THE IMPACT OF R&D INVESTMENT IN THE ICT SECTOR ON LABOUR PRODUCTIVITY

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The Impact of R&D Investment in the ICT Sector on Labour Productivity

Abstract

R&D is a crucial determinant of labour productivity and it is fairly dependant on firms' ICT level. The main purpose of this paper is to assess whether private R&D investment in ICT has a positive impact on labour productivity. We use cross-sectional data on 22 member states of the EU, taken from the PREDICT and AMECO databases, to run and analyse two regressions: estimation of the impact of the variation of R&D investment in the ICT sector on the variation of productivity; and the estimation of the impact of the variation of R&D investment in the non-ICT sector on the variation of productivity. The main finding is that the impact of R&D investment in the non-ICT sectors is higher than the impact of R&D investment in the ICT sectors, but a word of caution is required, as the models may face limitations concerning omitted variable bias.

Keywords

R&D Investment; ICT Sector; Non-ICT Sector; Labour Productivity

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1. Introduction

During the COVID-19 pandemic, there was a major effort to accelerate the digital transformation of services from both the private and public sectors, in Portugal and also in most countries around the world.

Historically, the Portuguese economy has always been characterized by low productivity when compared to other European countries. This feature of the Portuguese economy has negatively impacted our living standards when compared to central or north Europeans. Taking into account the importance that productivity has to our country's output and consequently, in our living standards, the objective of our work was to study how can R&D investment in the Information and Communication Technologies sector (ICT) affect a country's productivity.

Productivity can be measured as the output of an hour of work. If the population of a country is more productive than another, the most productive can have more leisure time while earning more, both positively impacting welfare. The productivity level of a country depends on other factors such as the accumulation of physical capital, human capital, the number of hours worked (since labour has diminishing marginal returns), and also technology.

Although income is not the only factor influencing someone's quality of life, the GDP per capita has a great influence on a population's welfare. This indicator can be seen as the average output of a population and is the product of two factors: the number of hours worked and what is produced on average by one hour of work. Both of these variables differ from country to country, but, due to biological constraints and individual choices, the average amount of hours worked is less volatile across countries than productivity.

The disadvantage in productivity that Portugal has motivated us to do this study. With the pandemic, everyone experienced a massive progress in the adoption of new technologies, this progress in the digitalization in the private and public sectors can be seen as a technological shock in the economy. Now that the pandemic seems to be closer to the end and there are no restrictions or lockdowns, some of this progress in digitalization can be applied in the economy to make it more productive. For Portugal, there could be convergence with the most productive countries. Given this opportunity and the fact that Portugal is going to receive an unprecedented amount of funds to apply the PRR (*Plano de Recuperação e Resiliência*), we have a unique opportunity to increase our productivity which is key to improve our quality of life. This is the purpose of this project, to find how the investment in the ICT sector (Information and Communication

Technologies) impacts the productivity of the economy, and what it can mean for our future given the changes that happened during the pandemic and the investment that will be made in the years to come.

This paper has 10 sections and is organized in the following way. Section 2 presents some literature about investment. Section 3 e 4 are focused on a brief context on R&D and technological innovation. Section 5 is dedicated to a literature review on this topic. Section 6 explains the data used in our analysis. In Section 7, we describe how the data was handled and the methodology used in the process. In Section 8, we present the results stemming from our analysis. In Section 9, we present some of the limitations of this paper. And lastly, in Section 10, we present the conclusion of our study.

2. The Role of R&D Investment in Productivity

Research and Development (R&D) comprises the creative and systematic work carried out in order to increase the stock of knowledge and to conceive new applications of available knowledge (OECD, 2015).

Globally, empirical literature points out that R&D investments seem to be related with both direct and indirect positive effects on the companies' value added; with the indirect effect being the increase of total factor productivity (TFP). Moreover, research suggests that R&D undertaken in one firm can have externalities, as it affects competing firms and thus may lead to a convergence of TFP levels within an industry. In this context, as innovation may have a high social rate of return, but a low private rate of return, it is also important that the government intervenes in this field.

Actually, after the economic crisis, governments have devoted more attention to the design of R&D policies in order to restore competitiveness and reach a strong and sustainable growth. In this field, innovation policy mix has been changing gradually with targeted ones being more important as compared to generic policies.

Although in the area of innovation there is a variety of actors, instruments and aims, it is important to highlight the role of information and communication technology (ICT) in a new world where people telework, firms export more (e-commerce), environmental concerns exist and reorganization and automatization of processes are crucial for efficiency. ICT is defined as "different types of communications networks and the technologies" which "fulfil or enable the function of information processing and communication by electronic means" (OECD, s.d.).

According to (Biagi, 2013), ICT can be generally considered a General-Purpose Technology (GPT) given its potential to generate increases in the productivity in the whole economy. Hence, R&D investment in ICT sectors can lead to new ICT goods and services that can also be used by non-ICT sectors, amplifying the effects on productivity. As a result, the diffusion of ICT could be justified on the grounds of the spillover effects associated with them: vertical spillovers between the ICT producing sector and a particular productive ICT-using sector; horizontal spillovers between different ICT-using sectors. To better understand these dynamics, this study will be devoted to the analysis of the impact on productivity of R&D investments made by firms in the ICT sector.

3. Technological Innovation in Portugal

Technological innovation is a crucial determinant of productivity and, consequently, of wages, having both been persistently lower in Portugal relatively to the OECD average. Furthermore, as endogenous growth model shows, such as Romer (1990) or the Ramsey growth model, long term economic growth depends heavily on technological progress. Hence, studying in depth its trends allows for a more accurate explanation of wages stagnation and prediction of long-term growth in Portugal considering that, in the long run, there is a close relation between wages and productivity.

This section focuses on the technological evolution in Portugal over the past decades, through the lens of development of Information and Communications Technology (ICT). In plain terms, ICT is the technology that households and firms use every day, such as cell phones, television, or computers. Formally, ICT encompasses the set of technological devices and applications which allow its users to store, create, share, or exchange information or personal data.

While it is true that R&D is a crucial determinant of worker´s productivity, it seems that it is fairly dependant on firm´s ICT level to realize its full return. In fact, nowadays, there is more of a consensus in the literature for causality between investment in information technology and workers´ productivity (Oliner and Sichel, 2000; Colecchia et al., 2002; Zhu et al., 2021), as it renders the processes in the firms more efficient and lowers the transactions costs. However, there is one important caveat. To fully grasp its benefits, IT innovation must be tied with organizational changes within the firm (Brynjolfsson and Hitt, 2003; Bresnahan et al., 2002). As these become more technological oriented, the skills demanded by workers tighten and decision making in the firm become more decentralized. That is, employees become more autonomous and less reliant on superior´s orders. Since these changes are likely to have a realization lag, benefits from ICT investment are more strongly felt in the long run.

Given the importance of ICT to determine workers´ productivity, it is vital for Portugal to channel funds to fund its investment. However, in most indicators, Portugal ranks quite low when compared to the OECD average.

Despite ranking particularly well in terms of the share of innovative firms (Figure 1), each firms' investment in innovation, measured by R&D and intangible assets, is considerably lower than the OECD average.

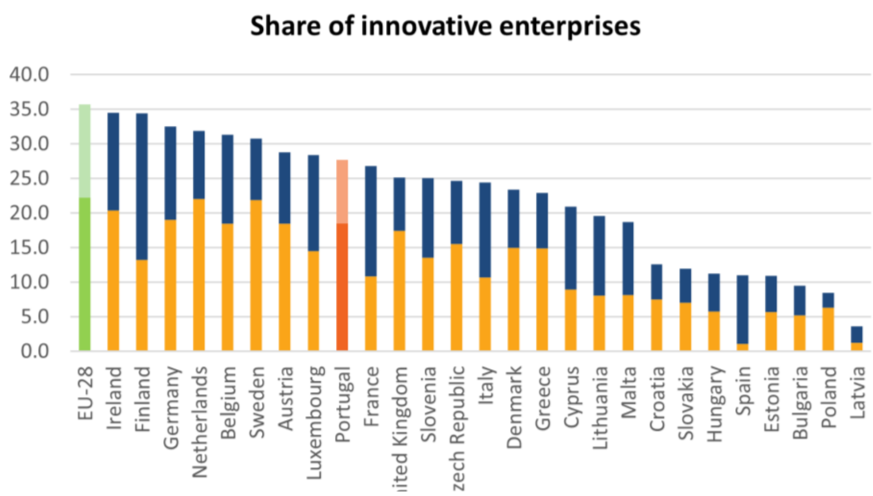

Figure 1 - Share of innovative firms, as a percentage of total firms.

Source: OECD database

This seems to indicate that Portuguese firms are mostly innovative, but the actual technological advances do not seem to be so significant. There are several reasons for this phenomenon, but one particularly important to deepen is the ability to reap gains of such investment. If gains are lower, firms have less incentives to attempt (larger) innovations, rendering less profitable to issue patents. Typically, this is the case for smaller firms, as larger firms benefit from economies of scale. The former represents the majority of Portuguese firms in the IT sector. As the data shows, Portuguese firms issue, on average, less patents than their European counterparts. The share of ICT-related patents is 10 percentage points below the OECD average and this figure jumps to 92% when one considers the aggregate number of patents per GDP (Figure 2).

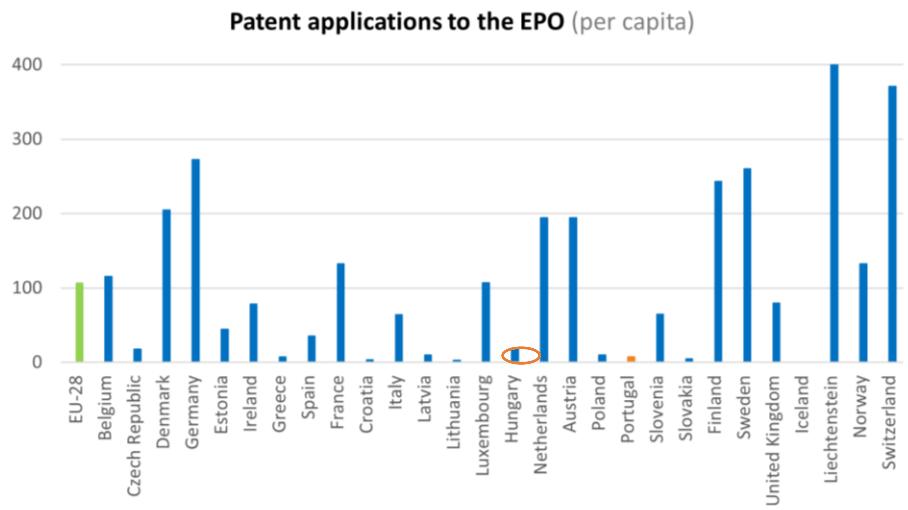

Figure 2 - Patent applications to the European Patent Office, per capita

Source: Eurostat database

A large driver of the high costs in issuing patents seems to be the red tape involved. According to Jin (2021), Portugal leads the ranking in productivity gains in firms resulting from lower regulation. This is indicative of how legislation acts as a deterrent to issue patents and, consequently, to invest in more significant innovations. As concluded by Sorbe et al. (2019), for a proportional fall in regulation, Portugal could increase its productivity, after 3 years, by 3.5% if half the gap to the country with the least strict regulation in the sample is closed.

Low investment in technology by firms is also allied to the lack of funding from government towards digital training, which results in a labour force without the necessary skills required by the tech sector.

Portugal ranks low in the majority of the indicators measuring worker´s digital capabilities. As of 2019, only 44% of workers in Portugal regularly used computer in their work, 12 p.p. below the EU28 average and the gap widens to 17 p.p. when it incorporates computers with internet access. Furthermore, only 11% of Portuguese firms purchased cloud computing services, such as email or storage of files, compared to the 26% of EU28 average. This mirrors a labor force poor in digital knowledge and firms with lack of incentives to invest in them.

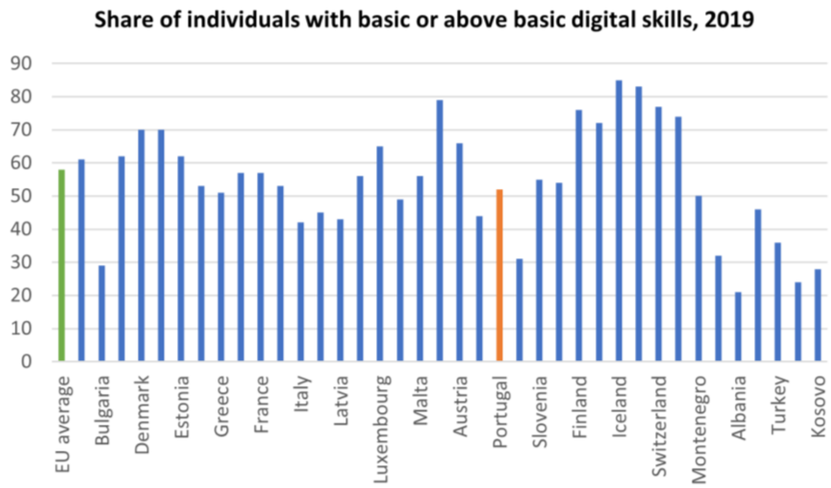

Figure 3 - Percentage of individuals with basic, or above basic, digital skills (2019)

Source: Eurostat database

If the labour force does not acquire digital skills because firms are not demanding it, there is scope for government to promote digital training. Instructing workers with digital skills will be crucial to break this cycle, as it gives incentives for firms to invest in ICT. As previously mentioned, such organizational changes are crucial to absorb the gains of such investment. The mere acquisition of computers does not suffice. It requires a collection of complementary investments which redesign the production processes. These include job training, as well as create new ways to interact with customers and suppliers (Brynjolfsson and Hitt, 2003).

The analysis undertaken above is readily summed into one index: the Digital Economy and Society Index (DESI, hereafter). It summarizes the digital performance of EU countries across several indicators into a single index. It encompasses five key areas: Human capital, Connectivity, Integration of digital technology, Digital public services and R&D in ICT. The graph below divides the DESI into the former four categories.

As expected, Portugal ranks below the EU average, mainly due to lack of human capital, which reflects poor digital skills of its labour force.

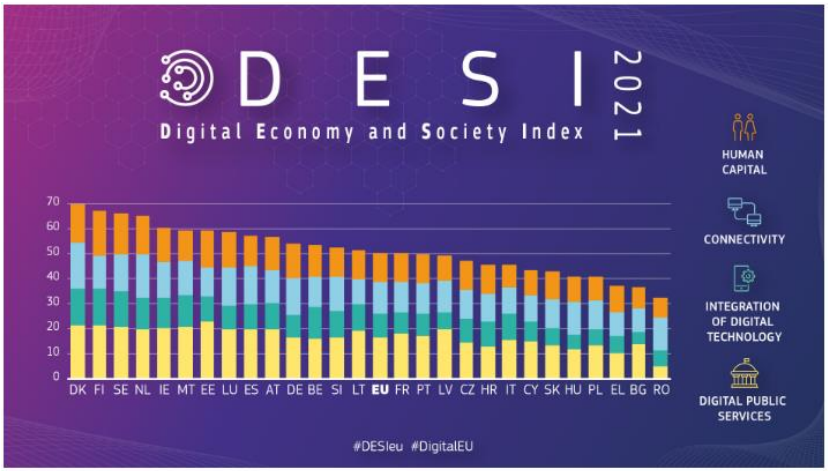

Figure 4 - DESI for each EU country, subdivided into four main areas: Human capital, Connectivity, Integration of Digital Technology and Digital Public Services, 2021

Source: European Commission

This index is expected to improve in the coming years following the two major new policy initiatives launched to boost digital transformation in the EU: Recovery and Resilience Facility (RRF) and the Digital Decade Compass, with specific information on the new measures to boost.

4. The Importance of European Funds for Technological Progress

At the end of 2017, Portugal started *Estratégia Portugal 2030*, which was designed to answer the recent challenges and trends regarding the transformation of economies and societies, to dismantle the structural obstacles that persist, and face the new challenges of structural nature associated with the pandemic that impose the necessity of a new cycle of reformist policies.

In line with this recovery, under the *NextGenerationEU* (a temporary instrument designed to boost the recovery), European countries will receive an unprecedented amount of grants and loans to help rebuild a post-COVID-19 Europe and have a greener, more digital, and more resilient Europe. With the combination of the European funds from the Multiannual Financial Framework and the *NextGenerationEU*, Portugal will receive around 50 thousand million euros (M€) from 2021 to 2029, considering only subsidies. To benefit from the EU recovery and resilience funds, each country had to prepare a plan that had to be approved by the European Commission. The PRR, which stands for *Plano de Recuperação e Resiliência*, was created with this purpose, and its resources come from two different sources: 14 M€ from subsidies and 2.7 M€ from loans.

In this section, we are going to analyse only the measures from the PRR, since the PT 2030 is still in conclusion.

The PRR has three main dimensions: Resilience, Climatic transition, and Digital transition. The first one will be dedicated to the recovery of the economy and the other two are focused on the transition of our society and our economy to an eco-friendlier and more digital version.

This study will be more oriented towards the last dimension since its aim is to analyse the impact of technological developments on the productivity of Portuguese enterprises and the investment in the country's digital transformation can be useful to measure its effect on productivity.

The pandemic showed the need to have our society capable, structured, and able to use digital technologies. Although there were developments in this field and a great effort to accelerate this transition, there are still barriers to surpass, namely the access to the new technologies and training to use them. This transition can translate into great structural gains for our economy's efficiency and productivity which is one of our major pitfalls.

Having this importance in mind, 18% of PRR funds will be spent on this dimension in reforms and investments that will promote the education of the society in digital literacy, the inclusion of people in this process through education, the simplification of the legal system, the digital transformation of both enterprises and the public administration (this latter contributing to a higher quality and sustainability of the public finances, a more competitive economy that attracts investments and a public administration that works more efficiently and closer to the citizens).

In the dimension of Digital Transition there are five components: 1) Digital School, 2) Enterprises, 3) Quality and Sustainability of Public Finances, 4) Economical Justice and Business Environment, 5) Public Administration.

According to the PRR (Ministério do Planeamento, 2021), the main predicted results are:

- "Acquisition of 260 000 computers for students and professors.
- Educate 800 000 with digital skills (employees and entrepreneurs).
- Enhance the digital transition of enterprises, requalifying 36 000 workers and supporting 30 000 small and medium enterprises (SME).
- Promote the digitalization of the Public Administration, reinforcing the access to public services, in particular to Health, Social Security, Finances, and Justice.

- Increase the qualification and rejuvenation of human resources of the Public Administration.
- Promote the development of advanced information systems, integrating artificial intelligence and the utilization of advanced computation and its application in the Public Administration and enterprises.”

The component of Enterprises, with the specific goal of enhancing the digitalization of enterprises, aims at catching up with the digital transition process, allowing access to knowledge and digital technological means that promote modernization of work and production processes, elimination of workflows, mitigation of skills deficits in the use of digital technologies, balanced inclusion of women and men, incorporation of remote working tools and methodologies, creation of new digital channels for marketing and selling products and services, adoption of a culture of experimentation and innovation, strengthening of the national entrepreneurial ecosystems, and incorporation of disruptive technologies in enterprises’ value propositions.

In order to reach the previous objectives, there are a set of specific goals:

- Reinforce the digital competencies of workers.
- Modernize the business model of enterprises, as well as their production processes.
- Create new digital channels for the commercialization of products and services.
- Incorporate disruptive technologies in the value proposition of firms.
- Stimulate digital-based entrepreneurship.

The investments to be implemented in this dimension surpass 650 million euros and are supposed to be developed in three areas:

I. Digital Empowerment of Enterprises (150 million euros)

II. Digital Transition of Enterprises (400 million euros)

III. Catalysing the Digital Transition of Enterprises (100 million euros)

I. Digital Empowerment of Enterprises

This investment is coordinated by *Agência para a Competitividade e Inovação* (IAPMEI, I.P.) in association with the public entities responsible for employment, vocational training, and qualifications, and has the objective to create two interconnected training programs using innovation approaches that aim to fill gaps in the digital skills of workers and enterprises.

The first is the *Portugal Digital Academy*, a platform and large-scale digital skills development program that should allow workers in the business sector to:

1. Produce a self-assessment of their current digital skills level, taking into account the Portuguese Digital Skills Framework (PCDF).
2. Receive a personalized digital skills training plan with concrete goals, considering individual levels in each domain, personal goals and specific demand of the labor market.
3. Access online training resources that allow the acquisition of new skills and attainment of the proposed goals.
4. Develop a personal passport that centralizes and certifies information on the worker's digital skills.

The second program is *Digital Jobs 2025*, a program for digital technologies skills building that aims to respond to the challenges and opportunities in a number of business sectors, especially industry, commerce, services, tourism and agriculture, the sea economy and construction, which are all sectors that were strongly impacted by the COVID-19 pandemic and where digital transformation plays an important role. This program is a specialist strand of the *Portugal Digital Academy* that is supposed to work on a face-to-face and blended learning format. It is aimed at company workers regardless of their digital skills level and should contribute towards improving such skills to meet the specific needs of the enterprise sector and business areas in which they currently operate.

The goal of this area is to reach 800 000 trainees with digital skills diagnostics, individual training plans and access to online training, of which 200 000 will attend face-to-face or blended training.

II. Digital Transition of Enterprises

This investment is also coordinated by IAPMEI, I.P. in collaboration with various public bodies and associations, and it will contribute to the transformation of Portuguese SME business models and their digitalization, with the goals of achieving greater competitiveness and resilience.

The four programs are:

1. *National Test Beds Network* – Creation of a national test beds network through infrastructures that aim to create the necessary conditions for enterprises to develop new products and services, and accelerate the digital transition process, whether in a

physical space or via a virtual stimulator.

Digital Commerce – Program for the digitalization of SMEs, with a focus on micro-SMEs in the area of commerce, with a view to activating their e-commerce channels, incorporating technology into business models as well as dematerializing processes involving clients, suppliers and logistics through the use of information and communication techologies and support for internationalization.

2. *Support for Digital Transition Business Models* – Framed within the national program for industry, this initiative seeks to encourage the integration of technology within enterprises in support of the development of organizational processes and skills promoting the digital transformation of organizations' business models.
3. *Entrepreneurship* – Investments that result in enhancing the strategic focus on the development of the entrepreneurial ecosystem, which involves directly supporting start-ups, usually during the seed phase that is aimed at developing new products and services with a strong digital and green component, consolidating existing entrepreneurship support structures, and supporting the development of incubators and accelerators.

Among other objectives, the investment is expected to support more than 50 000 SMEs, set up 50 digital commerce districts, 10 digital accelerators, support the creation of 30 Test-Beds and reach 4 000 enterprises with theoretical training and consultancy focused on industry, and issue vouchers for 3 000 start-ups.

III. Catalysing the Digital Transition of Enterprises

This investment is also coordinated by IAPMEI, I.P. in collaboration with other entities, and is made via public technological catalysation projects that seek to reduce the use of paper through the dematerialization of invoicing, creating a more secure and reliable digital business environment through a set of certifications, and generally reducing context costs. It will also encourage the development of knowledge transfer structures, where the intention is to stimulate the development of knowledge transfer structures, where the intention is to stimulate the development of more technological products and services as well as support skills development.

The investment is made of three programs:

1. *Digital Innovation Hubs* – DIHs seek to centralize a set of support services for the digital

transition of enterprises under more accessible conditions, focusing this process on three disruptive technologies: AI, HPC and Cybersecurity. This project aims to extend and develop a national DIG network, enhancing the investment forecast by complementing the network that is already under development.

2. *Dematerialization of Invoicing* – An initiative that aims to automate the process of affixing a qualified electronic signature for issuing invoices through AMA's Electronic Invoice Signature Service and to increase the use of digital invoicing by providing a solution that uses the Unique Digital Address, enabling invoices to be sent to the customer by email.
3. *Certification Seals for Cybersecurity, Privacy, Usability and Sustainability* – Investment in four new certification platforms involving cybersecurity, privacy, usability, and sustainability, as well as a promotion campaign and training of conformity assessment bodies and technical assessment laboratories, and the award of seals.

Among other objectives, the investment is expected to reach 4 000 enterprises impacted by the spread of key technologies, complementing those integrated into the DEP's European Hubs, reach the goal of sending one million electronic invoices in digital format, and achieve 15 000 certifications across all four platforms.

5. Literature Review

This literature review will be divided into two main segments: assessing the impacts that R&D investment have on the productivity and growth of the ICT sector in comparison to the non-ICT sector; and assessing the overall impact of ICT capital and R&D investment on firms' productivity.

Concerning the comparison between ICT and non-ICT sector, there are several papers evaluating the greater positive impact that R&D investment has on the productivity of the ICT sector compared to the non-ICT sector.

(Hunady, Pisar, & Durcekova, 2020) conducted a study assessing the impact of R&D investment in the European ICT sector. In fact, the authors found that the share of innovative firms is higher in the ICT sector (both in the manufacturing and services sectors). Despite a rather low proportion of ICT sector on the total economy in some countries, the authors claimed that the share of R&D expenditures in this sector is very high. They also found evidence of a positive relationship between R&D expenditure and apparent labour productivity as well as value-added in the ICT sector.

(Koutroumpis, Leiponen, & Thomas, 2020) examined the contribution of R&D investment to European firms' productivity and found that both large and small ICT firms have the greatest effects compared to non-ICT firms, in such a way that doubling R&D capital yields a 9.0% increase in revenue for large ICT firms, and an even more substantial 10.4% increase for small ICT firms. Also, if R&D capital is doubled, sales in ICT firms will grow by 9.6% while there is a negligible negative effect for non-ICT firms, suggesting that ICT firms may enjoy greater return on R&D capital than non-ICT firms.

(Canarella & Miller, 2018) used data from 85 US ICT firms to examine the effects of R&D investment among other variables and the authors found that R&D investment affects positively growth, as it enables firms to achieve a greater performance in terms of firm growth.

(Hong, 2017) observed the causal relationship between R&D investment in the ICT industry and economic growth in Korea and the authors found a bidirectional causality between total ICT R&D investment and economic growth. Additionally, concerning the funding of R&D investment, private investment has a short run and long run causality on economic growth, whereas public investment only has a short run causality on economic growth.

(De Prato, Simon, & López Cobo, 2017) described the dynamic features of the ICT sector, through a comparison among countries - EU, Australia, Canada, Brazil, China, India, Japan, US, Korea, Norway, Russia, Taiwan and Switzerland – of the evolving role of investments in R&D in ICT. The authors claimed that productivity tends to be much higher than the average for total economy in the countries of their sample. Additionally, these countries except for Canada had registered a positive growth in business expenditure in R&D in the ICT sector, so that ICT sector is characterised by having a very high intensity of R&D on production.

However, there are authors who claim that R&D investment does not impact particularly firms' productivity in the ICT sector. (Edquist & Henrekson, 2017) showed that in the Swedish business sector there is no clear evidence of the impact of ICT and R&D capital in the aggregate value-added growth, since the impact of these variables are associated with specifications based on industry-level data. One additional remark of this study is that when dividing ICT capital into hardware and software, only software is considered significantly associated with value added. The authors defended that it might be explained by the fact that all industries invest in hardware, but only the industries that successfully invest and implement software are able to enjoy greater positive effects from

ICT. Furthermore, this study found a positive interaction effect between high-skilled labour and ICT investments.

Regarding the impact of ICT capital and R&D investment on firms' productivity, the results are less clear and straightforward. (Edquist & Henrekson, 2017) explored the impact of ICT and R&D on TFP and reached the conclusion that, in the short run, only growth in R&D capital is positively associated with TFP growth, while ICT capital growth is not significantly associated with TFP growth. Also, when using longer time periods, the authors found no positive association between ICT capital and TFP growth. However, when dividing their sample into two time periods and introduce a lagged ICT component, it was identified a significant association between lagged ICT capital and TFP growth.

On the other hand, there are many authors defending the positive impact of ICT and R&D on productivity and growth.

(Lotti, Hall, & Mairesse, 2012) found that R&D and ICT both contribute to innovation, even though to a different extent: R&D seems to be the most relevant input for innovation, but since 34% of the firms in their sample invest in R&D while 68% have investment in ICT, the role of technological change embodied in ICT should not be underestimated. Hence, the authors argued that ICT and R&D contribute to productivity both directly and indirectly through the innovation, but they are neither complements nor substitutes.

(Fernandez-Portillo, Almodovar-Gonzalez, & Hernandez-Mogollon, 2020) found a positive moderate influence of ICT on productivity in high-income countries. Additionally, the authors highlighted the importance of use of video calls and social networks on economic performance, as both represent an improvement in access to communication and information. Overall, the authors claimed that both broadband connectivity and the use of Internet are of relevant importance when assessing the impact of ICT on economic growth.

Additionally, (Vecchi & Venturini, 2018) estimated that R&D and ICT have accounted for almost 95% of TFP growth, even though the ICT capital contribution is a bit lower compared to R&D – 36,8% against 56,6%. Another key remark of this paper is the presence of complementarities between ICT and R&D as ICT may complement R&D in the reorganisation of production during the innovation process. Nevertheless, it is possible to verify industry heterogeneity since, even though both low-tech and high-tech industries benefit from increasing investments in R&D, the effect of ICT capital is positive and significant in high-tech sectors and insignificant in low-tech industries.

(Liu, Chen, Huang, & Yang, 2013) analysed the impact of e-commerce and R&D in Taiwanese manufacturing firms and concluded that both e-commerce and R&D capital have a positive impact on productivity, nevertheless R&D has a stronger productivity-enhancing effect: In addition, e-commerce and R&D capital appear to have a complementary relationship in their influence on productivity.

6. Data

6.1. Description of Data

To study the impact of R&D investment in the ICT sector on productivity, our project utilizes cross-sectional data on the 27 member states of the European Union with the exception of Bulgaria, Croatia, Cyprus, Malta, and Romania. The reason we chose to leave out the prior listed member states is because there is insufficient data, incomplete or missing years and we could not find values for key variables as such was unavailable. Thus, the data included in our models examines the span of time from 2010 to 2018.

With regard to building our regressions, we choose to include the variables based on economic reasoning and taking into account the potential explanatory variable based on their correlation with the dependent variable.

6.2. Independent Variable

To assess whether private R&D investment on ICT has a positive impact on productivity, the dependent variable in our model is the Gross Value Added per hour worked (GVAHOURS), which is the proxy for the change in each country productivity. We decided to work with the logarithm of GVAHOURS as it improves the fit of our model and because we are interested in the variation of productivity, that is, how the productivity changes over time with investments towards the ICT sector. This variable is taken from the PREDICT database.

6.3. Dependent Variable

We decided to go forth with three total explanatory variables in our two final models, the variation of R&D investment in the ICT sector (RD_EXP_ICT) and the variation of R&D investment in the non-ICT sector (RD_EXP_NONICT) each being included solely in one of the regressions to better evaluate whether the impact of R&D investment is stronger in the ICT sector or in the non-ICT sector. Finally, with regard to the impact of education level on productivity, the variation of the share of people with secondary education (SECONDARY_SHARE) is the variable that is included in both regressions which serves as a control in our models. The following variables are also taken from the PREDICTS database with the exception of the variable regarding education level which is taken from the AMECO database.

6.4. Descriptive statistics

On Figure 5, we present some descriptive statistics of our variables (Gross Value Added per hour worked, R&D investment in the ICT sector, R&D investment in the non-ICT sector and share of people with secondary education). The logarithm with base of Gross Value Added per hour worked is also presented since it was used in our regression. The descriptive statistics presented are the: mean, standard deviation, minimum, maximum, median and the 1st and 3rd quartiles, as it is observable in Figure 5.

	Mean	Standard Deviation	Min	Max	Q1	Median	Q3
GVA/HOURS	37,66	13,33	19,15	71,15	25,23	37,71	47,41
LOG(GVA/HOURS)	1,55	0,15	1,28	1,85	1,40	1,58	1,68
R&D_EXP_ ICT	1109,10	1603,32	4,09	6388,69	83,12	553,50	1290,61
R&D_EXP_NONICT	6044,63	11073,35	32,64	60007,77	544,40	2013,70	6310,27
SECONDARY_SHARE%	47,58	13,00	19,10	73,17	39,98	44,25	57,87

Figure 5- Descriptive statistics of our variables

7. Methodology

The focus of our analysis is based on two different regressions, whose difference consists on the investment in R&D in different sectors: first in ICT sectors and then in non-ICT sectors.

In the first regression, we will estimate through a linear regression with random effects the impact of the variation of R&D investment in the ICT sector on the variation of productivity, while controlling with the variation of the share of people with secondary education:

$$\Delta GVAHOURS = \beta_0 + \beta_1\ \Delta RD\_EXP\_ICT + \beta_3\ \Delta SECONDARY\_SHARE + \varepsilon \qquad [1]$$

In the second regression, we will estimate the impact of the variation of R&D investment in the non-ICT sector on the variation of productivity, while controlling with the variation of the share of people with secondary education:

$$\Delta \text{GVAHOURS} = \beta_0 + \beta_1 \, \Delta \text{RD\_EXP\_NONICT} + \beta_3 \, \Delta \text{SECONDARY\_SHARE} + \varepsilon \quad [2]$$

After estimating both regressions, we will be able to compare β_1 of each one and conclude in which type of sector (ICT or non-ICT) the investment in R&D will make a higher impact in terms of productivity.

In this project, we will only assess the effect of the investment in R&D in each sector controlling for the share of people with secondary education. However, in future projects related with this issue, this effect should be also controlled for the intensity of capital and other factors that could overcome endogeneity issues.

In order to deal with problems of heteroskedasticity, each regression will be corrected with the method of Generalized Least Squares (GLS), that will give us robust standard errors. After correcting for the problem of heteroskedasticity, we will be able to perform an analysis about the statistical significance of each regressor.

Then, to test for the presence of multicollinearity, we will use a metric known as the Variance Inflation Factor (VIF), which measures the correlation and strength of correlation between the explanatory variables in a regression model. By using the command "vif", a VIF value will be attributed to each of the explanatory variables in the model. A general rule for interpreting VIFs values states that a value above 10 indicates that multicollinearity is likely a problem in the regression model.

Since we are using panel data, the Hausman Test can help to choose between a fixed effects model or a random effects model. The null hypothesis is that the preferred model is random effects, while the alternative hypothesis is that the model is fixed effect. Essentially, the tests assess if there is a correlation between the unique errors and the regressors in the model. The null hypothesis is that there is no correlation between the two.

Finally, we will test for the existence of omitted variables. In order to do so, we have to calculate the fitted values and add them to each regression. The objective is to verify if non-linear combinations of the explanatory variables have power to explain the dependent variable. Each model will look like the following:

$$\Delta \text{GVAHOURS} = \beta_0 + \beta_1 \, \Delta \text{RD\_EXP\_ICT} + \beta_3 \, \Delta \text{SECONDARY\_SHARE} + \beta_4 \, \text{YHAT} + \beta_5 \, \text{YHAT}^2 + \beta_6 \, \text{YHAT}^3 + \beta_7 \, \text{YHAT}^4 \quad [3]$$

$$\Delta GVAHOURS = \beta_0 + \beta_1\ \Delta RD\_EXP\_NONICT + \beta_3\ \Delta SECONDARY\_SHARE + \beta_4\ YHAT + \beta_5\ YHAT^2 + \beta_6\ YHAT^3 + \beta_7\ YHAT^4 \quad [4]$$

The model is considered to have omitted variables if the coefficients associated with these fitted values are jointly statistically significant.

8. Results

For both regressions, the Hausman test indicated towards using the random effects model, in alternative to the fixed effects, as the p-value exceed the significance level of 5%. Hence, both estimations were obtained by resorting to the former model.

Regarding the first regression, both R&D expenditure in the ICT sector and share of people with secondary education are statistically significant, with the standard errors being quite small. The former has associated a positive coefficient of 0.078, meaning that a 1% increase of investment in R&D in the ICT sectors leads to an increase of 0.078% in productivity. The latter has associated a negative coefficient of 0.257, meaning that a 1% increase in the share of population with secondary education decreases productivity by 0.257%. Such negative coefficient for education may indicate that countries with higher secondary education are the ones that have less tertiary education and therefore less qualified people had a negative impact on productivity.

We now present the results for the second regression, that substitutes the first variable in the former model for R&D expenditure in the non-ICT sector. Both variables are statistically significant, and the standard errors are small. R&D investment in the non-ICT sector has an associated coefficient of 0.101, which means that a 1% increase in such investment increases productivity by 0.101%. Whereas secondary education has a coefficient of negative 0.250. That is, a 1% increase in the share of population with secondary education decreases productivity by 0.250%.

In the first equation, the Variance Inflation Factor (VIF) was below 10 for both variables, which indicates absence of considerable multicollinearity in the model, while in the second equation it has a value of 15 which may indicate multicollinearity. Nevertheless, the reference value of VIF (10) is also highly debatable in the literature.

However, both models fail to pass the endogeneity test. As explained on the previous section, one can test for potential omitted variables bias by including the fitted values of the regression. Since the coefficients associated with such fitted values is jointly statistically significant, with p-value = 0.000 in either case, it suggests that most likely there are variables important to the model which are not being accounted for.

As we do not resort to instrumental variables, this issue may be hard to overcome, especially if those variables are not measurable, such as: working culture of workers and company, individual ability, or motivation. It is expected that they are correlated with productivity, thereby creating biased coefficients.

Despite such issue, we obtain an important result from such econometrical analysis – the importance of R&D investment in boosting workers' productivity. Unfortunately, Portugal ranks quite below the EU average on this indicator. The gross domestic expenditure on R&D, as a percentage of GDP, was 1.3% and 2.2%, respectively. Hence, policy advice on this matter should encompass an increase on the amount of funds channelled to research and development.

9. Limitations

Despite the relevance of the models beforementioned, it is appropriate to mention the limitations and constraints faced in this paper.

Firstly, beyond the relevant variables (R&D investment in the ICT and non-ICT sector), it was only possible to control for education (whose effect was captured by the share of population with secondary education). Indeed, there were many other variables which were intended to be included such as capital (given its importance on productivity) as well as more broad indicators such as the doing business (as to capture the differences among the countries). Nevertheless, there were multicollinearity issues, which did not allow the inclusion of such relevant variables in the final model. That's why it then arose the omitted variable problem, as there are still different indicators that could control different effects on productivity that were not taken into account.

Secondly, a limitation that arose initially is concerning the data as there were relevant indicators such as the percentage of population in the ICT sector that had secondary and tertiary educations. However, the data was insufficient and incomplete, hence why it was not possible to use it in the models to better control the differences between the ICT and the non-ICT sectors.

Hence, for further research on this topic it would be advisable to collect data more specific on the ICT sector to better isolate the ICT and the non-ICT sectors to assess the impact of R&D investment more easily on labour productivity.

10. Conclusion

The main question that we wanted to answer at the beginning of our project was how the investment in the ICT sector impacts the productivity of the economy. With the results from the previous section, we can see that the impact of the investment in R&D in the ICT sectors on productivity is very small, while controlling this effect with the effect of the share of population with secondary education. In fact, when we compare the coefficients from our two final models, we can see that the impact of R&D investment in the non-ICT sectors is higher than the impact of R&D investment in the ICT sectors, which can be counterintuitive, especially when taking into account the literature analysed in our project.

Regarding the education variable, we can see that, in both models, an increase in the share of population with secondary education leads to a decrease in productivity. Even though, at a first analysis, this result may seem counterintuitive as well, the correlation between the share of population with secondary education and the share of population with higher education is negative, meaning that a higher share of population with secondary education is associated with a lower share of population with higher education, which is an essential requisite to achieve a higher level of productivity in both the ICT and non-ICT sectors.

However, we also have to take into consideration that our models present evidence for the existence of omitted variables and that there were other essential variables that we wanted to include in our analysis that we were not able to due to the lack of data and multicollinearity issues.

With the collection of more specific data on the ICT sector, which we recommend, we would be able to improve our model and take better conclusions regarding this topic in future research, which could be an important tool to evaluate the impact of the economic recovery plans that are being presented in a post-pandemic scenario.

References

Hunady, J., Pisar, P., & Durcekova, I. (2020). *R&D Investments in the European ICT sector: Implications for Business Performance.* Retrieved from Business Systems Research: https://hrcak.srce.hr/ojs/index.php/bsr/article/view/12907

Koutroumpis, P., Leiponen, A., & Thomas, L. (2020). *Small is big in ICT: The impact of R&D on productivity.* Retrieved from Science Direct: https://www.sciencedirect.com/science/article/pii/S0308596119301004

Canarella, G., & Miller, S. (2018). *The determinants of growth in the U.S. information and communication technology (ICT) industry: A firm-level analysis.* Retrieved from Science Direct: https://www.sciencedirect.com/science/article/pii/S0264999317309483

Hong, J.-p. (2017). *Causal relationship between ICT R&D investment and economic growth in Korea.* Retrieved from ScienceDirect: https://www.sciencedirect.com/science/article/abs/pii/S0040162516306175#:~:text=This%20study%20examined%20the%20Granger,economic%20growth%20and%20vice%20versa.

De Prato, G., Simon, J., & López Cobo, M. (2017). *Dynamics of ICTs: assessing investments in R&D. A global cross-comparison.* Retrieved from ECONSTOR: https://www.econstor.eu/handle/10419/168535

Edquist, H., & Henrekson, M. (2017). *Swedish lessons: How important are ICT and R&D to economic growth?* Retrieved from ScienceDirect: https://www.sciencedirect.com/science/article/abs/pii/S0954349X17301509

Edquist, H., & Henrekson, M. (2017). Do R&D and ICT affect total factor productivity growth differently? *Elvesier.*

Lotti, F., Hall, B., & Mairesse, J. (2012). *Evidence on the Impact of R&D and ICT Investment on Innovation and Productivity in Italian Firms.* Retrieved from NBER: https://www.nber.org/papers/w18053

Fernandez-Portillo, A., Almodovar-Gonzalez, M., & Hernandez-Mogollon, R. (2020). *0160-791X/© 2020 Elsevier Ltd. All rights reserved.Impact of ICT development on economic growth. A study of OECD European union countries.* Retrieved from Elsevier:

https://reader.elsevier.com/reader/sd/pii/S0160791X20304188?token=E52078291B52057F78E810E2F7DE2646FD24161C9D94AC57ACA5550E771ECF940FC7411D5D1C74259AFEEA474C61BDFC&originRegion=eu-west-1&originCreation=20220429134523

Ministério do Planeamento. (2021, April). *PRR – Recuperar Portugal, Construindo o Futuro*. Retrieved September 9, 2022, from Recuperar Portugal. https://recuperarportugal.gov.pt/wp-content/uploads/2021/10/PRR.pdf

Vecchi, M., & Venturini, F. (2018). *Modelling the joint impact of R&D and ICT on productivity: A frontier analysis approach.* Retrieved from NIESR: https://www.niesr.ac.uk/publications/modelling-joint-impact-rd-and-ict-frontier-analysis-approach-research-policy?type=journal-article-book-chapter

Liu, T.-K., Chen, J.-R., Huang, C., & Yang, C.-H. (2013). *E-commerce, R&D, and productivity: Firm-level evidence from Taiwan.* Retrieved from Elsevier: https://reader.elsevier.com/reader/sd/pii/S0167624513000309?token=E6569B84786B653C0887E7D1B7F62CF320CDA11EF46366863373E1976659EC742AB2CCA77A87A41581A2BB298BF9EFA8&originRegion=eu-west-1&originCreation=20220429143825

Appendix

```
Fixed-effects (within) regression               Number of obs     =        198
Group variable: YEARS                           Number of groups  =          9

R-squared:                                      Obs per group:
     Within  = 0.2551                                         min =         22
     Between = 0.9588                                         avg =       22.0
     Overall = 0.2589                                         max =         22

                                                F(2,187)          =      32.03
corr(u_i, Xb) = 0.0709                          Prob > F          =     0.0000
```

LGVAHOURS	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
LRD_EXP_ICT	.0771948	.0124365	6.21	0.000	.052661	.1017286
LSECONDARY_SHARE	-.257474	.0711733	-3.62	0.000	-.3978797	-.1170683
_cons	4.079226	.297029	13.73	0.000	3.493267	4.665184
sigma_u	.04484716					
sigma_e	.30820623					
rho	.02073421	(fraction of variance due to u_i)				

F test that all u_i=0: F(8, 187) = 0.46 Prob > F = 0.8807

Annex 1 | STATA output of the first model

Variable	VIF	1/VIF
LRD_EXP_ICT	9.69	0.103173
LSECONDARY~E	9.69	0.103173
Mean VIF	9.69	

Annex 2 | Test of multicollinearity of the first model

```
Fixed-effects (within) regression               Number of obs     =        198
Group variable: YEARS                           Number of groups  =          9

R-squared:                                      Obs per group:
     Within  = 0.3390                                         min =         22
     Between = 0.9765                                         avg =       22.0
     Overall = 0.3425                                         max =         22

                                                F(2,187)          =      47.95
corr(u_i, Xb) = 0.0753                          Prob > F          =     0.0000
```

LGVAHOURS	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
LRD_EXP_NONICT	.1009379	.0123194	8.19	0.000	.076635	.1252407
LSECONDARY_SHARE	-.2504784	.0666637	-3.76	0.000	-.3819879	-.1189689
_cons	3.752145	.2871271	13.07	0.000	3.185721	4.31857
sigma_u	.04189118					
sigma_e	.29034371					
rho	.02039259	(fraction of variance due to u_i)				

```
F test that all u_i=0: F(8, 187) = 0.46                     Prob > F = 0.8860
```

Annex 3 | STATA output of the second model

Variable	VIF	1/VIF
LRD_EXP_NO~T	15.86	0.063070
LSECONDARY~E	15.86	0.063070
Mean VIF	15.86	

Annex 4 | Test of multicollinearity of the second model

	Coefficients (b) fe	Coefficients (B) re	(b-B) Difference	sqrt(diag(V_b-V_B)) Std. err.
LRD_EXP_ICT	.0771948	.0787528	-.001558	.0020265
LSECONDARY~E	-.257474	-.2599135	.0024395	.0106781

```
                 b = Consistent under H0 and Ha; obtained from xtreg.
  B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

    chi2(2) = (b-B)'[(V_b-V_B)^(-1)](b-B)
            =   0.71
Prob > chi2 = 0.7012
```

Annex 5 | Hausman test for the first model

	Coefficients (b) fe	(B) re	(b-B) Difference	sqrt(diag(V_b-V_B)) Std. err.
LRD_EXP_NO~T	**.1009379**	**.1025522**	**-.0016143**	**.0020342**
LSECONDARY~E	**-.2504784**	**-.2529355**	**.0024571**	**.0100883**

```
                 b = Consistent under H0 and Ha; obtained from xtreg.
  B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

    chi2(2) = (b-B)'[(V_b-V_B)^(-1)](b-B)
            =   0.74
Prob > chi2 = 0.6894
```

Annex 6 | Hausman test for the second model

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