoral interactions into GDP estimation, such as supply chain effects, vulnerability to external shocks and the multiplier effects, recognizing their potential

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[3] Johan Norberg's thoughts about GDP
https://www.theseus.fi/bitstream/handle/10024/38524/Topi%20Tjukanov%20-%20Gross%20Domestic%20Product%20as%20a%20ModernDay%20Economic%20Indicator.pdf?sequence=1

to influence overall economic output[4]. Weitzman (1976) demonstrated that in a scenario where all transactions occur in competitive markets and where economic welfare is solely reliant on the consumption of goods traded in markets, alterations in net domestic product (NDP, which is GDP adjusted for depreciation) serve as a reliable indicator of changes in economic welfare. This assertion stands because one can perceive an individual's or a nation's 'wealth' as the current discounted value of consumption. In "Insidie delle cifre" (Il Mulino, 8 February 1993), Giorgio Fuà initially demonstrated his pragmatism and common sense by cautioning against expanding the concept of national income to encompass various other factors. He expressed that while every endeavor to scrutinize non-commodified activities and satisfactions is commendable, he believed it preferable for these analyses not to be incorporated within the framework of national economic accounts. According to him, as long as the economic accounts confine themselves to presenting the flows of goods valued at actual prices, they can maintain a significant degree of completeness, coherence, and usefulness as a market map[5]. Paul A. Samuelson ("Economics: An Introductory Analysis" - 1998), who discussed GDP as a crucial measure of economic activity and national income. He emphasized several key points regarding GDP. Specifically, he emphasized the importance of GDP as a primary indicator of an economy's overall size and performance. Samuelson broke down GDP into its main components, including consumption, investment, government spending, and net exports and he discussed how changes in these components can impact overall GDP growth and provide insights into the drivers of economic activity.

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[4] Richard Stone Input-Output Explaination https://fastercapital.com/content/Gauging-Economic-Growth--Richard-Stone-s-Impact-on-GDP-Estimation.html

[5] Price Deflator tool https://www.investopedia.com/terms/g/gdppricedeflator.asp

CHAPTER 2

2. R&D's Vital Role in Economic Growth: Empirical Insights and Perspectives

Factors affecting economic growth are emphasized in many studies. Documenting myself among the vast literature, the importance of R&D as a crucial factor affecting the economic growth is often underlined. It is the most crucial element because it creates knowledge, goods, abilities, and technologies. It encourages innovation and inventions, enhances productivity, creates methods that improve the efficiency of the production processes, and it leads to higher value addition and growth in the overall economy. Previous studies have focused on the effect of R&D expenditure on the economic growth of the nations, and the outcomes of these are varied. The data set used for these studies included a very small set of countries, such as OECD[6] countries, developing or developed countries, etc. In most of the studies, the results obtained have shown a positive relationship between the R&D expenditure and economic growth. R&D not only stimulates innovation but also plays a crucial role in the adoption of new technologies. The most important aspect of the new development process is technological advancement[7]. The fact that income increased more than ten folds in USA and some European countries in the 20th Century is beyond doubt the result of technological progress. The more economy has these inputs and ensures the development of new products and technologies by means of conveying these resources to the R&D sector successfully, the more the rate of the economic growth will be higher (Romer 1990, Grossman and Helpman 1991, Aghion and Howitt 1992, Ateş 1998). With the adoption of the fact that technological change is one of the most important factors

[6] OECD - Organization for Economic Cooperation and Development: https://www.oecd.org/about/

[7] Studies about the relationship between R&D and GDP: https://www.avekon.org/papers/1776.pdf

which will affect economic growth, numerous theoretical and empirical studies analyzing the effects of R&D, which is an indispensable component of technological change on economic growth have taken place in the literature. Goel and Ram (1994), in their study covering 52 countries for the period 1960-1980, found that there is a significant relationship between R&D expenditures and economic growth in the long term; however, the direction of causality between the variables could not be determined[8]. Freire - Seren (1999) found out that the estimated coefficient corresponding to the R&D regressor reveals a strong positive relationship between the growth of total R&D expenditure and the growth of the GDP, detecting a 1 % increase in total R&D expenditures increases real gross domestic product (GDP) at a rate of 0.08 %[9]. Blackburn, Huang, and Pozzolo (2000) provided evidence in favor of this theory, stating that R&D produces innovations and ideas that enhance production quality and keep current technologies up to date. According to the model they created, an increase in an individual's knowledge and skill set results in economic growth. The accumulation of human capital stimulates innovation and research while also quickening economic growth. Additionally, it raises the manufacturing standard. Slywester (2001) did not find any association between R&D expenditures and economic growth for a set of 20 OECD countries. However, he found a positive association between industry R&D and economic growth for the G-7 countries. He stated that one possibility for this disparity is that R&D is more important in explaining growth for those countries at the technological frontier. Another possibility for the lack of stronger findings regarding R&D and economic growth is due to the growth of the service sector which now accounts for over half of economic output in these countries[10]. Asian economists such as Yanyun and Mingqian (2004) have used Partial Least Square (PLS) regression model by using the data pertaining to some Asian countries and found that there is

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[8] Goel and Ram R&D studies: https://www.journals.uchicago.edu/doi/abs/10.1086/452087
[9] Freire – Seren analysis about relationship between R&D Expenditure and economic growth: https://digital.csic.es/bitstream/10261/1959/1/43699.pdf
[10] Slywester R&D and Economic Growth relationship: https://link.springer.com/article/10.1007/bf02693991

an interactive relationship between R&D expenditure and economic growth. They illustrated that R&D expenditures mainly depends on the level of their development[11]. In a similar manner, Falk (2007) analyzed the long-term relationship between R&D investments and economic growth for the period 1970-2004 and put emphases on that as the share of R&D investments in GDP becomes larger, GDP per capita also increases. In particular, using a system GMM estimator in order to control for endogeneity, he found that both the ratio of business enterprises' R&D expenditures to GDP and the share of R&D investment in the high-tech sector have strong positive effects on GDP per capita and GDP per hour worked in the long term[12]. A special mention to a professor from my own UNIVPM university, Sterlacchini (2008), who conducted a study to find out the association of regional disparities in R&D and higher education with regional economic growth. He collected data between 1995 and 2002 from 197 regions across 12 European countries. The empirical data confirmed that knowledge, educational attainment, and the level of R&D spending have a positive and considerable impact on the economic growth of European regions. But R&D spending was only found to be significant in the EU's most developed regions. Therefore, public funding for R&D and higher education can be a useful tool to reap the benefits of innovation and knowledge. The study also suggested that weak relationship between public universities and business firms may be one of the most important reasons keeping European Union (EU) regions away from reaping the fruits of R&D and higher education[13]. Coming to more recent analyses, authors such as Argentino Pessoa have added that yes, there's a positive correlation between the R&D intensity (i.e., R&D outlays/GDP) and the level of development, but there are also specific factors that are crucial

[11] Yanyun and Mingqian - R&D and Economic Growth:
http://www.karyiuwong.com/confer/seoul04/papers/zhao.pdf
[12] Martin Falk - R&D spending in the high-tech sector and economic growth:
https://www.sciencedirect.com/science/article/pii/S1090944307000294
[13] Khan, J. (2015). The role of research and development in economic growth: a review.
https://mpra.ub.uni-muenchen.de/67303/1/MPRA_paper_67303.pdf

in modeling the R&D-growth link, and an innovation policy that only relies on increasing R&D outlays is ineffective in increasing the economic rate growth[14]. John Nkwoma Inekwe (2015) explored the impact of R&D spending on economic growth in developing countries, using annual data from 66 nations. These countries were categorized into lower middle-income and upper middle-income economies based on income levels. The study employed the System GMM[15] (as Falk did) panel estimator to address simultaneous equation bias and the PMG approach to examine short-term and long-term effects. The findings indicated that R&D spending positively affects economic growth in developing countries overall and has a particularly beneficial impact on upper middle-income economies. However, it showed no significant effect on growth in lower middle-income countries at conventional levels. In the short run, R&D spending may contract growth, but it has an expansionary effect in the long run for developing countries. Conversely, in upper middle-income economies, R&D spending yields immediate positive impacts but becomes insignificant in the long run. His study underscored the importance of R&D for growth in developing countries and suggests the need for more effective investment in R&D, particularly in lower middle-income countries. Zhang conducted a study examining the connection between spending on science and technology activities and economic growth. The findings indicated that investment in research and development (R&D) significantly contributes to economic growth. R&D initiatives offer valuable opportunities for generating new knowledge and improving the capacity to incorporate and utilize external knowledge. Consequently, allocating increased resources to

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[14] Argentino Pessoa's research on the relationship between R&D and economic growth: https://www.sciencedirect.com/science/article/pii/S016517651000011X/pdf

[15] System GMM estimator: https://www.bristol.ac.uk/efm/media/workingpapers/working_papers/pdffiles/dp07595.pdf

R&D fosters robust capabilities in research and technology, leading to advancements in processes and products, thus enhancing overall performance[16].

These examples, in addition to the extensive literature provided in the paragraph, serve to highlight the critical role that research and development plays in promoting long-term economic growth and prosperity, the transformative impact that innovation can have on productivity, competitiveness and overall economic performance.

[16] The relationship between expenditure for science technology and economic growth in China: https://www.researchgate.net/publication/273856154_Research_on_Relationship_between_Expenditure_for_Science_Technology_Activities_and_Economic_Growth_in_China

2.1 The symbiotic relationship between R&D and Patents: empirical insights and literature frameworks

Returning to what we want to analyze in this work, (the analysis between Patents and GDP per capita), in the previous paragraph we focused on the importance of R&D because we know that R&D activities and patents are closely intertwined in the innovation process. Before analyzing this synergy, we first need to make a distinction between R&D and patents: R&D refers to the process of investigation and experimentation aimed at discovering new knowledge, ideas or technologies and developing those discoveries into improved products, services or processes. According to the Frascati Manual, 2002, R&D is defined as a "creative work undertaken on a systematic basis in order to increase the stock of knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications". Investments in R&D are precisely the fundamental ones for stimulating innovation and technological progress in various sectors and constitute the patent creation process. On the other hand, patents, as legal protections granted by governments, give inventors or assignees exclusive rights to their inventions for a limited period, generally 20 years from the filing date of the application (WIPO[17]). It is often assumed that greater investment in basic R&D will lead to greater applied research and to an increase in the number of inventions. This linear perception of the innovation process places localized R&D investment as the key factor behind technological progress and eventually, economic growth. The implications of this approach are that the higher the investment in R&D, the higher the innovative capacity and the higher the economic growth. Moreover, patents also serve as indicators of innovation performance. The number and quality

[17] WIPO - World Intellectual Property Organization: https://www.wipo.int/portal/en/index.html

of patents obtained can reflect the success of a company's innovation strategy. High patent output resulting from R&D efforts may signal effective innovation practices. Additionally, patents facilitate knowledge transfer and collaboration within industries. Companies may cross-license patents with one another, enter research partnerships to develop patented technologies jointly, or use patents as a basis for collaboration agreements. This is to say that R&D and patents are intimately linked, with R&D driving innovation and patents providing the legal framework to protect, commercialize, and collaborate on the innovations resulting from R&D efforts. I point out the evidence in the literature by Florence Jaumotte and Nigel Pain (2005), who undertook to find a link between R&D and patenting[18]. The sample they have been working on covered 19[19] OECD countries over the period 1986-2000: it suggested that there is a clear positive link between R&D and subsequent patenting. Specifically, the primary driver of innovation and economic impact is identified as R&D within the business sector, where commercial incentives such as gaining a competitive advantage and increasing profitability fuel innovation efforts. Meanwhile, public sector R&D activities also make a positive contribution, albeit driven by broader social needs rather than commercial gains. While these initiatives may not prioritize patenting innovations, they often focus on disseminating knowledge for the benefit of society. The sample implied that in the long run, a 1% increase in the stock of R&D to GDP yields an increase of about 2% in triadic patents per capita, and of 1.7% in domestic patents per capita. Other authors such as S.A. Meo and A.M. Usmani reported that innovative activities are essential to improve performance and they constitute the main driver of the growth process in advanced economies: it is precisely the innovation of scientific

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[18] Link between R&D and Patenting, by Florence Jaumotte & Nigel Pain: https://www.oecd-ilibrary.org/docserver/702226422387.pdf?expires=1708622978&id=id&accname=ocid56004655&checksum=53EB4529FD252CA61ED6DE056FE1E955

[19] Triadic patents, i.e. patents filed at three of these major patent offices: https://www.oecd-ilibrary.org/industry-and-services/triadic-patent-families/indicator/english_6a8d10f4-en#:~:text=Triadic%20patent%20families%20are%20a,and%20Trademark%20Office%20(USPTO).

research that offers multi-directional solutions to overcome challenges and help improve standards and quality of life. They state that there is a direct relationship between research and the overall development of nations as well as individual countries. They also pointed out research outcome does not depend upon GDP, but it depends on how much percentage of total GDP is being spent on R&D. So, the level of R&D investment is closely linked to the rate of research outcomes, thus the national capacity for innovation relies heavily on R&D investment[20]. Jerome Danguy, Gaetan De Rassenfosse, and Bruno Van Pottelsberge De La Potterie underscored a notable relationship between investments in R&D and the number of patents generated (2010). Their findings suggest that patents serve as vital mechanisms for transferring technology from the public to the private sector, thereby fostering the dissemination of knowledge and driving overall advancements[21]. Building upon this understanding, they proposed a conceptual framework to elucidate the patent-to-R&D ratio, suggesting that this relationship is influenced by factors such as appropriability propensity and strategic considerations. This framework offers a nuanced interpretation of the observed correlation, moving beyond a simplistic measure of R&D expenditure. Empirical findings further support this perspective, revealing a positive albeit modest elasticity of patents with respect to R&D expenditure. Moreover, the analysis demonstrated a productivity effect, particularly from basic and academic research, on the R&D-patent ratio. By integrating these insights, a comprehensive understanding of the R&D-Patents relationship emerged: patents serve not only as indicators of R&D investments, but also reflect the intricate interplay between appropriability, strategic considerations, and innovation outcomes. Another interesting research, extracted from a volume of the National Bureau of Economic Research, was

[20] The impact of R&D expenditures on research publications and patents by S.A. Meo, A.M. Usmani https://www.europeanreview.org/wp/wp-content/uploads/1-91.pdf

[21] Danguy, Jérôme; de Rassenfosse, Gaétan; van Pottelsberghe de la Potterie, Bruno: The R&D-patent relationship: An industry perspective: https://www.econstor.eu/bitstream/10419/44900/1/618781218.pdf;The

conducted by Frederic Scherer (1984). He delved into the intricate process of linking patents to research and development data[22]. After describing the patenting process after completion of the major coding activity, he discussed the relationship between R&D spending and the probability of patenting, highlighting that at low levels of R&D spending, the probability of patenting remained below 1.0. In relation to this, giving a purely subjective interpretation to the numerical data that Scherer provided, although investing less in R&D does not preclude the possibility of completely obtaining patents, the probability of patenting them is lower when the levels of R&D spending are minimum. Scherer's research highlights the importance of investment in research and development in promoting innovation and generating patentable inventions. This suggests that although the possibility of patenting still exists even with lower R&D expenditures, allocating more resources to R&D activities generally increases the likelihood of obtaining patents. Ariel Pakes and Zvi Griliches, in their paper "Patents and R&D at the Firm Level: A First Look" (1984) also carried out empirical analyzes regarding the relationship between R&D and patents, exploring everything through a statistical lens, with the aim to understand the dynamics between these two variables[23]. The analysis used a log-log model with correlated firm effects and a time trend (121 firms during 1968-75). Through this analysis, although the analysis highlighted the complexities and uncertainties of the relationship, the two authors underlined that patents constitute a valuable indicator of the progress of knowledge, particularly between different companies. The data suggests a strong correlation between the number of patents and the level of knowledge advancement achieved by companies. In addition, research conducted by Valentina Meliciani (2000) investigated the relationship between R&D, investment, and patents across countries, industries, and over time, utilizing the negative binomial model to accommodate the discrete nature of the dependent

[22] Frederic Scherer, "Using Linked Patent and R&D Data to Measure Interindustry Technology Flows": http://www.nber.org/chapters/c10061
[23] Ariel Pakes and Zvi Griliches, “Chapter Title: Patents and R&D at the Firm Level: A First Look”: http://www.nber.org/chapters/c10044

variable. Results indicated the significance of investment activities in contributing to technical change. Sectoral analysis revealed that R&D expenditures are generally more effective in generating patents in science-based industries, with sectors like Radio, TV and communication equipment, Drugs and medicines, and Non-metallic mineral products exhibiting the highest elasticity. Conversely, investment appears to play a more critical role in supplier-dominated and production-intensive sectors. For instance, Chemicals, Rubber and plastic products, and Metal products show significant coefficients for investment impact.

The study also found that in most sectors, the estimated R&D and investment coefficients lied outside the confidence intervals calculated around the pooled coefficients, indicating potential misleading results if equal effects across industries are assumed. The empirical evidence supports the notion of sectoral differences in the sources of technical change, as well as the varying effectiveness of R&D across different activities. These findings underlined the necessity of considering sectoral specificity in innovation policy. The paper also suggested that countries' technological specialization may impact their ability to generate new knowledge, as we previously said[24].

[24] Valentina Meliciani, 2000, "The relationship between R&D, investment and patents: a panel data analysis", Applied Economics, 32:11, 1429-1437, https://doi.org/10.1080/00036840050151502

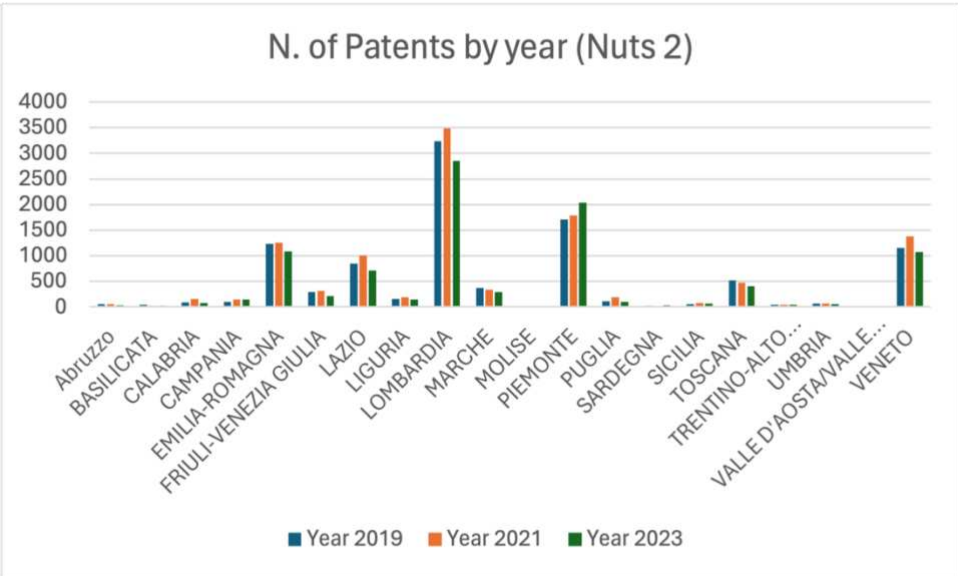
2.2 The heterogeneity of countries and the disparities between regions - the case of Italy

Having reported literature and empirical analyzes regarding the relationship between GDP, R&D and economic growth in general, we will focus on this analysis no longer at the Country level, but at the regional level, called by official sources such as Eurostat with "Nuts 2". The limitations arise because the country-level data fails to capture the diverse characteristics of individual regions. Understanding these regional heterogeneities and economic disparities is crucial, especially when analyzing the Eurostat data on NUTS 2 regions. These data provide insights into the varying economic conditions and growth patterns across different regions. Before starting with our empirical analyses, by documenting myself, I focused on an academic article that is particularly close to what we want to analyze: "The Geographic Distribution of Patents and Value Added Across European Regions" by Marjolein C. J. Caniëls (1997), who underlined as the object of the study the examination of spatial differences across European regions. He used data from the European Patent Office, and he covered the years 1986-1990, according to the NUTS classification[25]. His analysis revealed a high concentration of patenting activity in specific regions, particularly in northern Italy, Rhone-Alpes and Paris in France, the south and west of the Netherlands, and the south of the United Kingdom, leaving aside Germany, even before the fall of the Berlin Wall (1989), which however nowadays represents the nation that patents the most at a European level. Given that the analysis in question was made for the years 1986/1990, we can see how even today there are disparities between regions in terms of economic development and related patenting activity, and in this regard, I have collected some data: as an Italian student, the first example I will take is that of Italy. I sampled

[25] "The Geographic Distribution of Patents and Value Added Across European Regions" by Marjolein C. J. Caniëls (1997) http://collections.unu.edu/eserv/UNU:1037/rm1998-004.pdf

3 years: 2023, where the patenting activity restarted at full speed (also because companies find innovative ways to address problems) after the Covid-19 Pandemic, 2021, the year of the full Pandemic, and 2019, one of the years before the Pandemic without general shocks., so as to have a general picture and see the trends of all the Italian regions. Here is the graphic representation:

Fig. 1

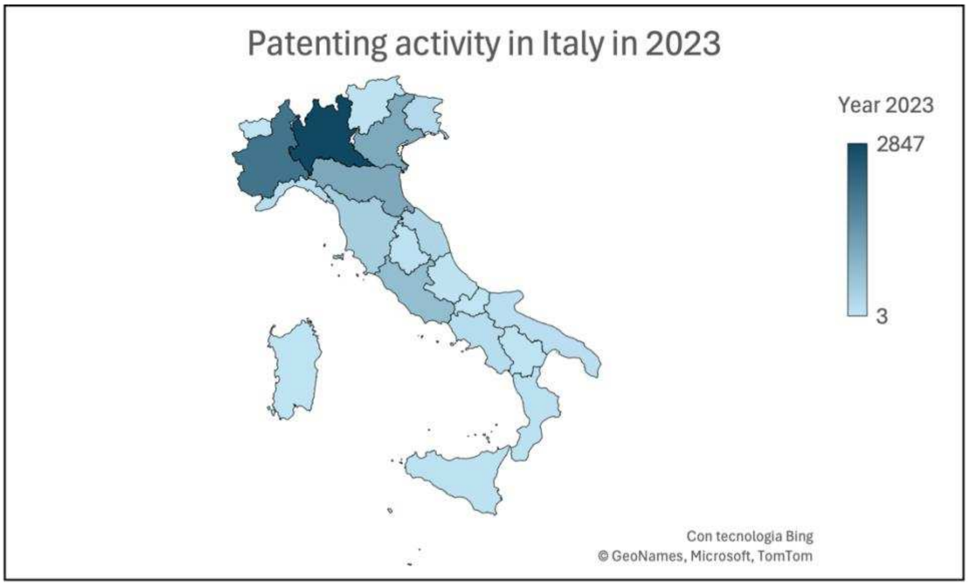


As illustrated in the provided graphic (see Fig. 1), the regions of Lombardy, Piedmont, Veneto and Emilia Romagna stand out prominently for their remarkable patenting activity, recording substantial numbers of patents — 3.491, 1.787, 1.378 and 1.259 respectively (for the year 2023). Conversely, the regions of Basilicata, Sardinia, Sicily, Abruzzo and Umbria exhibit considerably lower patent counts, with figures as low as 26, 28, 62, 35, and 50 respectively, excluding Molise and Val D'Aosta due to their smaller size[26]. This data vividly highlights the pronounced disparity in patenting activity across different regions of Italy, indicative of varying levels of innovation and research intensity. And that's the same for the years 2020 and 2018. I would like to clarify and specify the legend of the following grouped column graph, where the

[26] UIBM site, to see the quantity of Italian patents: https://statistiche.uibm.gov.it

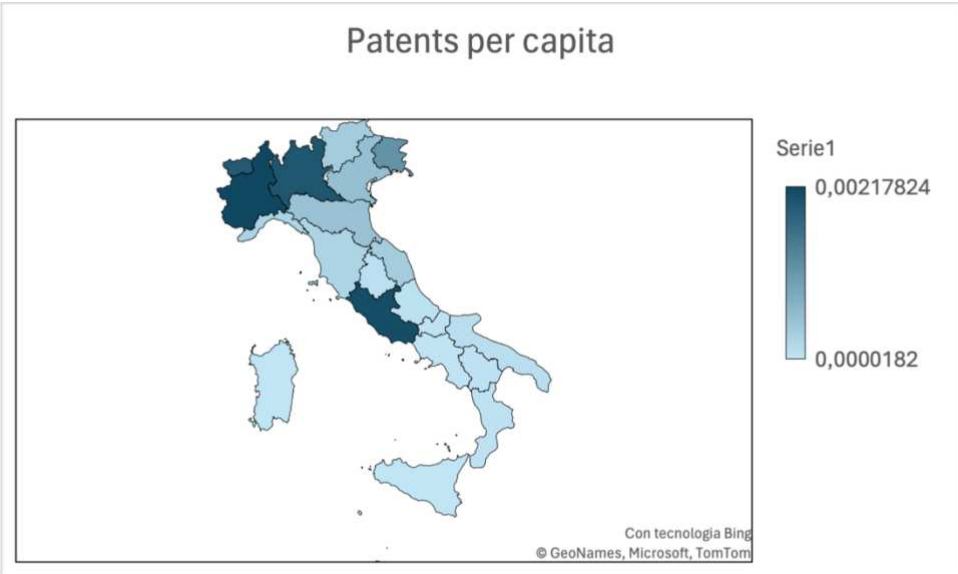
blue color represents the year 2023, the orange color the year 2020 and the green color the year 2018. When visualized on a map (see Fig.2), this divergence becomes even more apparent, with the northern regions appearing in darker shades to denote higher patenting rates, while the southern regions are depicted in lighter shades, indicating lower levels of patenting activity. This trend of regional inequality in patenting activity persists across multiple years, including 2021 (the year of Covid-19 Pandemic) where Lombardy, Veneto, Piedmont and Emilia – Romagna consistently maintain their positions as the top patenting regions. This continuity underscores the enduring nature of the north-south divide in Italy's research and development landscape, emphasizing the need for targeted interventions to promote innovation and bridge the gap between regions.

Fig. 2



Furthermore, to conclude on the chapter regarding the enormous heterogeneities of the Italian nation, I have created a further map again concerning 2023 (see Fig.3), which shows us the intensity of patents, necessary as regions differ in terms of number of people. In particular, the graph highlights, always from a lighter color which signifies a low level of intensity to a darker color which indicates the opposite, the values of the patents per capita, values that I obtained from the following formula: № of patents / № of inhabitants of the region. By calculating patent intensity, we can see how actively a region is involved in innovation relative to its population. Therefore, naturally, higher patent intensity indicates a region with a strong innovation environment and a higher concentration of inventive activity. As expected, we can see how the central-northern and northern regions have a much higher propensity to patent than the southern regions, characterized by very low values. Here's the map:

Fig. 3

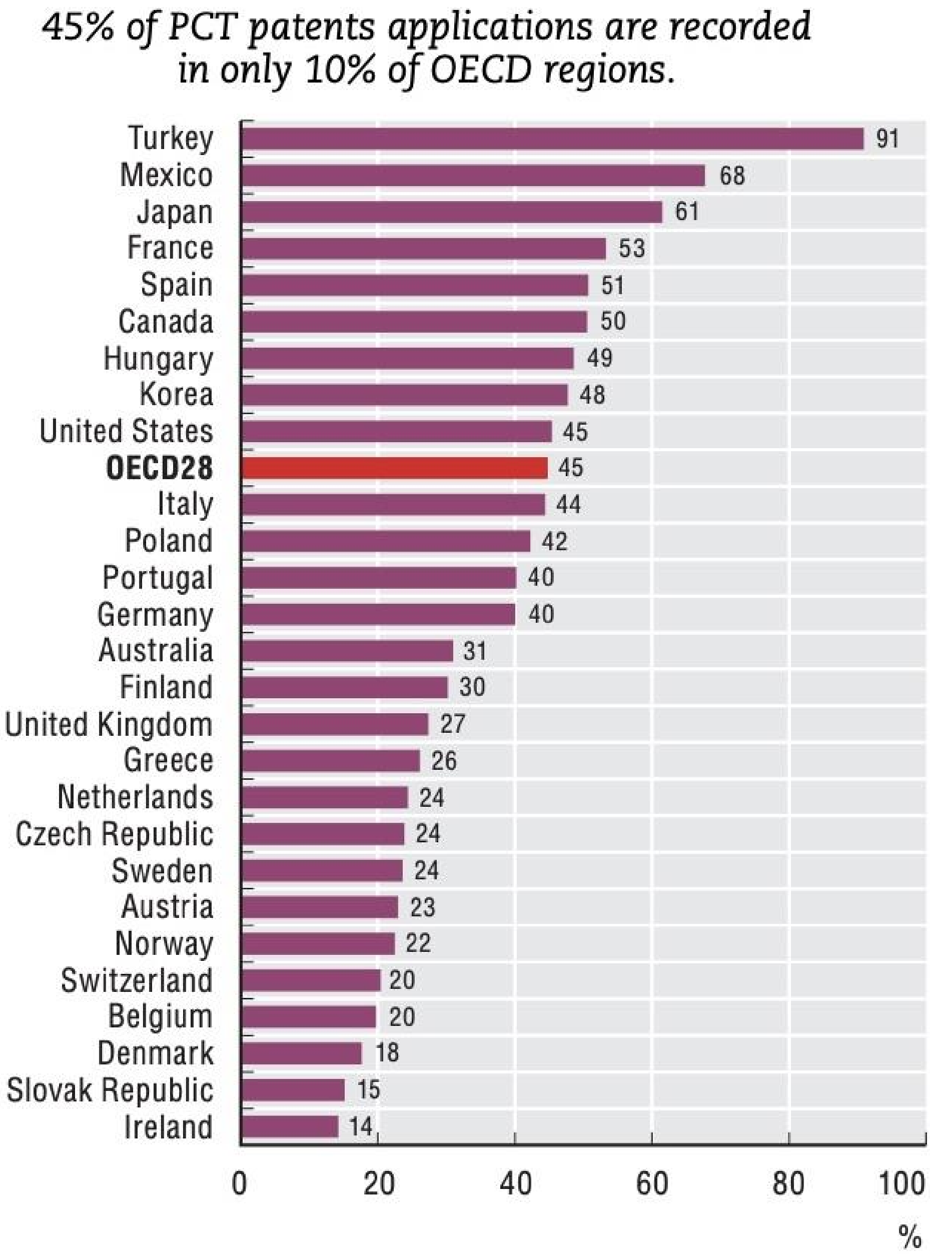


As we wanted to demonstrate, also by reflecting the number of patents granted per person within a given area over a specific period, our thesis analyzed previously is confirmed. In addition, I would like to add that in the Appendix there is a summary table of the values of the patents per capita of each individual region.

2.3 Regional disparities across European regions

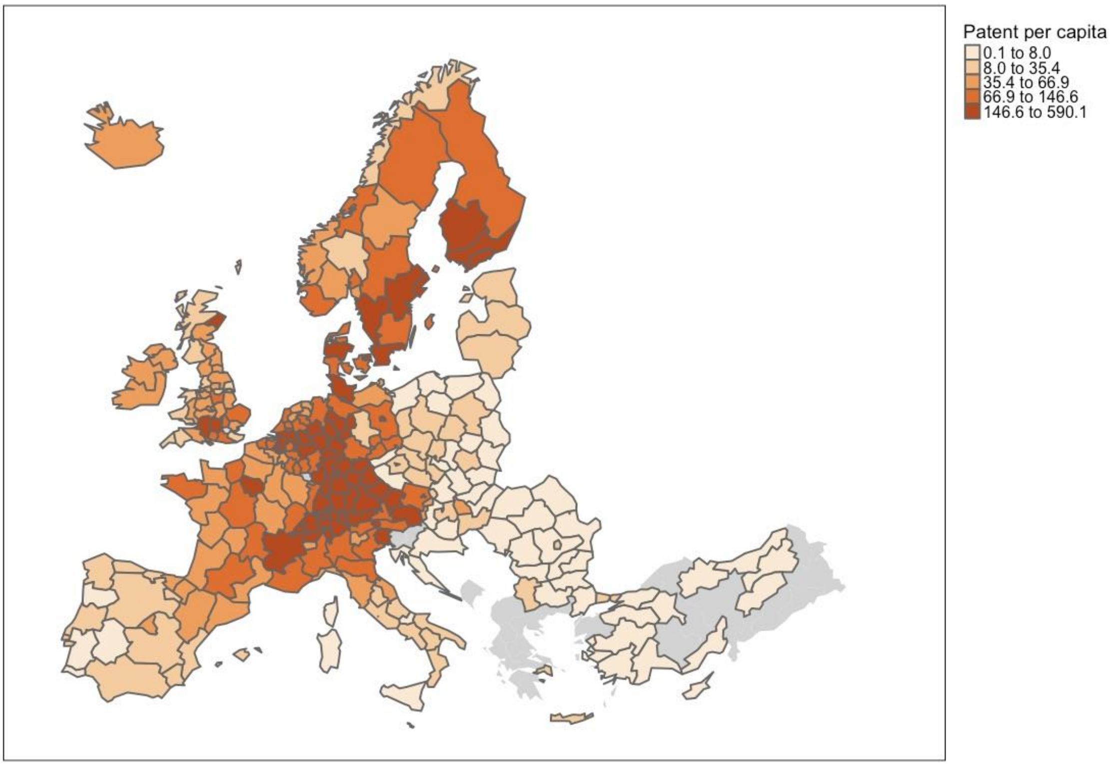
So, what do we see from the previous data? A complex tapestry of regional disparities across Italy: the data reveals stark discrepancies among its regions. Over the span of 2018, 2020, and 2023, Lombardy, Lazio, and Piedmont consistently emerge as patenting powerhouses, showcasing sustained innovation and research vigor. This pattern is likely fueled by robust industrial bases, thriving research institutions, and supportive policy environments. Conversely, regions such as Basilicata, Sardinia, Umbria, Abruzzo, and Calabria, predominantly situated in the southern and central-southern parts of Italy, consistently lag in patent numbers. Despite minor fluctuations, this gap persists, underscoring enduring disparities in innovation capacities. Factors such as differential investment in R&D, resource availability, collaboration dynamics between academia and local industries, and industrial structures play pivotal roles. The OECD underscores that patent concentration often stems from geographical clusters of investment, infrastructure, and sectoral activities. Italy's economic dualism, as described by Sylos Labini (1985, pp. 7-8), continues to be evident, with persistent disparities in GDP per capita and productivity levels between the north-central and southern regions. The aforementioned Italian regions that patent more, in which the business sector spends more on research and development activities, tend to innovate more. The business sector tends to focus more on applied research which, being directed primarily towards a specific practical purpose or objective, more frequently generates a patentable result. And not coincidentally, the OECD reports that patent applications are concentrated in a small number of regions within each country, just like Italy. In 2005, 45% of all patent applications in OECD countries were recorded by 10% of regions (see Fig. 4). A clear example is that of Turkey, where the regions of Istanbul, Bursa and Kocaeli account for 91% of the total number of patent applications.

Fig. 4



The concentration of patents is also related to the fact that generating patents requires inputs (e.g. investments and physical and human capital) and infrastructure (e.g. laboratories) which tend to be geographically clustered. Sectoral concentration of industries also has an influence on the concentration of patents, as some sectors have a higher propensity to patent than others. Precisely regarding the areas of high concentration and polarization, the OECD found out that this trend is reinforced by the increased availability of economic opportunities and wider availability of services stemming from urbanization itself, all supported by the thesis that, in the period 1995-2005, predominantly urban regions grew faster predominantly than rural regions. Now, having looked at the literature and OECD data up to 2005, I consulted, via Eurostat, the database relating to the number of patents in each European region (always at Nuts 2 level) per million inhabitants[27]. The values under consideration date back to the year 2012, which would also be the latest available in terms of data. Using RStudio, I mapped the numerical values and something like this came out:

Fig. 5



[27]Database relating to the number of patents of each European region per million: https://ec.europa.eu/eurostat/databrowser/view/pat_ep_rtot__custom_11049937/default/table?lang=en

At first glance, what catches the eye is that the regions with the highest number of patents per capita are concentrated in Northern and Western Europe, characterized by a dark red color. These regions include Switzerland, Finland, Sweden, Netherlands, Belgium, Germany and Austria. On the other hand, the regions with the lowest number of patents per capita are concentrated in Eastern and Southern Europe. These regions include Bulgaria, Romania, Greece, Portugal, Spain, and Italy and are characterized by a very pale orange. A situation like that analyzed in the previous chapter (the case of Italy) appears to be emerging: the northern regions patent more, while the southern regions have a very low number of patents. In addition to this, given that the legend ranges from 0.1 to 590.1 patents per million inhabitants, also Eastern Europe falls into the lower end of that range. Here too, in support of this thesis, by delving into the relevant literature, I found that Manfred M. Fischer & Thomas Scherngell (2005), from EPO-patent activities data ranging from 1985 to 2002 (therefore the period before our analysis period), found that the Eastern European regions and Southern European regions (except Northern Italy) display very little patent activity. These latter authors also focused on the localization of knowledge spillovers in patents. Their research compared the likelihood of citing patents originating from the same location as the original patent with control patents matched for timing and technology classification. The results they found strongly support the idea that spillovers are geographically localized. By "spillover" we refer to the process by which knowledge, technologies or skills developed in a specific context spread or transfer to other contexts, as a result of interactions, collaborations or competition. In this context, "knowledge spillover" refers to the transfer of technological or innovative knowledge from one organization or place to another, which can occur through various modalities, such as the publication of patents, the mobility of skilled workers or the collaboration between industries. For example, in 1995, the region of Ile-de-France showed the strongest localization effect, followed by German regions (Darmstadt, Dusseldorf, and Oberbayern) and Switzerland. As reported by the map I created by RStudio, it is visible how these last three countries fall into the most colored area, basically the one where the most patents are made. The proportion of citing patents matching the location of their originating patents is significantly greater than control patent location matches at both country and region levels. Statistical analysis confirms the significance of these findings. Their study concludes that regional and national systems of innovation are crucial, with significant policy implications. The localized nature of knowledge flows suggests that European regional cohesion is at stake, emphasizing the importance of fostering innovation at regional levels[28]. But what causes this lack of patentability and the consequent lack of contaminatio in the surrounding regions? Historically since the early 1990s, these countries (Eastern Europe and the former Soviet Union) have experienced a painful transition from a closed centralized economy to a free market one. Suddenly, they started on the path to a free market economy. The Eastern Countries were largely cut off from the global trade and idea flows, making it difficult for them to diversify and stay up to date with the newest technologies. In contrast, the Western European countries increased their R&D commitments, and their subsequent development in commercial innovation was driven by an active business environment (Murrel, 1990). In summary, these factors have made it difficult to compare the Eastern Countries' progress with the more dynamic Western countries. Specifically, two key reasons stand out: first, since the late 1970s, the inventive productivity of the Eastern Countries has been declining due to the increasing inefficiencies of the communist regime. Secondly, the shortage of funding caused the transitory shock to significantly reduce overall commitments to research and development, which worsened the situation. The situation is different for southern European nations. For example, in 1998, France stood out with a significantly larger research workforce (315,000 people) compared to Spain (97,000 people) and Italy (140,000) people.

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[28] Fischer, M. M., Scherngell, T., & Jansenberger, 2006, "Patents, patent citations and the geography of knowledge spillovers in Europe." Innovation, Networks, and Knowledge Spillovers: Selected Essays, 233-250: https://doi.org/10.1007/3-540-35981-8_11

This highlights the difference in researcher employment across these European nations, with France having a more substantial presence in both public and private R&D activities (Fabrizio Cesaroni and Andrea Piccaluga, 2005).

CHAPTER 3

3. Relationship between GDP, Graduates, and ICT

The interplay between graduates and ICT plays a crucial role in shaping regional economic growth across European regions at the NUTS 2 level. Graduates, particularly those with tertiary education, are pivotal in driving productivity and innovation, thereby bolstering GDP. Studies consistently show that regions with higher numbers of tertiary-educated individuals tend to experience greater economic development, attributed to their enhanced skills and ability to absorb and apply new technologies. For instance, empirical analyses reveal that increases in the proportion of graduates correlate positively with GDP growth over time, highlighting the economic advantages of investing in higher education. Simultaneously, ICT acts as a catalyst for economic growth by revolutionizing productivity and fostering innovation. Investments in ICT infrastructure and technologies streamline processes, optimize resource allocation, and enhance communication, thereby boosting economic efficiency and output. For example, digital advancements in sectors like AI and biotechnology not only create new economic opportunities but also contribute significantly to GDP growth by enabling novel product developments and industry formations. In conclusion, the combined impact of graduates and ICT on GDP underscores the importance of investing in education and digital infrastructure. Regions that successfully integrate these factors not only enhance their productivity and innovation capabilities but also position themselves favorably in the global economy through sustained economic growth and competitiveness.

3.1 Relationship between GDP and Graduates

Returning to the title of this thesis, i.e. some of the socio-economic factors linked to GDP concerning the European regions (always at Nuts 2 level), I would like to analyze whether there is a close correlation between GDP and the number of graduates, checking in particular what the most important academics have written about it and carried out an empirical analysis like the one previously done for the relationship between GDP and investments in R&D. First of all, I would say that higher levels of education can lead to increased productivity and innovation, which in turn can contribute to economic growth. Countries with a higher number of tertiary students tend to have a more skilled workforce, which can drive economic development in both manufacturing and service sectors. Additionally, educated individuals tend to have higher earning potential, which can further stimulate economic activity and contribute to GDP growth. To reinforce this thought, I found research, conducted for the UK Department for Business, Innovation and Skills (BIS), that found that a higher-educated workforce significantly contributes to long-run economic growth. The GDP per unit of labor input should be related to the share of labor of a specific type, weighted by the average human capital of the worker type, according to a theoretical framework derived from a standard Cobb-Douglas production function. Through the EU KLEMS[29] initiative, this data has lately been compiled for many advanced economies. This data has been used for 15 different countries between 1982 and 2005: first, researchers shown that in every country, GDP per employment

[29] EU KLEMS: https://economy-finance.ec.europa.eu/economic-research-and-databases/economic-databases/eu-klems-capital-labour-energy-materials-and-service_en

hour grew between 1982 and 2005. Finland (2.7%), Japan (2.5%), and the UK (2.4%) had the largest annual average percentage changes. In 1982, these nations had the lowest GDP per employment hour. Second, in every nation, the percentage of workers with tertiary education rose between 1982 and 2005. Australia had the largest annual average percentage change (5.0%), followed by the UK (4.9%). In 1982, the employment rates of tertiary educated individuals in both of these countries were comparatively low, at 6.0%, in contrast to 22.1% in the United States and 18.7% in Finland. Lastly, according to growth accounting study, the UK's GDP grew by about 20% between 1982 and 2005 as a result of the recruitment of graduate skills. This method ignores any externalities to higher education that could increase productivity across the economy and restricts the estimated impact to the productivity gain directly attributed to graduates[30] (tertiary education generally culminates in the receipt of certificates, diplomas, or academic degrees). In addition to this, in the recent years, the contribution of graduates to countries' economic success has become the focus of greater attention, since tertiary education is anticipated to boost the availability of skilled labor and improve the environment for innovation, resulting in significant social and economic advantages (McNeil and Silim, 2012). For instance, research by Barro (2013) showed that the estimated rate-of-return to an extra year of education is higher at the secondary and tertiary levels than at primary level for industrialized nations. He showed, through panel regression estimates (see the scatter plot in the appendix at page 78), that for males aged 25 and older, the average number of years of schooling completed at the secondary and higher levels has a positive and considerable impact on the rate of economic growth that follows. The resulting coefficient implies that an extra year of education (around one standard deviation) increases

[30] "The relationship between graduates and economic growth across countries" (2013), Bis Researcher N.110, Dawn Holland, Iana Liadze, Cinzia Rienzo and David Wilkinson: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/229492/bis-13-858-relationship-between-graduates-and-economic-growth-across-countries.pdf

the impact's growth rate by 0.44% annually. As previously indicated, one explanation for this effect could be that a workforce with secondary and tertiary education facilitates the absorption of technologies from more advanced foreign countries. As a conclusion, they said that education influences growth by making it easier for new technologies to be absorbed, which is likely to complement workforce educated to these higher levels[31]. Moreover, Craig Holmes (2013) emphasizes the significance of the correlation between students enrolled in tertiary education and economic expansion. He posits that higher education can impact economic growth through several avenues: the enhancement of productive skills and capacities, the facilitation of innovation and the creation of new knowledge, and the acceleration of the uptake of advanced technologies. For example, if university education contributes to the augmentation of human capital, one would anticipate sustained growth over an extended period as fresh graduates enter the workforce, potentially offsetting the departure of fewer highly educated retirees. Furthermore, he highlighted the significance of disparities in student quality or skillsets. Proficiency in technical skills cultivated through higher education is crucial for engaging in advanced research and can also spill over into other sectors, fostering accelerated growth through heightened productivity and swifter assimilation of emerging technologies. Indeed, heightened skill levels facilitate the rapid uptake of novel technology and the cultivation of fresh concepts, thereby fueling innovation and progress[32]. Delving further into the academic literature, I uncovered an intriguing observation stemming from a study involving 506 Italian startups operating in high-tech sectors, encompassing both manufacturing and

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[31] Robert J. Barro, 2013, "Education and Economic Growth", Harvard University, Annals of Economic and Finance 14-2, 301–328:
https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=756ea3bc9225033cf7d82530d0a1ef28be6bf95e

[32] Craig Holmes, 2013, "Has the Expansion of Higher Education Led to Greater Economic Growth?", National Institute Economic Review, 224:R29-R47, doi:10.1177/002795011322400103:
https://ora.ox.ac.uk/objects/uuid:f6531b5b-8c72-4b6a-b726-9554327be28d/download_file?safe_filename=Higher%2Beducation%2Bfor%2Beconomic%2Bgrowth%2BAuthor%2BApproved%2BVersion.pdf&file_format=application%2Fpdf&type_of_work=Journal+article

services. It suggests that startups founded by individuals with greater human capital tend to experience superior growth due to their unique capabilities (Colombo & Grilli, 2005). These findings align with competence-based theories, asserting that the abilities of founders, as reflected in their human capital attributes, play a pivotal role in the growth of new technology-based firms (NTBFs). Specifically, the education and professional background of founders were found to impact growth differently based on their nature. While the number of years of education isn't directly correlated with growth, undergraduate and graduate education in economic and managerial disciplines, and to a lesser extent in technical and scientific fields, positively influence growth. Additionally, the study highlights the synergistic effects stemming from the presence of specific complementary capabilities within the founding team, originating from educational backgrounds and industry-specific work experience. Particularly, the absence of technological competencies renders founders' commercial skills less impactful on firm performance. However, when both technical and commercial competencies are present within the founding team, they significantly contribute to growth. The research suggests that NTBFs achieve the highest growth when industry-specific technical and commercial skills are combined within the founding team[33]. In addition, I found a paper, for two of the EU countries such as the Czech Republic and the Slovak Republic, in which the authors (Emilia Krajnakova, Vaida Pilinkiene and Patrik Bulko, 2020) conducted a regression analysis to explore the relationship between employment/unemployment rates among graduates and the GDP of the above-mentioned countries. In the case of the Slovak Republic, the analysis revealed a moderately strong positive correlation (correlation coefficient = 0.784) between the unemployment rate of graduates and the level of GDP. This can suggest that as GDP increases, the unemployment rate among highly educated individuals tends to decrease. In simpler terms,

[33] Massimo G. Colombo & Luca Grilli, 2005, "Founders’ human capital and the growth of new technology-based firms: A competence-based view", Research Policy, Volume 34, Issue 6: https://www.sciencedirect.com/science/article/pii/S0048733305000776

when the economy grows, there are typically more job opportunities available for those with higher education qualifications. Conversely, for the Czech Republic, the correlation between the unemployment rate of tertiary educated individuals and GDP was weaker (correlation coefficient = 0.357). This indicates that the relationship between GDP and unemployment among highly educated individuals is not as pronounced in the Czech Republic compared to the Slovak Republic[34]. However, it's important to note that the correlation between employment of graduates and GDP is strong for both countries. This implies that higher employment rates among highly educated individuals tend to coincide with higher GDP levels, irrespective of the strength of the correlation with unemployment. Overall, this applied research suggests a positive association between the employment status of graduates and GDP, particularly in the Slovak Republic. This implies that policies aimed at increasing the proportion of highly educated individuals in the workforce may potentially contribute to economic growth in these regions.

[34] Emilia Krajnakova, Vaida Pilinkiene and Patrik Bulko, 2020, "Determinants of Economic Development and Employability of Higher Education
Institutions Graduates", Vol. 31 No.2:
https://doi.org/10.5755/j01.ee.31.2.24751

3.2 Relationship between GDP and ICT

As the fourth indicator influencing GDP I chose ICT, which stands for "Information and Communication Technology". ICT encompasses a wide range of technologies and services that facilitate the processing, storage, and communication of information. This includes hardware like computers and smartphones, software applications, telecommunications networks, and internet services. But what is the relationship between these two indicators? It can be described as highly interconnected and mutually influential, and there are several ways in which ICT can influence GDP, all intertwining to bolster economic prosperity. Productivity enhancement, a cornerstone, stems from streamlined processes and swift communication afforded by ICT investments. Automation of tasks and adoption of cloud computing not only cut costs but also elevate output per worker. We can think for example of a family-owned restaurant that adopts ICT tools such as online reservation systems. By implementing an online reservation system, the restaurant could simplify the booking process for customers and optimize table allocation. These ICT implementations not only can improve customer service but also can contribute to the restaurant's growth and competitiveness within the hospitality industry. Simultaneously, ICT fuels innovation, birthing novel products and industries through research in AI, big data, and biotechnology. Such breakthroughs create economic avenues, nurturing growth. Moreover, globalization flourishes under ICT's embrace, dismantling borders for businesses via e-commerce platforms and digital payment systems. This heightened connectivity fosters specialization, driving efficiency and economic expansion. Concurrently, human capital burgeons, necessitating skilled ICT workforces, cultivated through education and training programs. Infrastructure development further fortifies this ecosystem, fostering digital innovation and entrepreneurship. This symbiosis propels GDP growth, contingent on technological adoption, regulatory frameworks, and socioeconomic contexts. In tandem, ICT augments productivity by streamlining tasks and enhancing communication, amplifying output and economic progression. The advent of e-commerce and online marketplaces broadens businesses' horizons, amplifying sales and GDP. If we consider a neighborhood bookstore that embraces ICT, implementing a digital inventory management system and digitizing inventory and sales records, the bookstore streamlines operations and reduces administrative tasks. Additionally, by selling books online via an e-commerce platform, the bookstore expands its customer base beyond local users, increasing sales and revenue. Furthermore, ICT catalyzes innovation and entrepreneurship, democratizing entry into markets and invigorating competition. Governance, too, undergoes transformation, as ICT fosters efficiency and transparency, refining resource allocation and fostering a conducive business environment. Evidence buttresses this nexus, underpinning the correlation between ICT development and GDP expansion, particularly per capita. Simultaneously, with the progression of ICT, society faces growing economic challenges in managing malware and spam (Koscher et al., 2010). As technology advances further and informatization deepens, a range of adverse consequences, including hacking attacks, massive, distributed denial of service attacks, and other threats to data privacy and security, emerge in increasingly sophisticated forms. Regarding the difficulties that can arise with the investment in ICT, I report that, at the literature level, many empirical studies before the 1990s found that productivity would fail due to the increasing investment in ICT. As Solow (1987) mentioned in the "Information Productivity Paradox"[35] he was skeptical about the idea that investment in ICT would lead to productivity growth. However, after that, the opposite results became dominant. Since the 1980s, there has been a considerable focus on the correlation between ICT investment and economic growth, with numerous studies exploring this connection. According to Brynjolfsson & Hitt (2003), there has been a notable rise in both nominal and real investments in computers by companies over

[35] Information Productivity Paradox: https://cs.stanford.edu/people/eroberts/cs201/projects/productivity-paradox/background.html

time, particularly intensifying during the 1990s. This surge suggests that companies perceived the potential for substantial profit growth through the adoption of these new technologies[36]. Additionally, computers possess the capacity to influence multifactor productivity growth by reshaping production processes and fostering complementary innovations within and among firms. By integrating computers with other innovations, companies can fundamentally transform their production processes, potentially resulting in greater output elasticity than the share of computers as inputs and generating surplus returns on computer capital stock. The principal findings from this econometric analysis indicated that the measured output contributions of computerization in the short term are roughly equivalent to computer capital costs. However, in the long run, these contributions are significantly higher than computer capital costs, with estimates suggesting a factor of five or more. This suggests that while the initial costs of computerization may seem substantial, the long-term benefits far outweigh these expenses. Such results underscored the importance of considering the long-term effects and potential returns on investment when evaluating the impact of computerization on economic growth. In addition to this, G. Madden and S.J. Savage (1998) discussed the relationship between telecommunications investment (which are a fundamental component of Information and Communication Technology) and economic growth, particularly in Central and Eastern European (CEE) countries[37]. Their finding suggests that there is a positive relationship between telecommunications investment and economic growth, especially when measured by factors like the number of main telephone lines. This implies that investing in telecommunications infrastructure can contribute to economic growth in CEE countries. They also stated that addressing underinvestment in this sector could have broader positive impacts on the economy

[36] Brynjolfsson, E., & Hitt, L. M., 2003, Computing productivity: Firm-level evidence. Review of economics and statistics, 85(4), 793-808: https://direct.mit.edu/rest/article-abstract/85/4/793/57428/Computing-Productivity-Firm-Level-Evidence

[37] Gary Madden & Scott J. Savage, 1998, "CEE telecommunications investment and economic growth", Volume 10, Issue 2: https://doi.org/10.1016/S0167-6245(97)00020-6

(38). M. Cardona, T. Kretschmer and T. Strobel (2013) provided insights into how ICT investments contribute to labor productivity growth[38]. In particular, they discovered that the US experienced a productivity resurgence after the mid-1990s, driven by high investments in IT and significant productivity increases, particularly in the IT producing sectors. They also compared the contribution of ICT to productivity growth between the US and Europe. They noted that the US experienced a higher contribution from ICT, especially during the period from 1995 to 2000, compared to Europe. In summary, empirical research illustrates that ICT has a significant impact not only on daily life but also on productivity metrics. Moreover, this empirical study suggest that this impact is not only substantial and positive but also growing progressively. Additionally, it's emphasized that ICT should be integrated with complementary organizational investments, skills, and industry frameworks (39). One of the most interesting studies is the one conducted by Yeong-wha Sawnga, Pang-ryong Kim and JiYoung Park (2021), which investigated how investment in the industry of Information, Communication and Technology (ICT) has been interlocked with the GDP growth of South Korea. I considered it particularly interesting firstly because it is one of the most recent studies found in literature, secondly because Korea has the 4th largest economy in Asia, the 13th largest in the world and it is one of the few countries that has successfully transformed itself from a low-income to a high-income economy and it's also a global leader in innovation and technology. Based on time-series data from the period beginning in the first quarter of 1999 and ending in the second quarter of 2016, they used four econometric techniques to elucidate the relationship between ICT investment and GDP/economic growth. With the Unit Root Test, they indicated that GDP data alone exhibits non-stationarity at the level, meaning it doesn't exhibit consistent behavior over time. However, when GDP data is differenced, it becomes stationary, suggesting a more

[38] M. Cardona, T. Kretschmer and T. Strobel, 2013, “ICT and productivity: conclusions from the empirical literature", Volume 25 - Issue 3, Pages 109-125, ISSN 0167-6245: https://doi.org/10.1016/j.infoecopol.2012.12.002.

stable relationship with ICT investment. This suggests that changes in ICT investment could potentially impact GDP growth over time. With the Co-integration Test, the results suggested that there's at least one co-integration equation between GDP and ICT investment. This implied that there exists a long-term equilibrium relationship between the two variables, indicating that they move together over time, albeit possibly with short-term fluctuations. With the Vector Error Correction Model, the results suggested that, while bidirectional causality exists between the two variables in the long run, indicating that changes in one variable influence the other and vice versa over extended periods, the short-run relationship is unidirectional, with GDP growth impacting ICT investment but not the other way around. This implied that in the short term, changes in GDP have a more immediate effect on ICT investment. Finally, they also used Elasticity Estimation. A calculated elasticity of 0.4 implies that a 1% increase in ICT investment leads to a 0.4% increase in GDP in the long term. This suggested that ICT investment is an important driver of economic growth, albeit with a certain degree of responsiveness. Overall, these findings underscored the importance of ICT investment as a driver of economic growth, highlighting its role in shaping the trajectory of economic development[39].

[39] Yeong-wha Sawng, Pang-ryong Kim, JiYoung Park, 202, "ICT investment and GDP growth: Causality analysis for the case of Korea," Telecommunications Policy, Volume 45 - Issue 7, 102157, ISSN 0308-5961: https://doi.org/10.1016/j.telpol.2021.102157.

CHAPTER 4

4. Correlation between GDPs per capita and R&D expenses per capita

I began my analysis journey by exploring the data provided by Eurostat, focusing on information relating to GDP per capita and Research and Development (R&D) per capita spending in European regions (Nuts 2 Level). Using RStudio, I imported the Excel files containing this data using the `readxl` library, allowing me to examine the structure and organization of the datasets. After confirming the correct data import, I moved on to transforming and preparing the datasets for subsequent analysis. I adopted a "long" structure for the data, allowing for greater flexibility in performing the analyses. This allowed me to explore the relationship between GDP and R&D per capita spending in more depth. Thus, I performed quantitative analyzes to better understand the dynamics of the data. Furthermore, to better understand the context of R&D expenditures per capita in different regions, I have identified the regions with the highest and lowest expenditures for each year, in particular by creating an Excel file in which I reported the top 50 regions with a greater expenditure on R&D per capita and a consequent high final GDP per capita, comparing them with the 50 bottom regions, i.e. those that find it more difficult to invest and with a consequent GDP per capita among the lowest in Europe. This gave me a clear overview of the differences in GDP per capita between these categories of regions, allowing me to draw conclusions about the role of R&D spending on the regions' economic performance.

Tab. 1

A	B	C	D	E
Year	**Nation**	**Region**	**GDP PC**	**R&D PC**
2021	Sweden	Stockholm	71.200	2.571
2021	Germany	Oberbayern	63.300	2.807
2021	Sweden	Västsverige	49.200	2.600

The image I show above (see Tab. 1) comes from the file I was talking about previously. The regions mentioned here are part of the top 50 that perform best and behave best. In particular, the Stockholm area (Year 2021) documented a GDP of EUR 71.200 per capita and R&D costs of roughly EUR 2.570,625 per capita. Here, the GDP stands out as notably high, and R&D investments are considerable relative to GDP. In the case of the Oberbayern region (Year 2021), the GDP per capita amounted to EUR 63.300, while R&D spending reached EUR 2.807,117 per capita. The GDP is considerable, and R&D expenses are notably significant compared to GDP. Lastly, considering the Västsverige region (Year 2021), we find a GDP of EUR 49.200 per capita and R&D expenditure of EUR 2.600,198 per capita. Once again, the GDP is notably high, and R&D investment is proportionately significant compared to GDP. After mentioning just some of the top regions, let's now move on to the bottom regions:

Tab. 2

Year	**Nation**	**Region**	**GDP PC**	**R&D PC**
2020	Romania	Sud-Vest Olt(	8.800	9
2018	Bulgaria	Severen tsen	5.500	17
2018	Macedonia	North Maced	5.700	19

This sample of regions (see Tab. 2) demonstrates that "bottom" regions with low GDP per capita tend to have proportionately low R&D expenditures per capita. There are no cases in which R&D expenditure exceeds GDP, but rather confirms that limited resources lead to reduced investment in research and development. For example, we can see how the South-West

Oltenia region has a GDP of EUR 8.800 per capita and R&D expenses of EUR 8,971 per capita (rounded to 9). R&D expenditures are very low compared to GDP, indicating that the region invests little in research and development, probably due to limited economic resources. The Severen Central (Bulgaria) region also has a GDP of EUR 5.500 per capita and R&D expenditure of EUR 17,115 per capita (rounded to the nearest 17). Although GDP is low, R&D expenditures are even lower in absolute terms. This confirms that the region does not invest much in R&D, consistent with the low GDP. Finally, the North Macedonia region has a GDP of EUR 5.700 per capita and R&D expenditure of EUR 18,827 per capita. Even in this case, R&D expenses per capita are very low compared to GDP per capita values. This reflects a common trend among regions with low GDP that do not invest significantly in R&D. My analysis continued how I could calculate a possible coefficient that would confirm the positive correlation between GDP and R&D spending, or something that would provide me with information on the degree of association between these two variables: I came across the Pearson correlation coefficient[40]. This coefficient helped me measure the strength and direction of the linear relationship between the two variables, GDP and R&D. The value of the Pearson correlation coefficient varies from -1 to 1, where:

a) 1 indicates a perfect positive correlation,

b) -1 indicates perfect negative correlation,

c) 0 indicates no correlation.

The result of the Pearson correlation coefficient that I obtained is 0.225 (rounded), which indicates a positive correlation between GDP and R&D expenditure for the regions considered. However, the value is relatively low, which suggests that the correlation is not very strong. A correlation closer to 1 would indicate a stronger positive correlation, while a correlation closer to 0 would indicate a weak or no correlation. So, in this case, a correlation of around 0.22

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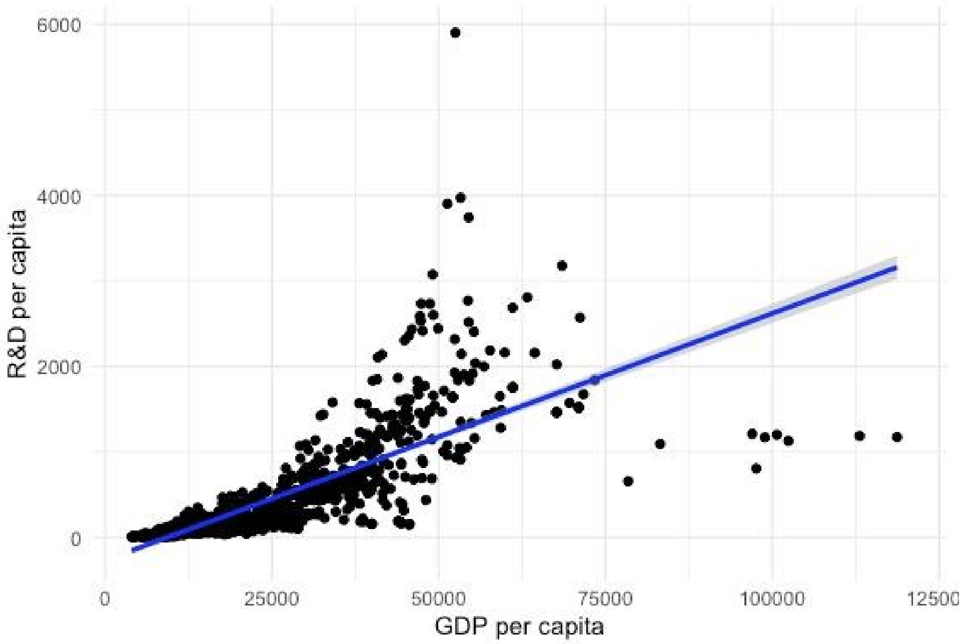
[40] Sedgwick, P., 2012, "Pearson's correlation coefficient", Bmj, 345: https://doi.org/10.1136/bmj.e4483

suggests that there is a positive, but not very strong, correlation between GDP and R&D spending for the regions considered. Now I will check the same among the bottom regions. The correlation number I get is 0.5078685. Approximately, a Pearson correlation coefficient of around 0.51 suggests a moderate positive correlation between GDP (GDP) and R&D expenditures in the lower regions. This indicates that there is a trend where regions with higher GDP also tend to have higher R&D expenditures, and vice versa, although the link may not be extremely strong. Both values of the Pearson correlation that I obtained indicate a positive correlation between GDP and R&D expenditure. For the "Top" regions, the correlation coefficient is around 0.22, which indicates a positive but slightly weaker correlation. For the "Bottom" regions, the correlation coefficient is approximately 0.51, indicating a stronger positive correlation. In both cases, therefore, the positive sign of the correlation suggests that when expenditure on R&D, GDP tends to increase. Finally, to have a more exhaustive view of this binomial correlation, it was right to find the average coefficient between all the European regions (Nuts 2), not only between the top and bottom regions. The result is a coefficient of 0.76 (rounded). The Pearson coefficient of 0.76 reveals a strong positive correlation between GDP pro capita and R&D expenditure per capita in European regions: this suggests a significant trend where greater economic prosperity is associated with higher investments in research and development. An R^2[41] of 0.76 indicates a strong positive correlation, meaning 76% of the variation in R&D spending can be explained by the linear trend with PIL. To close the circle, again with RStudio, I mapped the relationship between GDPs per capita and R&D per capita, and this is the result:

[41] The coefficient of determination (or R2): https://www.ncl.ac.uk/webtemplate/ask-assets/external/maths-resources/statistics/regression-and-correlation/coefficient-of-determination-r-squared.html

Fig. 6



We see how the X-axis (Independent Variable) represents the GDP per capita, while the Y-axis (Dependent Variable) represents the R&D expenditure per capita. The line superimposed on the scatter plot of data points is the regression line. It represents the best-fit line that captures the overall trend in the relationship between GDPs per capita and R&D per capita. Moreover, in the context of our graph, the positive slope indicates a positive correlation, meaning precisely that regions with higher GDP tend to have higher R&D spending per capita. The intercept, instead, means the predicted R&D expenditure per capita when the GDP per capita is zero (which is not economically meaningful but helps define the equation of the line). Although this, the differences in correlation coefficients between the previous subgroups of "Top" and "Bottom" regions suggest that the relationship between these two variables may be more complex and needs more in-depth analysis: a strong correlation is just one piece of our puzzle. By exploring the data further and delving into potential causal relationships, we can gain a richer understanding of the complex dynamics between GDPs per capita and R&D expenditure per capita in European regions. The addition of other factors (such as those we have consulted in the academic literature) will certainly improve the model and make it even more faithful.

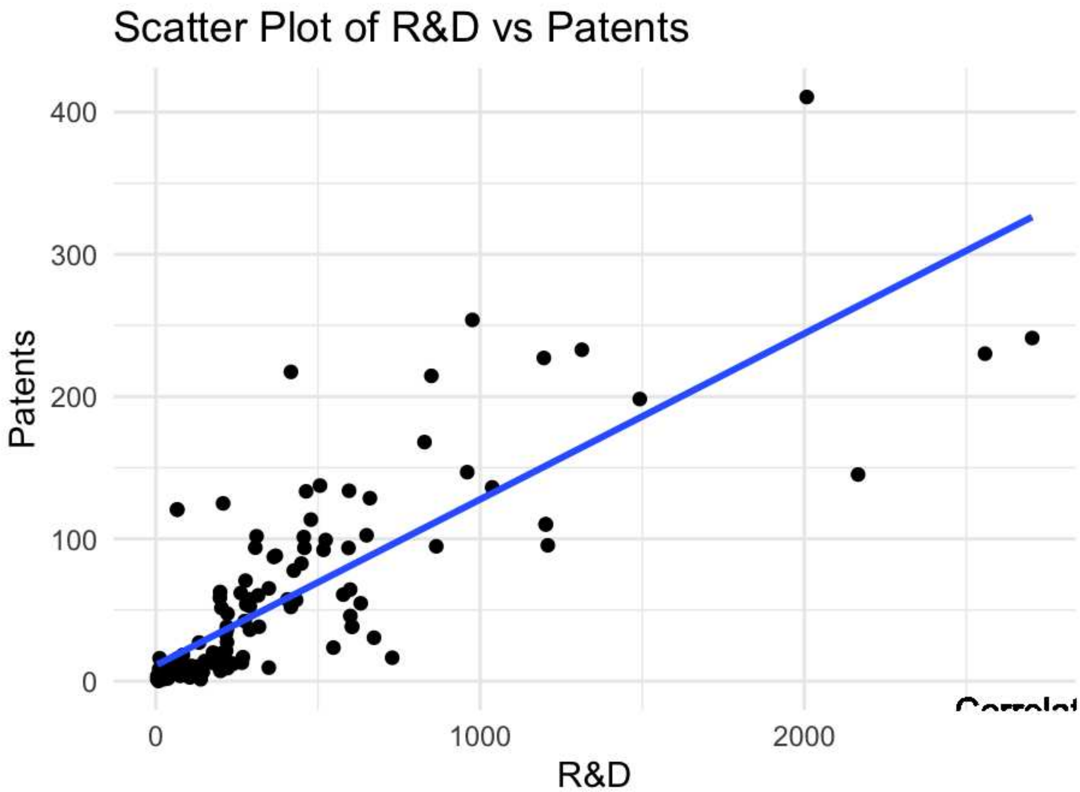
4.1 Correlation between R&D expenses and Patents

Analyzing the correlation between R&D expenditures and patents per million inhabitants is an excellent next step to implement the analysis of the relationship between GDPs per capita and R&D expenditures. While the GDP-R&D correlation indicates the potential impact of R&D investments on economic growth, examining the R&D-patents relationship provides insights into the effectiveness of those investments in generating innovative outcomes. The previous analysis focuses on the potential impact of R&D investments on economic growth. The R&D and patents correlation delves into the effectiveness of R&D investments in generating innovative outputs. In fact, patents serve as indicators of innovation, and a high number of patents can suggest that R&D investments are effectively translating into innovative outputs. Starting from this thesis, as before, I went in search of empirical evidence that would confirm this positive relationship. Again, thanks to RStudio, I uploaded the two datasets into it, the first relating to R&D in 2010 (given that, as we explained at the beginning of the thesis, R&D is the input of innovation), while the second relating to Patents (R&D output) of 2012, again at the European regional level (Nuts 2). I want to underline that I chose two databases from two different years (2010 for R&D and 2012 for Patents) as patents become accessible to the public 18 months after the filing date[42]. After creating the dataset combined with the columns named "region", which contains the name of each individual European region, "value_rd" which contains the values relating to R&D (euros per inhabitants) and "value_patents", which contains the values of the patents (per million inhabitants), I proceeded with the calculation of the correlation between the R&D values and the Patents values for each region. The result was that the correlation between R&D values and Patents values in the combined dataset is 0.8019858, so approximately 0.802, which indicates a strong positive correlation. In other

[42] Ministry of Business and Made in Italy: https://uibm.mise.gov.it/index.php/it/

words, there is a close association between the amount of money invested in R&D and the number of patents obtained. After calculating the coefficient, I considered drawing a graph that is informative, clear and visually attractive: I drew a scatter plot with regression line, (see Fig. 7) which allows us to visualize the relationship between R&D and Patents through a scatter diagram, with the values of R&D on the X-axis and the values of Patents on the Y-axis. Having overlaid a regression line helps us highlight the general trend of the data.

Fig. 7



At first glance, the general trend is that the graph shows a clear upward linear trend, with an increase in the number of patents filed as R&D spending increases. The data points are distributed relatively evenly around the regression line, with some exceptions. This variability may be due to several factors, such as the type of industry present in the region, the effectiveness of R&D activities and the patenting strategy adopted by individual regions. Then, if we want to interpret the results, we can verify that investment in R&D is an important factor for patenting activity: the regions that invest more in R&D tend to have a greater number of patents. This is in line with expectations, as R&D activities are often necessary to develop new inventions that can be patented.

4.2 Empirical Perspectives: R&D Expenditure, Economic Performance, and Innovation in European Regions

The previous empirical studies unveil significant insights into the economic dynamics of European regions, highlighting the crucial role of R&D investments. Specifically, the correlation coefficient for GDP and R&D expenditure averages around 0.76 across all regions, indicating a strong positive correlation. This suggests a significant trend where greater economic prosperity is associated with higher investments in research and development. Additionally, the correlation between R&D expenditure and patents stands at approximately 0.802, highlighting a robust positive association between investment in R&D and the generation of innovative outputs. For instance, regions with higher GDP tend to allocate more resources to R&D, as evidenced by illustrative examples such as the Stockholm area with a GDP of EUR 71.200 per capita and R&D costs of roughly EUR 2.570,625 per capita, and the Oberbayern region with a GDP per capita of EUR 63.300 and R&D spending of EUR 2.807,117 per capita. Similarly, regions with lower GDP exhibit proportionately lower R&D expenditures, as illustrated by cases such as the South-West Oltenia region with a GDP of EUR 8.800 per capita and R&D expenses of EUR 8.971 per capita. However, it's important to acknowledge the time gap between the R&D expenditure data (2010) and the patent data (2012, reflecting potential filings in 2010 or earlier). This two-year discrepancy limits the ability to definitively establish a direct causal relationship between R&D investments and patents obtained. Ideally, data with a more recent timeframe would be preferable for a more robust analysis. And since we do not have recent official data, the only available time frame where all these three variables are accessible is 2010: the main problem is that, as anticipated before, the data relating to patents are difficult to find, as require a long analysis. The availability of data can be influenced by various factors, such as legal restrictions, organizational protocols, and the frequency of dataset updates. Eurostat appears to substantiate this observation, as evidenced by the delay in its data. As of 2024, the most recent data provided by Eurostat dates to 2012. In all this I decided to make a summary correlation of the three variables used above, namely GDP, R&D and the number of Patents, for the year 2010. Again, through RStudio, I combined the three datasets downloaded from Eurostat, I calculated the Correlation Matrix and then visualized it with 'corrplot', which made it easy for me to see these values and quickly identify the relationships between the variables. The results suggest and strengthen our thesis that these factors are closely related, and that GDP, R&D and innovation reinforce each other.

Tab. 3

	GDP_per_inhabitant	RD_per_inhabitant	Patents_per_million_inhabitants
GDP_per_inhabitant	1.0000000	0.7270920	0.6815877
RD_per_inhabitant	0.7270920	1.0000000	0.8215386
Patents_per_million_inhabitants	0.6815877	0.8215386	1.0000000

The values within the correlation matrix (see Tab. 3) are calculated using the Pearson correlation coefficient, which ranges from -1 to 1. This coefficient measures the strength and direction of the linear relationship between two variables. A value close to 1 indicates a strong positive linear correlation, suggesting that as one variable increases, the other tends to increase as well. Conversely, a value close to -1 indicates a strong negative linear correlation, indicating that as one variable increases, the other tends to decrease. A strong positive correlation is observed between GDP per capita and R&D expenditure per capita, with a coefficient of 0.727. This implies that nations with higher GDP per capita tend to allocate more resources towards research and development. Furthermore, a positive correlation exists between GDP per capita and Patents per million inhabitants, with a coefficient of 0.682. This suggests that countries with higher GDP per capita also exhibit a greater number of patents filed. Finally, the matrix reveals a strong positive correlation between R&D expenditure per capita and Patents per million inhabitants, with a coefficient of 0.822. This finding reinforces the direct link between R&D investments and the production of patentable innovations. In essence, the correlation matrix unveils a reinforcing interplay between GDP, R&D expenditure, and Patents. These factors strengthen each other, fostering a virtuous cycle of economic growth, innovation, and technological advancement. Investing in R&D emerges as a key driver of a nation's development, fueling its global competitiveness and enhancing the well-being of its citizens. Moreover, while these correlations provide valuable insights, they are not exhaustive in explaining the economic performance of European regions. Factors such as the relationship between GDP and the level of students enrolled in tertiary education, and the correlation between GDP and Information and Communication Technologies (ICT), represent just a few of the many variables that can influence regional economic growth. Integrating such factors into future analyses will contribute to a more comprehensive understanding of the determinants of economic growth and innovation in European regions. Our findings underscore the crucial role of R&D investments in driving technological advancement and fostering a culture of innovation within regions. By understanding the interplay between GDP, R&D expenditure, and patents, policymakers and stakeholders can make informed decisions to foster growth and competitiveness within their respective regions.

4.3 Efficiency of R&D Investments: The Patents/R&D relationship

To calculate this efficiency metric, the total number of patents granted in a region is divided by the total R&D expenditure in that same region. This ratio is obtained by dividing the number of patents per million inhabitants by the per capita spending on R&D. In other words, it relates the quantity of innovation produced (measured by patents) with the investments made (measured by R&D spending). It allows us to compare regions not only based on their absolute levels of investment and output but also on how effectively they utilize their R&D funds. A higher value of the ratio indicates greater efficiency in producing patents with the same amount of spending. To further analyze this efficiency metric, I used RStudio to create two files that identify the top 10 regions with the highest patents to R&D expenditure ratio and the bottom 10 regions with the lowest ratio. Using the R programming language, I calculated the ratio for each region and then sorted the data accordingly. The first file lists the regions that are the most efficient in utilizing their R&D funds, while the second file highlights the regions with the least efficiency. These files allow for a clear comparison and provide insights into which regions are leading in innovation efficiency and which are lagging. This is the file relating to the 10 Top Regions with a most effective Patents/R&D ratio:

Tab. 4

	region	patents_per_million_inhabitants	rd_expenditure_per_inhabitant	patents_per_euro_rd
1	Åland	120.618	65.587	1.8390535
2	Åland	120.618	65.587	1.8390535
3	Lubuskie	16.112	11.282	1.4281156
4	Opolskie	8.561	9.882	0.8663226
5	Severen tsentralen	3.550	4.184	0.8484704
6	Provincia Autonoma di Bolzano/Bozen	124.963	207.098	0.6034003
7	Friuli-Venezia Giulia	217.363	416.432	0.5219652
8	Severozapaden	1.399	3.905	0.3582586
9	Yuzhen tsentralen	2.665	7.751	0.3438266
10	Veneto	101.837	310.289	0.3282005

I would like to point out that the efficiency reported by the data (see Tab. 4) might seem surprising. For example, Åland has a relatively small population. This can affect the data as even a small number of patents may seem large when compared to the population and R&D expenditure. Among the regions listed above, I highlight the Patents/R&D ratio of Åland, which is the most efficient region with a ratio of 1.84 (proxy), indicating high productivity in terms of patents per euro spent on R&D. It means that for every unit of R&D expenditure per inhabitant, the region of Åland produces approximately 1.84 patents per million inhabitants. This value may include the fact that few high-profile technology companies contribute to a prosperous economy. Furthermore, the data could be truthful because, according to Eurostat, as of 2006 Åland was the 20th-wealthiest of the EU's 268 regions, and the wealthiest in Finland, with a GDP per inhabitant 47% above the EU mean. For example, wind power is rapidly developing, aiming at reversing the direction in the cables to the mainland in coming years. Next, I highlight the Lubuskie region which shows good efficiency with a ratio of 1.42812. Sources belonging to the Lubuskie Voivodeship government say that this region covers development in the area of innovative (modern) traditional industries generated on the basis of automotive industry, metal industry and wood, furniture and paper industries, enjoying innovative effects such as acceptance of pro-innovative attitudes, increased interest in selling new or istocuts improved products / services introduced to the market, with new solutions both in the field of medical technologies and services, and in relation to companies in the agri-food sector and companies supporting the development of specialization, especially in the field of information technology[43]. Among the first Top regions of the year 2010, 3 Italian regions stand out: Friuli-Venezia Giulia,Veneto and the Autonomous Province of Bolzano/Bozen

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[43] Lubuskie Specialization III: Innovative industry: https://innowacje.lubuskie.pl/en/smart-specializations/specialization-ii-innovative-industry

(which theoretically is a province and not a region, but is among the basic regions because it has significant autonomy and unique socio-economic characteristics). In contrast, some European regions show significantly lower efficiency in converting R&D expenditures into patents. Here are the ten regions (see Tab.5) with the lowest values in the patents/R&D expenditure ratio:

Tab. 5

	region	patents_per_million_inhabitants	rd_expenditure_per_inhabitant	patents_per_euro_rd
131	Canarias	5.048	124.881	0.040422482
132	Norte	7.230	199.011	0.036329650
133	Sicilia	4.378	138.391	0.031635005
134	Molise	2.938	103.316	0.028437028
135	Kýpros	2.900	105.230	0.027558681
136	Kýpros	2.900	105.230	0.027558681
137	Bratislavský kraj	9.513	348.094	0.027328825
138	Yugoiztochen	0.233	8.645	0.026951995
139	Nord-Norge	16.463	728.769	0.022590149
140	Extremadura	1.358	138.030	0.009838441

The region with the lowest conversion efficiency is Extremadura, which is a predominantly rural region of Spain, which may have an economic and industrial structure that is not conducive to high patent production, with a limited focus on technological innovation. One factor that led me to think about this is that it ranks last in Spanish communities by income and the population density is very low. The ratio is also very low in some island regions such as Cyprus, Sicily and the Canary Islands, which share a common characteristic: an economy heavily based on tourism. In these regions, the tourism sector dominates the economy, leaving less space and resources for investment in technological research and development. In Cyprus, for example, the situation is characterized by a strong dependence on tourism and financial services. With a ratio of patents per million inhabitants of 2.9 and R&D expenditure per inhabitant of 105.23 euros, the efficiency in converting research into patented innovation is very low, with a ratio of just 0.03. Sicily also shows a low conversion rate of R&D expenditure into patents. R&D expenses per inhabitant amount to 138.39

euros, 4.379 patents per million inhabitants, with a consequent ratio of 0.03164. This is because the Sicilian economy, dominated by tourism and agriculture, does not favor significant investments in innovative and technological sectors, thus limiting the production of patents. In addition, the Canary Islands, with a strong dependence on tourism, reflect an economic model similar to that of Cyprus and Sicily. Here, with R&D expenses per inhabitant of 124.88 euros and 5.05 patents per million inhabitants, the ratio is 0.04. The priority given to the tourism sector reduces the resources available for research and development, resulting in a low rate of patents compared to investments in R&D. To conclude, as we have already anticipated in the chapter regarding the disparities between Italian regions, in addition to the island regions, Molise emerges as another area with poor efficiency in the patent/R&D relationship. With a weak and poorly developed economy, it results in a ratio of 0.03. This region, with a small population and a strong focus on the primary sector, significantly limits opportunities for significant investment in research and development, making Molise one of the least effective regions in Italy in producing patented innovations. In summary, these regions represent clear examples of how a strong dependence on traditional economic sectors, such as tourism and agriculture, can hinder investment in research and development, thus reducing the ability to generate patents.

CHAPTER 5

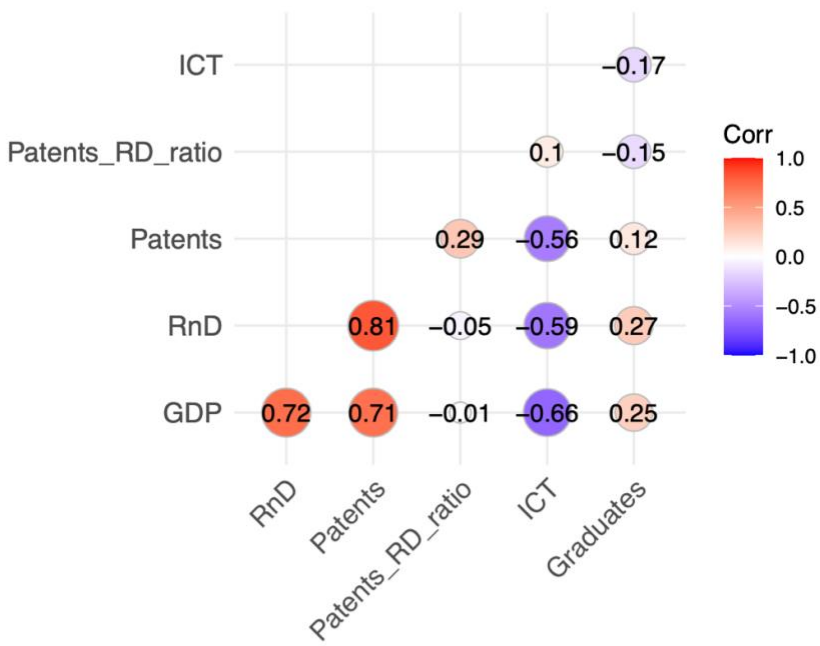
5. Determinants of GDP

In the previous chapters, we have meticulously examined the relationships between GDPs per capita and key economic indicators such as R&D expenditures and patent output across European regions. These analyses have illuminated the significant, albeit varied, positive correlations between these factors, highlighting the essential role of research and development in fostering regional economic growth and innovation. To deepen our understanding of the multifaceted drivers of economic performance, it is crucial to integrate additional dimensions into our analysis. Information and Communication Technology (ICT) infrastructure, in particular people who never used a computer , represents a pivotal factor in modern economic systems, facilitating innovation, productivity, and connectivity. Similarly, the level of students enrolled in tertiary education within a region serves as a proxy for human capital, indicating the availability of a skilled workforce capable of driving and sustaining economic growth. By employing correlation and regression analyses, we seek to unravel the complex interplay between these variables and their collective impact on regional economic performance.

5.1 Final driver's Correlation

In this concluding analysis, we take a more comprehensive approach by investigating the correlations between GDP and multiple drivers believed to influence regional economic growth in Europe. Specifically, we delve into the correlations between GDP (Euro per inhabitants), R&D expenditures (Euro per inhabitants), Patents (per million inhabitants), Patents on R&D, ICT infrastructure (related to broadband access, in particular I downloaded the dataset of people who never used a computer) and the human capital level (in particular the graduates' percentage). I conducted a correlation analysis using RStudio. The process started with loading the datasets from Eurostat into RStudio via the `read_excel()` function. Each file contained regional data for GDP, R&D, Number of Patents, Patents/R&D Ratio, ICT, and next, I eliminated duplicates to ensure data quality, thus avoiding inconsistencies when merging the datasets. We then renamed the "Values" columns to specific names such as "GDP" (per capita), "R&D", "Patents", "Patents_RD_ratio", "ICT", and "Graduates", to prevent confusion and duplication. Finally, the correlation matrix was calculated, revealing the relationships between the variables. This was the result:

Fig. 8



The graph (see Fig. 8) shows the correlation matrix between different economic and innovation variables for European regions. The variables considered are GDP, R&D, Number of Patents, Patents/R&D Ratio, ICT, and Graduates. Each circle represents the correlation between two variables: the color and size of the circle indicate the strength and direction of the correlation, respectively. The color of the circle indicates the direction of the correlation: for example, red indicates a positive correlation (the two variables tend to move in the same direction), while blue indicates a negative correlation (the two variables tend to move in opposite directions). In addition, the size of the circle indicates the strength of the correlation: larger circles indicate a stronger correlation, while smaller circles indicate a weaker correlation. As already represented in the previous chapters, the relationship between GDP and investments in R&D is clear: regions with a higher GDP tend to invest more in research and development. This means that more economically prosperous areas dedicate more resources to innovations and new technologies. Likewise, there is a close correlation between GDP and the number of patents. Regions with a higher GDP, in fact, tend to have a greater number of registered patents, which reflects greater inventive and creative activity. Not surprisingly, the correlation between R&D and Number of Patents is the strongest correlation in the matrix, indicating that regions with greater investments in R&D tend to produce more patents. The correlation matrix shows significant relationships between GDP, R&D, number of patents, patent/R&D ratio, ICT (measured as the percentage of individuals who have never used a computer) and graduates. Related to this, you are probably wondering about the fact because you see negative relationships. We see that GDP has a negative correlation with the data on non-use of computers. This means that in regions with a higher GDP, a smaller percentage of people have never used a computer. This is to be expected, as wealthier regions tend to have greater diffusion of technology and greater access to IT tools. Similarly, R&D also shows a negative correlation with the percentage of individuals who have never used a computer. This indicates that regions that invest more in research and development tend to be more technologically advanced, resulting in a minority of people who have never used a computer. Finally, we observe a negative correlation between the number of graduates and the percentage of people who have never used a computer. This suggests that in regions with a higher number of students enrolled in tertiary education, it is less likely to find people who have never used a computer. This relationship, although weak, nevertheless reflects the importance of higher education in the diffusion and use of technology. Overall, these relationships indicate that there is a positive link between economic growth, investment in research and development, patent production, efficiency in the use of research resources and access to higher education. These variables influence each other and contribute to the progress and competitiveness of the regions studied.

5.2 Final driver's Regression

As already mentioned, in my work I used RStudio to analyze the relationship between different economic and technological factors and gross domestic product (GDP). Here too, after having loaded various datasets containing numerical values on research and development (R&D), Patents, use of information and communication technologies (ICT) and number of graduates, I proceeded to merge these datasets, removing duplicates and handling any missing values to ensure the integrity of the combined dataset. Subsequently, as discussed in the paragraph preceding this one, I calculated the correlation matrix to evaluate the relationship between the variables and to measure the strength and direction of the linear relationship between two variables. A positive correlation indicates that, as one variable increases, the other tends to increase, while a negative correlation indicates that, as one variable increases, the other tends to decrease. To delve further, in this paragraph I ran a multiple linear regression using GDP as the dependent variable and the other variables as predictors. Regression allowed me to model the relationship between a dependent variable and one or more independent variables. While correlation only tells us that there is a relationship between two variables, regression allows us to quantify this relationship and also make predictions about the dependent variable based on the values of the independent variables. In my case, multiple linear regression helped determine how much and in what way factors such as R&D, patents, ICT and graduates influence GDP. Let's see the results from RStudio:

Fig. 9

Dependent Variable: GDP	Coefficient	Standard Error	Significance
(Intercept)	16,474.623	5,590.416	***
R&D	38.273	3.718	***
Patents	17.955	29.495	
ICT	-12,922.906	6,895.384	*
Graduates	243.178	90.838	**
Model Statistics	**Value**		
Observations	330		
R^2	0.708		
Adjusted R^2	0.704		
Residual Standard Error	12,480.000		
Significance Codes			
***	$p < 0.01$		
**	$p < 0.05$		
*	$p < 0.1$		

The table (see Fig. 9) shows the results of a multiple linear regression predicting GDP. Naturally, at first glance we can deduce little from these numbers which must be analyzed statistically. These linear regression outputs provide several key insights into the adequacy of the model and the importance of the independent variables in predicting GDP. Regarding the residuals:

- Min: -79838

- 1Q (First Quartile): -6782

- Median: 124

- 3Q (Third Quartile): 6456

- Max: 20821

These are the residuals of the regression, which represent the difference between the observed values of GDP in our dataset and the values predicted by the model. The distribution of residuals indicates that there are some data points with very high residuals (both negative and positive), suggesting that the model may not fully explain the variation in GDP.

Analyzing the Coefficients, we respectively have the GDP values which are the following:

- Estimate: 16474.623
- Std. Error: 5590.416
- t value: 2.947
- Pr(>|t|): 0.00344 (**)

Here the intercept represents the estimated value of GDP when all other independent variables are zero. It is significantly different from zero (p = 0.00344), meaning that the model found a significant value for the intercept. The values of R&D (Research and Development) are:

- Estimate: 38,273
- Std. Error: 3.718
- t value: 10.295
- Pr(>|t|): < 2e-16 (***). We see how R&D has a significant and positive impact on GDP (p < 0.001). A one unit increase in RD is associated with a 38.273 increase in the GDP estimator, controlling for other variables in the model. The values on the Patents are:

-Estimate: 17,955

- Std. Error: 29.495
- t value: 0.609
- Pr(>|t|): 0.54311. Patents is not found to be significant (p = 0.54311), which suggests that the relationship between Patents and GDP may not be statistically significant within this model. Regarding ICT, in this case people who have never used a computer, we have:

- Estimate: -12922.906
- Std. Error: 6895.384
- t value: -1.874

- Pr(>|t|): 0.06181. ICT shows a negative trend but is not statistically significant at the traditional level of $p < 0.05$ ($p = 0.06181$). This suggests that there is insufficient evidence to reject the null hypothesis that ICT does not have a significant effect on GDP. Regarding graduates, we have:

- Estimate: 243,178

- Std. Error: 90.838

- t value: 2.677

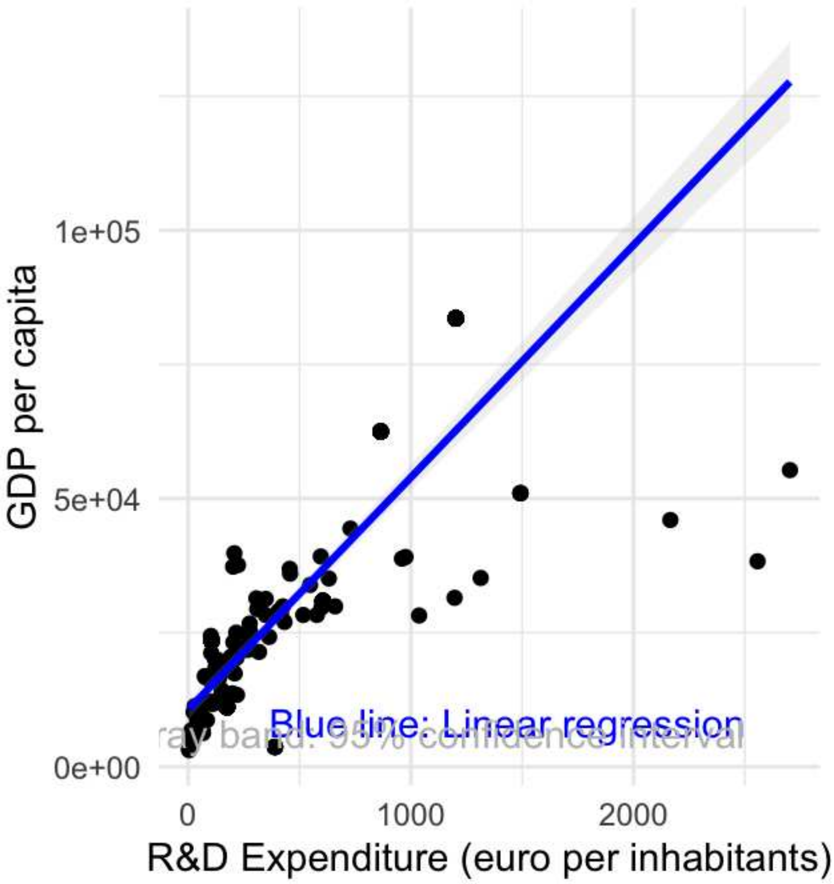
- Pr(>|t|): 0.00780 (**) Graduates are significant ($p = 0.00780$), indicating that there is a positive effect of having more graduates on the prediction of GDP. A one unit increase in the percentage of college graduates is associated with an increase of 243,178 in the GDP estimator. The other indicators of interest to us are:

- R-squared (R^2) of 0.708, which indicates that the model explains approximately 70.8% of the observed variation in GDP, which suggests that the independent variables considered (RD, Patents, ICT, Graduates) have a good collective predictive power on GDP. Adjusted - R-squared (corrected R^2) is 0.7044, therefore 70.44%.

- F-statistic: 197 out of 4 and 325 degrees of freedom, with a very low p-value (< 2.2e-16). Finally, the F-statistic is very high (very low p-value), indicating that the model as a whole is statistically significant.

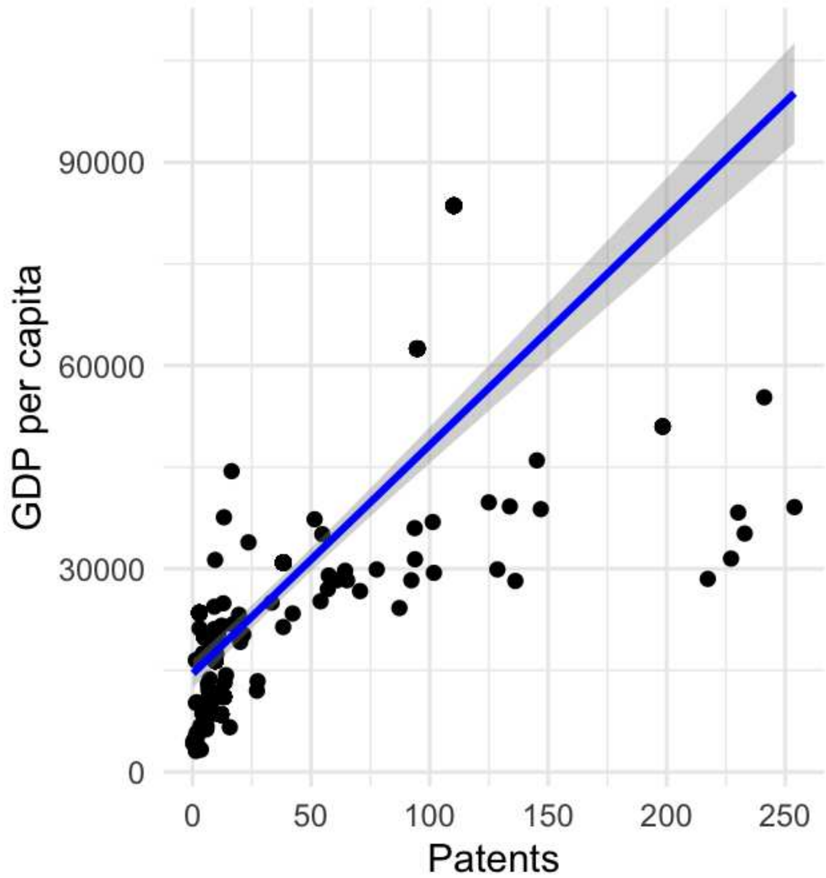
In addition to this, I tried to create one graph at a time that represents the relationship between an independent and a dependent variable, along with linear regression and confidence interval. I went in chronological order, starting from the relationship between GDP and R&D:

Fig. 10



The graph (Fig. 10) displays the relationship between GDPs per capita (y-axis, left) and R&D spending (x-axis, right). Each point represents a region or geographic area in the dataset. The gray area around the regression line represents the 95% confidence interval for the regression line estimate. The blue line represents the estimate of the linear relationship between R&D spending and GDP per capita. The positive slope of the line suggests that, in general, as R&D spending increases, GDP per capita increases. Furthermore, it suggests that, holding the other variables in the model constant, a unit increase in R&D spending is associated with an increase in GDP per capita of approximately 38.27 euros. This value is represented by the estimated coefficient for the RD variable in the regression model. Continuing in order, it is the turn of the direct relationship between GDP and Patents (see Fig. 11):

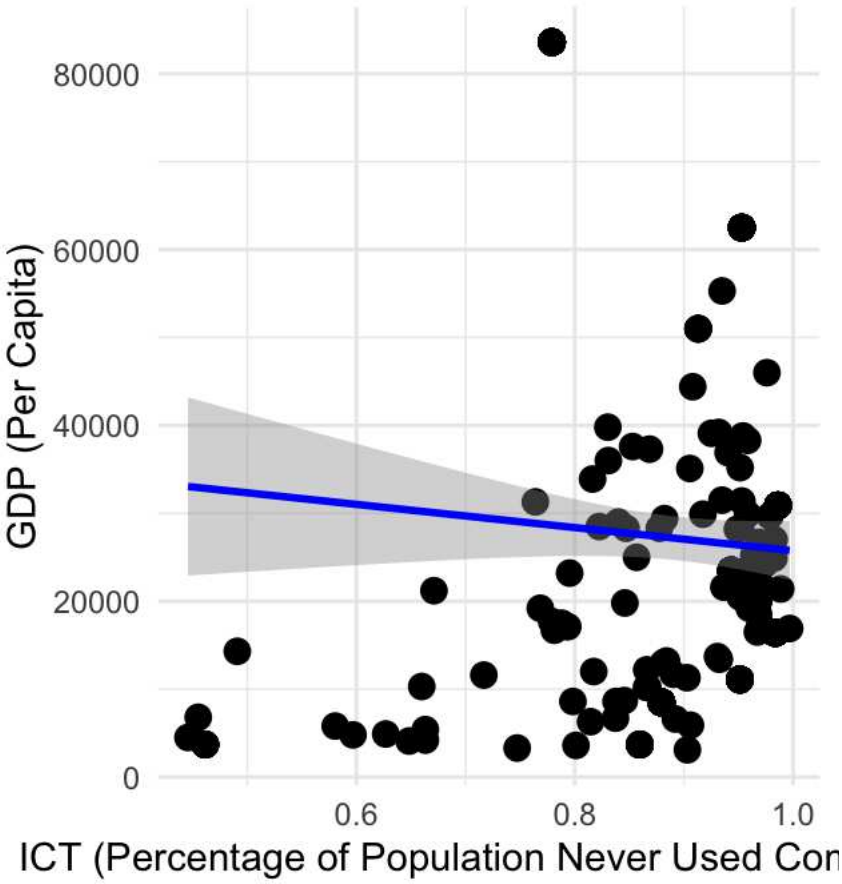
Fig. 11



From the linear regression we know that the coefficient for patents is 17.955 (although it is not statistically significant, p-value = 0.54311). Although the coefficient is not significant, the positive slope visible in the graph suggests a positive relationship between patents and GDP per capita and that a greater number of patents is associated with higher GDP. The dispersion of points around the regression line indicates that, although there is a positive trend, there are other variables not included in the model that could influence GDP. In conclusion, the graph shows that innovation and patenting activity can be important factors for the economic growth of regions.

Regarding the direct relationship between GDPs per capita and ICT (percentage of people who have never used a computer) we have the following graph (see Fig. 12):

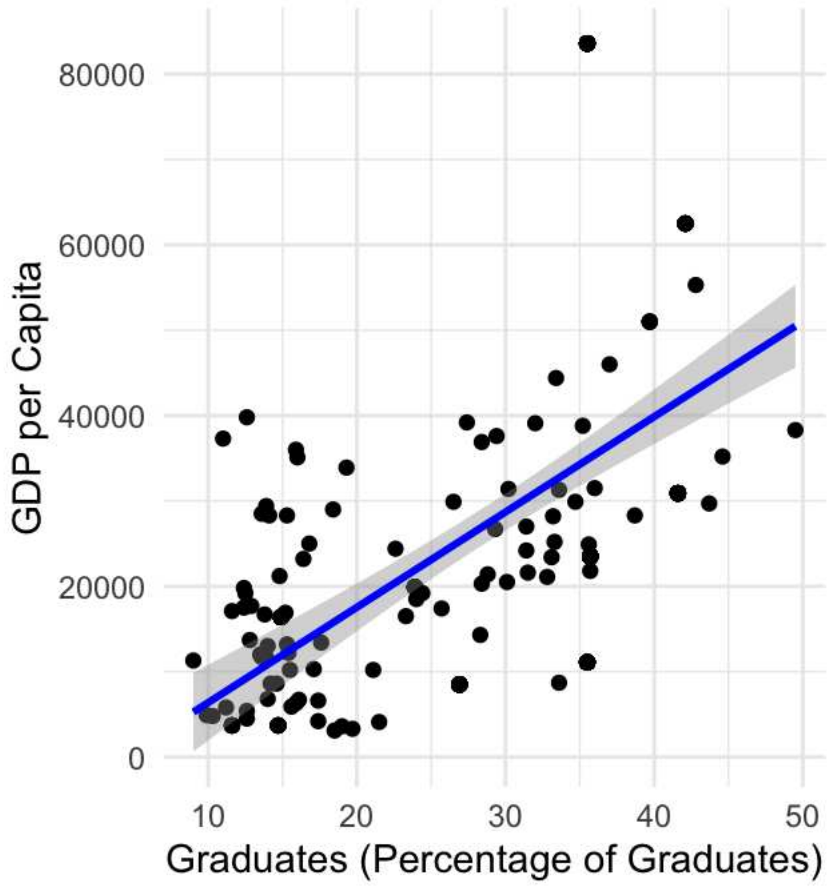
Fig. 12



Here too, the blue line represents the linear regression line that tries to model the relationship between ICT and GDP per capita. The negative slope of the line suggests a negative relationship between the percentage of people who have never used a computer and GDP per capita. This indicates that an increase in the percentage of people who have never used a computer is associated with a decrease in GDP per capita. From the linear regression we know that the coefficient for ICT is -12922.906 with a standard error of 6895.384, while the t-value is -1.874 and the p-value is 0.06181, indicating that the negative relationship between ICT and GDP is not statistically significant at the traditional level of $p < 0.05$ (but it is close, so it can be considered marginally significant). Overall, the negative relationship between ICT and GDP per capita suggests that a higher percentage of people who have never used a computer is associated with lower GDP per capita.

To end the round of direct relationships, we created the GDP - Graduates graph. Here are the results (see Fig. 13):

Fig. 13



The graph represents a relationship between gross domestic product (GDP) per capita and the percentage of graduates in the population. On the x axis we find the percentage of graduates, while on the y axis the GDP per capita is represented. The regression line has a positive slope, indicating a positive relationship between the percentage of graduates and GDP per capita. This suggests that, in general, an increase in the percentage of people with tertiary education is associated with an increase in GDP per capita. From the coefficient table of the regression model, we know that the coefficient for Graduates is statistically significant (p-value =

0.00780, which is below the significance level of 0.05). This means that there is statistical evidence that the percentage of graduates has a significant positive effect on GDP per capita. The confidence interval around the regression line is relatively narrow, indicating that the estimate of the relationship between graduates and GDP is quite precise. However, some uncertainty still exists, as indicated by the width of the gray band. As already mentioned, this relationship is statistically significant, suggesting that investment in tertiary education can be an important driver of economic growth.

CHAPTER 6

6. Conclusions

The initial literature review provided a comprehensive framework for understanding the various factors influencing regional economic growth. Going in chronological order, we have discussed the GDP and its evolutions throughout history through the classics, starting from the works of Kuznets, passing through Samuelson and mentioning the person to whom our faculty was dedicated, Giorgio Fuà. GDP is a fundamental measure of economic size and health. However, its limitations as a sole indicator of progress have been noted, necessitating a broader exploration of its determinants. Immediately afterwards, we moved on to research the role of R&D, driving innovation and economic growth, which is well-documented. Investments in R&D lead to the creation of new technologies and patents, which in turn spur economic development. The literature emphasized the symbiotic relationship between R&D and patents production, emphasizing that regions with higher R&D expenditure tend to generate more patents and experience greater economic growth. I also made a small focus on the disparities in generating patents in Italy, underlining the profound difference between North and South that continues to remain. Then I discussed the importance of human capital, particularly higher education, which in economic performance is a recurrent theme. Not by chance, regions with higher proportions of graduates are better positioned to leverage technological advancements and innovations, leading to higher GDP. I finished the literature by focusing on technological advancement, or the diffusion of information and communication technologies (ICT), which is another critical factor. Access to and utilization of technology are essential for modern economic activities. It's highlighted how regions with better technological infrastructure tend to perform better economically. After the literature part, I wanted to see firsthand whether the literary historical part aligned with the empirical results that I undertook to find, through statistical methods such as correlation and regression. This study provided robust empirical evidence, thanks to the strong correlation I found across the variables. The positive correlations between GDP and factors such as R&D expenditure, graduates and ICT usage underlined the multifaceted nature of economic development. The study also highlighted some nuances: for example, while R&D expenditure is positively correlated with GDP, the efficiency of this expenditure in terms of patent production varies across regions. This suggests that simply increasing R&D spending is not sufficient; effective management and conductive innovation ecosystems are also crucial. This analysis needed deeper research, which could be seen through the multiple linear regression that I used to model the relationship between GDP and independent variables including R&D, patents, ICT usage, and the number of graduates. The model's residuals ranged from -15,806.8 to 26,879.7, with a multiple R-squared value of 0.6435, meaning that approximately 64.35% of the variability in GDP is explained by the model. The F-statistic of 32.13 and a p-value less than 2.2e-16 indicate that the overall model is statistically significant. By "statistically significant" we refer to the determination that a result is unlikely to be due to random chance alone. It allows researchers to draw meaningful conclusions from their findings. So what can we conclude from our data? That pursuing good economic performance (GDP) in a European region through strategic investments in research and development (R&D), effective patenting policies, advanced ICT infrastructure and quality tertiary education is a complex but achievable goal. This combination takes on even greater importance if we consider the crucial role that young people will play in the future. Investing in their education today means preparing the innovative minds of tomorrow, capable of generating revolutionary ideas and transforming those ideas into patents that will drive technological progress and economic growth. The objective of any governance, in my opinion, should be to increase funding for scientific and technological research, with a focus on strategic and emerging sectors, investing in higher education, providing funding and resources to improve access and quality education, for example by fueling the deployment of high-speed digital infrastructure to ensure connectivity and the availability of reliable internet services. From personal experience, I have seen firsthand the level of education in the Marche region which in my opinion is progressively doing an excellent job, the desire of a young person is fueled by promoting collaboration between academic institutions, research centres, businesses and authorities public to promote the exchange of knowledge and best practices, also thanks to training and above all paid internships, which will bridge the gap between education and the world of work. Another focus that governance must fully focus on is imparting to young people, especially nowadays, solid digital skills that are fundamental for success in any field, in order to create a qualified and adaptable workforce. This is pursued providing children with early and adequate access to ICT technologies prepares them to face the challenges and opportunities of the world around them, especially in the digital era which will be implemented year after year. It is therefore clear that, taking up the analysis carried out in the previous chapter, regions with individuals who have never used a computer will always be profoundly behind. In conclusion, by prioritizing these investments in our youth, innovation, and digital infrastructure, regions can cultivate a fertile ground for sustained economic growth and a prosperous future.

Acknowledgements

I would like to express my deepest gratitude to Professor Riccardo Cappelli, whose mentorship has been invaluable throughout my thesis journey. His guidance in navigating the challenges and changes in choosing a suitable thesis topic was instrumental in its successful completion. From the outset, during his Industrial Organization course, Professor Cappelli provided unwavering support and was always available to assist whenever needed. His prompt responses and insightful guidance significantly enriched my research experience.

Mastering RStudio initially presented a significant challenge, but through his patient encouragement, I gradually became proficient with the software. This proficiency proved pivotal for achieving the empirical results of my thesis and conducting thorough and rigorous analyses.

Last but not least, I owe a profound debt of gratitude to my parents, whose unwavering support and encouragement have been the cornerstone of my academic journey. They have always ensured that I never lacked anything, providing me with the most optimal conditions, including the comforts and cutting-edge tools necessary for my thesis work. Their dedication to my education and their sacrifices—including staying at home and investing in my future—ensured I had every opportunity to excel. Their belief in me has been a constant source of strength and motivation, for which I am deeply thankful.

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Appendix

Pag. 21 - N. of Patents by year (Nuts 2)

Regions	Year 2019	Year 2021	Year 2023
Abruzzo	57	59	35
BASILICATA	42	25	26
CALABRIA	88	154	79
CAMPANIA	99	147	142
EMILIA-ROMAGNA	1237	1259	1082
FRIULI-VENEZIA GIULIA	293	316	214
LAZIO	844	1004	715
LIGURIA	159	191	146
LOMBARDIA	3232	3491	2847
MARCHE	377	333	298
MOLISE	2	12	8
PIEMONTE	1710	1787	2040
PUGLIA	114	189	105
SARDEGNA	20	15	28
SICILIA	55	82	62
TOSCANA	520	477	404
TRENTINO-ALTO ADIGE/S√úDTIROL	42	46	41
UMBRIA	61	71	50
VALLE D'AOSTA/VALLE D'AOSTE	1	4	3
VENETO	1156	1378	1076

The numbers in the table indicate the count of patents granted in various regions of Italy for the years 2019, 2021, and 2023. This data provides insights into the level of innovation and technological development occurring in each region over time, as measured by the issuance of patents.

Pag. 23 – Patents Intensity

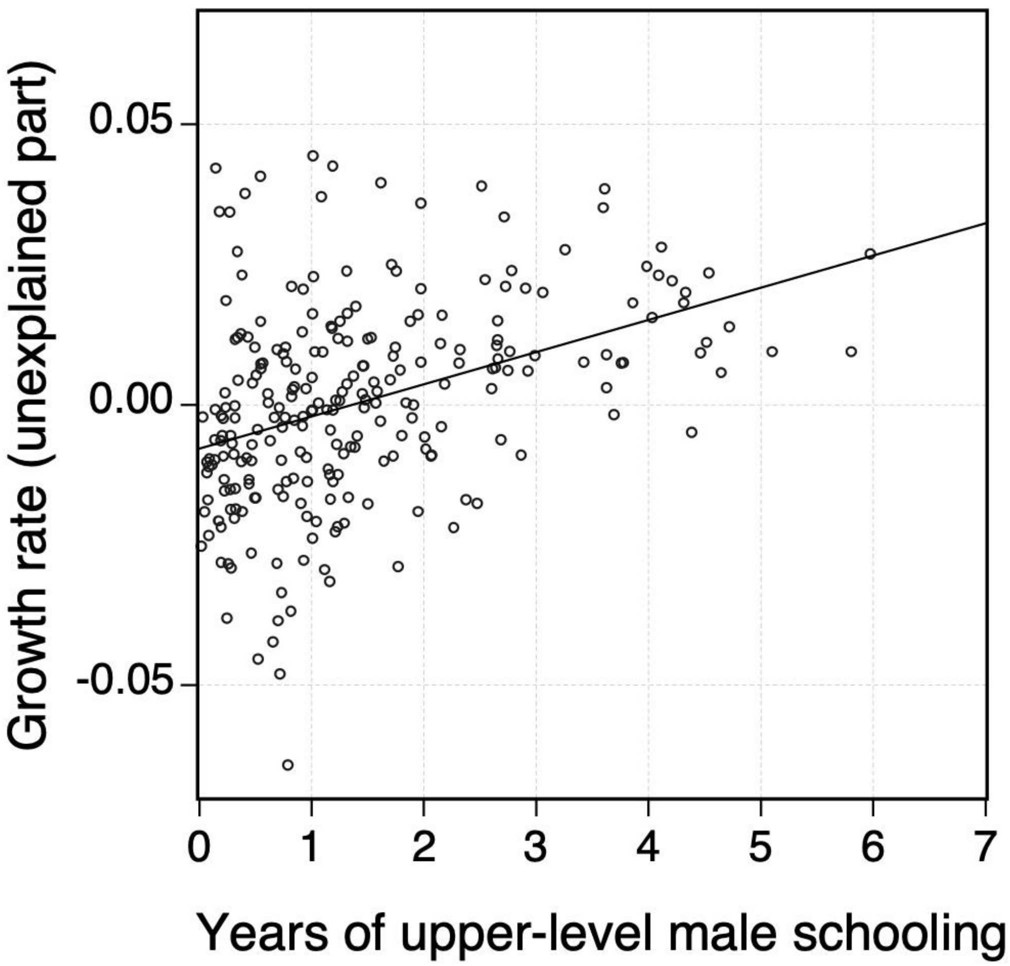
Regions	**Year 2023**	**Inhabitants per region**	**Patents per capita**
ABRUZZO	35	1.315.000	0,00007757
BASILICATA	26	567.118	0,00005466
CALABRIA	79	1.957.000	0,00005519
CAMPANIA	142	5.827.000	0,0000302
EMILIA-ROMAGNA	1082	4.453.000	0,00049607
FRIULI-VENEZIA GIULIA	214	1.216.000	0,00115132
LAZIO	715	5.897.000	0,00210802
LIGURIA	146	1.557.000	0,00025755
LOMBARDIA	2847	10.040.000	0,00197859
MARCHE	298	1.532.000	0,00035183
MOLISE	8	308.493	0,0000389
PIEMONTE	2040	4.376.000	0,00217824
PUGLIA	105	4.048.000	0,00010993
SARDEGNA	28	1.648.000	0,0000182
SICILIA	62	5.027.000	0,00002208
TOSCANA	404	3.737.000	0,00024512
TRENTINO-ALTO ADIGE/S√úDTIROL	41	539.898	0,00036674
UMBRIA	50	884.640	0,00008139
VENETO	3	4.905.000	0,00054088
VAL D'AOSTA	1076	126.202	0,00192548

This table provides a detailed overview of patent distribution across various regions in Italy, highlighting the significant regional disparities in innovation activity. The columns represent the regions, the number of patents, the population in each region, and the number of patents per capita.

Pag. 32 – Panel regression by Barro (2013)

EDUCATION AND ECONOMIC GROWTH

FIG. 2. Growth Rate versus Schooling



This is a scatter plot that shows the relationship between economic growth rate and average years of upper-level schooling for males in several countries. There is a positive correlation between these two variables, which means that countries with a higher average number of years of upper-level male schooling tend to also have higher economic growth rates. This suggests that education may play a role in economic growth.

GDP and R&D Correlation

Pag. 41 - Top 50 regions

Year	Regions	GDP_Top	R&D_Top
2021	Prov. Brabant wallon	52500	5901.458
2019	Stuttgart	53300	3971.883
2019	Braunschweig	51300	3901.82
2021	Stuttgart	54500	3742.424
2019	Hovedstaden	68500	3177.061
2021	Braunschweig	49100	3074.64
2021	Oberbayern	63300	2807.117
2019	Trøndelag	54400	2769.029
2021	Baden-Württemberg	48700	2733.913
2019	Baden-Württemberg	47400	2733.764
2019	Oberbayern	61100	2685.045
2021	Västsverige	49200	2600.198
2021	Tübingen	47200	2586.083
2021	Stockholm	71200	2570.625
2021	Karlsruhe	47300	2533.672
2018	Trøndelag	54500	2518.025
2020	Trøndelag	49900	2443.118
2019	Karlsruhe	46000	2435
2021	Prov. Vlaams-Brabant	47600	2416.546
2019	Tübingen	45500	2354.937
2019	Västsverige	44900	2305.94
2019	Stockholm	64400	2158.434
2020	Helsinki-Uusimaa	55500	2037.965
2018	Helsinki-Uusimaa	55100	1919.035
2022	Praha	59200	1651.299
2018	Région de Bruxelles-Capitale	69600	1572.616
2020	Zuid-Nederland	45100	1469.503
2020	Vlaams Gewest	40600	1449.601
2018	Norge	57100	1431.886
2020	Norge	53300	1349.828
2020	Manner-Suomi	43000	1260.598
2018	Zuid-Nederland	43800	1252.509
2020	Praha	44300	1240.452
2018	Vlaams Gewest	40900	1205.343
2022	Luxembourg	118700	1173.062
2018	Manner-Suomi	42300	1172.998

2018	Luxembourg	98900	1170.256
2020	Luxembourg	102400	1129.332
2018	Praha	44300	1110.467
2020	West-Nederland	51300	1079.199
2020	Région wallonne	29200	1067.476
2018	Nord-Norge	53400	1039.127
2022	Jihovýchod	23600	590.908
2022	Střední Čechy	22700	518.137
2022	Česko	25800	515.979
2022	Eesti	27000	481.859
2022	Eesti	27000	481.859
2022	Eesti	27000	481.859
2022	Eesti	27000	481.859

Pag. 42 - Bottom 50 regions

2018	Region Sumadije i Zapadne Srbije	4100	5.41
2018	Sud-Est	8800	7.356
2019	Region Sumadije i Zapadne Srbije	4400	7.543
2020	Region Sumadije i Zapadne Srbije	4500	7.692
2019	Sud-Est	9300	7.758
2018	Srbija - jug	4100	8.083
2020	Sud-Est	9000	8.305
2021	Region Sumadije i Zapadne Srbije	5300	8.546
2019	Srbija - jug	4400	8.73
2020	Sud-Vest Oltenia	8800	8.971
2021	Sud-Est	10200	9.935
2020	Srbija - jug	4500	9.965
2022	Region Sumadije i Zapadne Srbije	6100	10.008
2021	Srbija - jug	5500	10.017
2019	Region Juzne i Istocne Srbije	4300	10.25
2018	Macroregiunea Doi	7600	10.484
2019	Sud-Vest Oltenia	9000	10.707
2022	Srbija - jug	6300	10.827
2021	Sud-Vest Oltenia	9600	11.49
2018	Region Juzne i Istocne Srbije	4000	11.496
2022	Region Juzne i Istocne Srbije	6500	11.881
2021	Region Juzne i Istocne Srbije	5600	11.906
2018	Nord-Est	6700	12.836
2020	Region Juzne i Istocne Srbije	4400	12.878
2020	Macroregiunea Doi	8100	15.384
2019	Macroregiunea Doi	8200	15.807
2021	Macroregiunea Doi	8900	16.025
2018	Severen tsentralen	5500	17.115
2018	North Macedonia	5700	18.827
2018	Severna Makedonija	5700	18.827
2018	Severna Makedonija	5700	18.827
2018	Severna Makedonija	5700	18.827
2018	Severna Makedonija	5700	18.827
2019	Nord-Vest	10700	19.01
2020	North Macedonia	5800	19.476
2020	Severna Makedonija	5800	19.476

2020	Severna Makedonija	5800	19.476
2020	Severna Makedonija	5800	19.476
2020	Severna Makedonija	5800	19.476
2019	Severen tsentralen	5900	19.862
2019	North Macedonia	6000	19.943
2019	Severna Makedonija	6000	19.943
2019	Severna Makedonija	6000	19.943
2019	Severna Makedonija	6000	19.943
2019	Severna Makedonija	6000	19.943
2021	Nord-Est	8000	20.553
2021	Severen tsentralen	7100	21.768
2021	Yugoiztochen	8100	22.497
2021	Severna i Yugoiztochna Bulgaria	7500	23.963
2022	North Macedonia	NA	26.941
2022	Severna Makedonija	NA	26.941
2022	Severna Makedonija	NA	26.941
2022	Severna Makedonija	NA	26.941
2022	Severna Makedonija	NA	26.941
2022	Severozápad	17300	68.081
2022	Region Vojvodine	9100	78.629

The provided tables detail the economic and research and development (R&D) expenditures for the Top and Bottom regions in Europe, highlighting significant disparities. The first table lists regions with high GDP and R&D expenditures, demonstrating the correlation between economic output and investment in research and development. The second table shows regions with lower GDP and R&D expenditures, highlighting areas that may face economic and developmental challenges.

Region	Patents/R&D
Abruzzo	0,09648172
Åland	1,83905347
Algarve	0,05018233
Alsace (NUTS 2013)	0,27164176
Andalucía	0,04803807
Aquitaine (NUTS 2013)	0,12532645
Aragón	0,19399458
Auvergne (NUTS 2013)	0,18951139
Basilicata	0,08057754
Basse-Normandie (NUTS 2013)	0,12479729
Bourgogne (NUTS 2013)	0,2368076
Bratislavský kraj	0,02732882
Bretagne (NUTS 2013)	0,2375205
Bucureşti-Ilfov	0,09392592
Calabria	0,11873211
Campania	0,04864055
Canarias	0,04042248
Cantabria	0,06293738
Castilla y León	0,0514295
Castilla-La Mancha	0,06621521
Cataluña	0,13191921
Centre (FR) (NUTS 2013)	0,18435957
Centru	0,16920115
Champagne-Ardenne (NUTS 2013)	0,31673712
Comunidad de Madrid	0,06331607
Comunidad Foral de Navarra	0,10525778
Comunitat Valenciana	0,09877404
Corse (NUTS 2013)	0,10404465
Dél-Alföld	0,24162746
Dél-Dunántúl	0,19669917
Dolnośląskie	0,20528956
Eesti	0,07534298
Emilia-Romagna	0,28800544
Észak-Alföld	0,08785817
Észak-Magyarország	0,08745269
Etelä-Suomi	0,20284612
Extremadura	0,00983844
Franche-Comté (NUTS 2013)	0,1577917
Friuli-Venezia Giulia	0,52196517

Galicia	0,05655487
Haute-Normandie (NUTS 2013)	0,23838977
Helsinki-Uusimaa	0,20450001
Hovedstaden	0,08922893
Ile de France	0,13287618
Illes Balears	0,08990683
Innlandet	0,05920973
Jadranska Hrvatska	0,05821018
Jihovýchod	0,12515747
Jihozápad	0,04488935
Közép-Dunántúl	0,16368178
Kujawsko-pomorskie	0,24552575
Kýpros	0,02755868
La Rioja	0,04897105
Languedoc-Roussillon (NUTS 2013)	0,07641971
Länsi-Suomi	0,18986413
Latvija	0,23451802
Lazio	0,04309979
Liguria	0,14161613
Limousin (NUTS 2013)	0,21470881
Lombardia	0,20468515
Lorraine (NUTS 2013)	0,20140539
Lubuskie	1,42811558
Luxembourg	0,09166506
Małopolskie	0,22211549
Malta	0,09906826
Marche	0,29692554
Midi-Pyrénées (NUTS 2013)	0,07899546
Midtjylland	0,26016074
Molise	0,02843703
Moravskoslezsko	0,06734929
Nord-Est	0,14801266
Nord-Norge	0,02259015
Nord-Pas-de-Calais (NUTS 2013)	0,1751929
Nord-Vest	0,08932614
Nordjylland	0,22213866
Norte	0,03632965
Nyugat-Dunántúl	0,13805291
Opolskie	0,86632261
País Vasco	0,10746289
Pays de la Loire (NUTS 2013)	0,19129792
Picardie (NUTS 2013)	0,18212711
Piemonte	0,17855775
Pohjois- ja Itä-Suomi	0,13129414
Poitou-Charentes (NUTS 2013)	0,16399645
Pomorskie	0,14644267

Praha	0,04541731
Principado de Asturias	0,0415142
Prov. Antwerpen	0,15299254
Prov. Brabant wallon	0,09000524
Prov. Hainaut	0,12024767
Prov. Liège	0,24012106
Prov. Limburg (BE)	0,25573988
Prov. Namur	0,15428444
Prov. Oost-Vlaanderen	0,19486535
Prov. Vlaams-Brabant	0,17729326
Prov. West-Vlaanderen	0,30623994
Provence-Alpes-Côte d'Azur (NUTS 2013)	0,15766994
Provincia Autonoma di Bolzano/Bozen	0,60340032
Provincia Autonoma di Trento	0,08665648
Puglia	0,07253118
Région de Bruxelles-Capitale/Brussels Hoofdstedelijk Gewest	0,10961518
Región de Murcia	0,11408208
Rhône-Alpes (NUTS 2013)	0,25258786
Sardegna	0,04176982
Severen tsentralen	0,84847036
Severoiztochen	0,17471702
Severovýchod	0,20416156
Severozápad	0,24220008
Severozapaden	0,35825864
Sicilia	0,03163501
Sjælland	0,18277195
Śląskie	0,17292486
Stredné Slovensko	0,05179564
Střední Čechy	0,07099692
Střední Morava	0,09841944
Sud-Est	0,11363636
Sud-Muntenia	0,09300863
Sud-Vest Oltenia	0,04370111
Syddanmark	0,22472563
Toscana	0,18723421
Trøndelag	0,06706518
Umbria	0,1546031
Unterfranken	
Valle d’Aosta/Vallée d’Aoste	0,25482249
Västsverige	
Veneto	0,32820048
Vest	0,23219771
Východné Slovensko	0,10392754
Warmińsko-mazurskie	0,07292248
Wielkopolskie	0,148335

Yugoiztochen	0,026952
Yugozapaden	0,1111919
Yuzhen tsentralen	0,3438266
Zachodniopomorskie	0,31004759
Západné Slovensko	0,13611757

This table provides a detailed examination of the relationship between patents and R&D expenditures across various European regions, revealing significant differences in innovation efficacy. The "Patents/R&D" column represents the number of patents produced per unit of R&D expenditure, indicating the efficiency of converting R&D investments into patented innovations

Correlation - RStudio Codes

Pag. 57

```
# Caricamento dei dataset
GDP_2010 <- read_excel("Desktop/Tesi/Final regression/GDP 2010 (euro x inhabitants).xlsx")
RD <- read_excel("Desktop/Tesi/Final regression/RD (euro x inhabitant).xlsx")
Patents <- read_excel("Desktop/Tesi/Final regression/Patents per million inhabitants (2012).xlsx")
Patents_RD_ratio <- read_excel("Desktop/Tesi/Final regression/patents_rd_ratio.xlsx")
ICT <- read_excel("Desktop/Tesi/Final regression/ICT.xlsx")
Graduates <- read_excel("Desktop/Tesi/Final regression/Graduates.xlsx")

# Rimuovere i duplicati da ogni dataset
GDP_2010 <- GDP_2010[!duplicated(GDP_2010$Regions), ]
RD <- RD[!duplicated(RD$Regions), ]
Patents <- Patents[!duplicated(Patents$Regions), ]
Patents_RD_ratio <- Patents_RD_ratio[!duplicated(Patents_RD_ratio$Regions), ]
ICT <- ICT[!duplicated(ICT$Regions), ]
Graduates <- Graduates[!duplicated(Graduates$Regions), ]

# Rinominare le colonne 'Values' per evitare duplicati
names(GDP_2010)[2] <- "GDP"
names(RD)[2] <- "RnD"
```

```
names(Patents)[2] <- "Patents"

names(Patents_RD_ratio)[2] <- "Patents_RD_ratio"

names(ICT)[2] <- "ICT"

names(Graduates)[2] <- "Graduates"


# Unire i dataset in base alla colonna "Regions"

merged_data <- merge(GDP_2010, RD, by = "Regions", all = TRUE)

merged_data <- merge(merged_data, Patents, by = "Regions", all = TRUE)

merged_data <- merge(merged_data, Patents_RD_ratio, by = "Regions", all = TRUE)

merged_data <- merge(merged_data, ICT, by = "Regions", all = TRUE)

merged_data <- merge(merged_data, Graduates, by = "Regions", all = TRUE)


# Rimuovere le righe con valori mancanti

merged_data <- na.omit(merged_data)


# Calcolare la matrice di correlazione

correlation_matrix <- cor(merged_data[,2:7])  # Ignoriamo la colonna "Regions"
```

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```
# Abbiamo già creato il dataset `merged_data` e rimosso le righe con valori mancanti

# Rinominare le colonne per semplicità
colnames(merged_data) <- c("Regions", "GDP", "RnD", "Patents", "Patents_RD_Ratio", "ICT", "Graduates")

# Convertire le colonne in numerico
merged_data$GDP <- as.numeric(merged_data$GDP)
merged_data$RnD <- as.numeric(merged_data$RnD)
merged_data$Patents <- as.numeric(merged_data$Patents)
merged_data$Patents_RD_Ratio <- as.numeric(merged_data$Patents_RD_Ratio)
merged_data$ICT <- as.numeric(merged_data$ICT)
merged_data$Graduates <- as.numeric(merged_data$Graduates)

# Creare il modello di regressione lineare multipla
model <- lm(GDP ~ RnD + Patents + Patents_RD_Ratio + ICT + Graduates, data = merged_data)

# Visualizzare i risultati del modello
summary(model)
```