The impact of private and public R&D investment on Gross Value Added – ARDL and Granger Causality Assessment

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Abstract

Economists have been investigated the drivers of economic growth for decades and many studies have identified investment in R&D as a key factor.

This article assesses the impact of public and private investment in R&D on Gross Value Added for a group of eight European countries using the Autoregressive Distributed Lag with an application to the ICT service sector. In addition, through the Granger Correction model, it also seeks to analyze the causal effect between public and private investment in R&D.

Looking to short and long-term trends, the findings suggest that the Northern countries under this analysis benefit from private investments. However, this is not so evident for countries of the South.

Nevertheless, considering the Granger causality, and even in the presence of some heterogeneity across countries, we found that in general there is a positive causal effect of private investment on the total GVA of the economy. The same conclusion does not apply to public investment with only Portugal showing positive effects on value added.

A natural avenue of work would be to explore the relation between private and public investment and productivity since the country's distance to the frontier can determine the effect on GVA.

Keywords: Research and Development, Information and Communication Technologies, Autoregressive Distributed Lag, Gross Value Added

JEL Classification: O11, O43, O47

1. Introduction

Investment in Research and Development by companies plays a crucial role in improving production processes, in the development of better products and services, and hence in the creation of a knowledge-based economy, (COMPETE 2020, 2020).

Information and communication technologies (ICTs), in turn, have also been a key driver of innovation, technological change and socio-economic development in recent decades (OECD, 2017; Toader et al., 2018). They drive significant changes in economies' production methods and employment patterns.

The ability of an economy to develop new technologies and to adapt to a technological environment is seen as an essential competitive advantage for socio-economic development.

For this reason, the economic impact of Research and Development on the ICT sector has attracted considerable interest of firm managers, policy makers and economists in general (Koutroumpis et al., 2020).

In most OECD economies, spending on R&D in the ICT sector represents about 25% of total business expenditures on R&D (BERD). In addition, BERDs in the ICT sector represent about 0.8% to 1.9% of GDP (OECD, 2017). Moreover, according to the European Commission, investments in ICT account for 50% of all European productivity growth.

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Although investment in R&D is an important factor of economic growth, private investments in R&D are often below the social optimum due to the existence of several failures in the R&D market, which makes it necessary for the state to intervene. In this context, since investment in R&D is expensive, it is important to make sure that there is a positive return, but also to understand the best way to direct this investment. (Hall et al., 2009).

Furthermore, it is important for policymakers to realize what are the effects of private and public investment in R&D in order to understand what has been achieved and what might be reformulated in order to attain the goals.

The objective of this study is to assess the impact of investments in Research and Development on Gross Value Added, with an application to the ICT service sector. Based on the methodology used by Hong (2017), this study also seeks to determine the causal relationship between public and private investment in R&D and economic growth and to investigate the existence (or non-existence) of a virtuous cycle between private and public investments in ICT R&D.

Results will be measured for eight economies, representing southern (Portugal, Spain, Italy, Greece) and northern countries from Europe (Netherlands, Germany, France and United Kingdom) for the period between 2006 and 2016.

This paper is structured as follows. Section 2 briefly reviews the most relevant literature in this area; section 3 refers to the dataset; section 4 describes the methodology; section 5 presents the empirical results and section 6 concludes.

2. Literature Review

2.1. Impact of Research and Development

Innovation corresponds to the introduction of new solutions in response to problems, challenges or opportunities that arise in the social and/or economic environment (Fagerberg, 2017; Lewis, 2019). Research and Development is one of the sources of innovation and 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).

Since Romer (1990) and Solow (1957), economists recognize that technological innovations due to Research and Development (R&D) activities lead to sustained long-run growth. Solow (1957) defended that long-run economic growth depend on exogenous technological progress and Romer (1990) argued that technological change, that result from intentional investment decisions made by profit-maximizing agents, incentivizes continued capital accumulation and, therefore, increase output per hour overtime.

Similarly, Grossman and Helpman (1991) also argue that innovation is seen as a deliberate result of investments in industrial research by forward-looking, profit-seeking agents. According to the authors, innovation is an exogenous process or a result of investment in machinery and equipment. Aghion and Howitt (1992), through an endogenous growth model, consider that the vertical innovations generated by a competitive research sector drive the development of technological knowledge and, consequently, increase productivity and economic growth.

Literature about the effect of R&D shows that there is both a direct effect on the company's production and an indirect effect on total factor productivity (TFP) as it increases output per worker. Moreover, research suggests that R&D undertaken in one firm can positively affect value-added in competing firms and thus lead to a convergence of TFP levels within an industry. (Edquist and Henrekson, 2017a; Griliches, 1992; Hall et al., 2009; McMorrow and Röger, 2009; Solow, 1957). Thus, it is recognized in the literature that private and social returns from R&D are positive.

State intervention and support in this area, in addition to the perception of the positive relationship between R&D and economic development, are explained by the existence of market failures (Ravšelj and Aristovnik, 2020). The companies that generate R&D hardly take ownership of the total returns associated with innovation, that is, there is a diffusion of knowledge and technology transfer. Innovation may have a high social rate of return, but a low private rate of return, and, therefore, it becomes socially desirable to reduce the costs that these companies incur in carrying out R&D activities through State intervention (Arrow, 1962).

Governments, for the reasons given, have introduced several policy instruments to promote R&D in the private sector. These policy instruments are designed to bridge the gap between the social and the private optimum. The R&D policy instruments most used to stimulate business R&D are tax incentives and direct financing (subsidies). The conclusions regarding the impact of state support for R&D have been diverse, since the nature of policy tools, state investment and the typology of companies are different in different countries (Busom et al., 2012; OECD (2020); Zúñiga-Vicente et al., 2012). However, in general, the literature in this field reveals a positive effect from public spending on R&D (Goodridge et al., 2015; Hall and Van Reenen, 2000). In Portugal, the evaluation of the impact of the European funds on the performance of Portuguese firms also reveals positive effects of public support to R&D on investment, value-added, profits, exports and number of qualified workers (Compete 2020, 2020; Mamede and Pereira, 2018; Simões, 2019).

2.2. Impact of R&D investments in ICT sector

Researchers have been trying to establish a link between information and communication technology (ICT) and economic growth ever since Solow's 'Productivity Paradox' remark (1987) where the economist stated that computers can be found everywhere except in productivity statistics.

ICTs are key enablers of innovation and speed up the process of knowledge creation within the economy. This is since ICTs allow firms to reduce transaction costs and increase productivity due to ICT-related spillovers or network effects. Given the importance of ICT, business managers, policymakers and economists have been concerned with gauging the economic impact of Research and Development in the ICT sector (Koutroumpis et al., 2020).

The literature, in general, concludes that there is a positive impact of R&D in the ICT-sector and that this impact is sometimes greater when compared with companies in the non-ICT sector.

Analyzing the economic growth of Korea, Hong (2017) utilizes an error correlation model to conduct Granger-causality analysis and establishes that Korea's ICT R&D investment over the long run is driven by an increase in economic growth and/or vice versa. In the same study, through the separation of R&D investment into private and public, the author found evidence that private investment in digitalization is more effective in leading to economic growth than public investment. Besides, it is more likely that economic growth induces private investment in R&D than public investments. A crucial policy-relevant finding is the presence of a virtuous cycle between private and public ICT R&D investments. That is an increase in public investments in ICT will not only lead to greater private investments, but it also has the potential to create secondary value added and contribute to national wealth (Hong, 2017).

Canarella and Miller (2018), using a sample of 85 United States ICT' firms for the period of 1990 - 2013 and using an autoregressive dynamic GMM model, refute previous findings of smaller ICT firms growing faster than the larger counterparts do. The authors find a positive and significant estimator of 0.023 in one specification and 0.045 in another, implying that a 1% increase in size results in firms' growth of 0.023% and 0.045% depending on the specification used. In the US, the growth of larger ICT firms is higher than smaller ones until a certain point and, beyond that, size acts as a constraint to growth. The paper also finds significant evidence of a positive relationship between R&D investments in ICT and firm output.

Examining similar behaviors on a European panorama, Koutroumpis et al. (2020) investigate the contribution of R&D to firm productivity and its variation according to firm age and size. A major finding is that there is a greater effect of R&D investment on ICT firm revenues and performance when compared to non-ICT firms. The estimate shows that doubling R&D in ICT firms results in the growth of revenues by 9.6%. This can be explained by the fact that ICT is a general-purpose technology that can be adopted in almost all sectors and hence it is exposed to a larger market. Another reason for this could be linked to the network effect where the value of the product or service increases the more it is adopted by other users. Therefore, investments in the ICT sector could have an outsized impact on the revenue of those firms when compared to other sectors. Furthermore, the research suggests that smaller and older firms enjoy a greater impact of R&D on revenues. The regression shows that doubling R&D capital in these firms will result in the increase of revenues by 10.9%. Moreover, the results indicate no significant effects for non-ICT firms.

According to this last paper, decision-makers concerned with long-term growth should target R&D investments to smaller and older ICT firms. Contrary to the current idea of focusing on increasing start-ups and younger firms to invest in R&D.

Additionally, empirical evidence showed that R&D and patenting rose in the United Kingdom due to an R&D tax relief scheme (Dechezleprêtre et al., 2016). As such, tax relief schemes could have a large impact in the creation of firms in the ICT sector. Moreover, policy propositions could be designed in a way to stimulate R&D investment so that firms achieve superior growth (Canarella and Miller, 2018).

In addition, a recent Portuguese study revealed that R&D spending, as a percentage of GDP, in Portugal was the ninth-lowest (1.35%) of the 37 OECD economies as of 2018. This is also considerably lower than the 2.04% of the EU-28. On top of this, the R&D investment financed by businesses in the country was around 46.5% in 2017, which is also lower than the EU-28 average of 57.6%. This could suggest that even though there has been a positive evolution in the country's R&D expenditure in recent years it is still affected by the characteristics of Portugal's business sector. This shows that more R&D financing need to be conducted for Portugal to close the gap with its partnering economies (Mamede and Silva, 2020).

3. Data

This empirical research covered a panel dataset of eight economies which were split into south (Portugal, Spain, Italy, Greece) and north (Netherlands, Germany, France and United Kingdom) countries from Europe for the period between 2006 and 2016. All the variables used in this study are obtained in the PREDICT (Prospective Insights on R&D in ICT) dataset of the European Commission's joint research center and in the Eurostat database.

Since 2006 that the PREDICT research initiative analyzes and publishes an annual dataset on the evolution of ICT industries and R&D investments in ICT for twenty-seven EU nations and thirteen non-EU economies. The ICT sector is classified according to the EU's NACE Rev.2[4] definition and it is divided in ICT service and ICT manufacturing sector[5].

The objective of this study is to assess the impact of investments in R&D on Gross Value Added, with an application to the ICT service sector. Additionally, this study seeks to determine the causal relationship between public and private investment in R&D and economic growth and

[4] Statistical classification of economic activities in the European Community

[5] The ICT sector definition follows the sectors' comprehensive definition given by OECD (2007).

to investigate the existence of a virtuous cycle between private and public ICT R&D investments.

All variables and their descriptions can be further examined in Table 1 (Macro-Level Analysis) and Table 2 (ICT sector analysis) of Appendix A.

Moreover, the unit of measure for all the variables used is in terms of current million euros Purchasing Power Standards (PPS) to remove prices' differences between countries.

3.1. Macro Level analysis

The descriptive statistics for the macro-level variables displaying the number of observations, mean, standard deviation, minimum and maximum can be evaluated in Appendix B. From the summary statistics of the South countries (Portugal, Spain, Italy and Greece) in Table 1 of appendix B, we can conclude that the average GVA and spending on R&D (both private and public) seems to be stable within-country over time, although the standard deviation is larger across countries (between effects). Moreover, private and public investment represent on average an equivalent amount.

Likewise, Table 2 in Appendix B exhibits the descriptive statistics for the group of countries including Germany, France, Netherlands and the UK. As expected, the GVA of those countries is two times superior to the south countries' GVA. Considering the R&D spending variables (BERD and GBARD[6]), again there is a much larger deviation throughout the countries than within each of them overtime for this variable. For this group, on average, private investment is two times the public investment, which may be related to the level of development of those countries.

3.2. ICT Industry

Concerning the analysis of the ICT industry for the considered nations, all the definitions and descriptions of the relevant variables can be viewed in Table 2 in Appendix A. As mentioned above, the dataset for the ICT industry is split between ICT manufacturing and service sectors according to NACE Rev. 2.

Similarly, the summary statistics of the variables considered for the ICT industry for the Northern and southern EU countries can be examined in Table 3 and 4 of the same appendix.

Although the ICT sector is subdivided into ICT service and ICT manufacturing, our analysis focuses only on the ICT service sector due to the low weight of the ICT manufacturing sector on GVA and investment.

4. Econometric Specification

This study uses a panel of eight countries over an 11-year period, from 2006 to 2016. Therefore, to study the dynamic nature of the data, a Panel Autoregressive Distributed Lag (ARDL) model is utilized. This method is used to identify the possible causal nexus between the variables. The generalized ARDL *(p, q, q, …q)* model can be specified as:

$$y_{it} = \sum_{j=1}^{p} \delta_{ij} y_{i,t-j} + \sum_{j=0}^{q} \beta'_{ij} x_{i,t-j} + \varphi_i + \varepsilon_{it} \quad (1)$$

Where y_{it} is the dependent variable, x_{it} and φ_t are vectors of explanatory variables. Additionally, δ_{ij} are the coefficients of the lagged dependent variable and β'_{ij} are coefficient vectors; *p, q* are the optimal lag orders; φ_i is the unit specific fixed effect. Lastly, ε_{it} is the error term (Pesaran et al., 1997). Nonetheless, the model in interest to this study is the re-parameterized ARDL *(p, q, q, …q)* error correction model.

[6] Government budget allocations for R&D

$$\Delta y_{it} = \theta_i[y_{i,t-1} - \gamma'_i x_{i,t}] + \sum_{j=1}^{p-1} \delta_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \beta'_{ij} \Delta x_{i,t-j} + \varphi_i + \varepsilon_{it} \quad (2)$$

Here, θ_i is the group specific speed of adjustment coefficient, where θ is expected to be less that zero. Additionally, γ'_i is the vector of long-run relationships and the whole term in the square brackets is the error correction term (ECT) which represents the long-run information in the model. The short-run dynamics are represented by the coefficients of δ_{ij} and β'_{ij}.

Applying the re-parameterized model to this paper, the model for the macro level analysis is specified accordingly:

$$\Delta GVA_{it} = \theta_i[GVA_{i,t-1} - \gamma'_i x_{i,t}] + \sum_{j=1}^{p-1} \delta_{ij} \Delta GVA_{i,t-j} + \sum_{j=0}^{q-1} \beta'_{ij} \Delta x_{i,t-j} + \varphi_i + \varepsilon_{it} \quad (3)$$

In a similar fashion to equation (3) the re-parameterized model to analyze the ICT service sector is specified as:

$$\Delta ICT\ GVA_{it}^{Ser} == \theta_i[ICT\ GVA_{i,t-1}^{Ser} - \gamma'_i x_{i,t}] + \sum_{j=1}^{p-1} \delta_{ij}\ ICT\ GVA_{i,t-1}^{Ser} + \sum_{j=0}^{q-1} \beta'_{ij} \Delta x_{i,t-j} + \varphi_i + \varepsilon_{it} \quad (4)$$

Moreover, unit root tests were performed to test the presence of unit roots in the series. To get long-run relationships among the series, panel co-integration tests were performed after getting the integration 5 orders of the series.

5. Results

Our methodology was based on the analysis carried out by Hong (2017) for the Korean economy. Main outcomes will be presented along the text. Other details, such as test statistics, will be included in Appendix C.

5.1. Unit Root Test

The Im-Pesaran-Shin (IPS) test is conducted to test for unit roots in the panel dataset. The IPS unit root test has the null hypothesis that all the panels contain unit roots (Im et al., 2003). The results show the unit root test conducted with a constant term and with the inclusion of a trend term for the two groups. The results for this test can be seen in Table 1 (Appendix C) for the macro level analysis using the aggregate dataset. According to the IPS unit root test the dependent variable, GVA has a unit root in the Southern and Northern countries. However, after taking the first difference of the variable, the test confirms that it is stationary, i.e., GVA is I(1) for the two groups. Similarly, the private investment in R&D, BERD, is not stationary at level for any of the two groups. Nonetheless, by taking the first difference of this variable, it becomes stationary at a 1% significance level for Southern and Northern countries. The variable public R&D expenditures, GBARD, is stationary at level for the Southern countries at a 5% significance level. For the Northern countries, this variable has a unit root. Regardless, the unit root test confirms that it is stationary at first difference for two groups.

Furthermore, IPS unit root test is also conducted for the ICT service sector dataset. These results can be examined in Tables 2 (Appendix – C).

To conclude, even though the majority of the variables are first difference stationary, it is not possible to say that all are I(0). But it is possible to deduce that the series are I(0) or I(1) from the IPS unit root test. Therefore, these results give even more support to the application of the ARDL procedure as a methodology for this study.

5.2. Cointegration Test

Pedroni (1999, 2004) cointegration tests were performed to determine the long-run relationship among the series for the two groups. The null hypothesis of the test is that there is no cointegration and the alternative hypothesis is that the variables are cointegrated in all panels. Cointegration is used to analyze the common trend among the variables, which describe the long-run relationship between them. Furthermore, it is important to note that cointegration of variables is not a necessary requirement for Panel ARDL model. In the case that cointegration exists, ARDL model will have an error correction interpretation and there will be evidence that the long-run estimates are common across the panel.

Table 3 (Appendix C) displays the results of the Pedroni cointegration test of macro level analysis. All the results of the test include a column with trend term.

Considering the Southern nations, out of the seven test statistics only one provides strong evidence of cointegration. The inclusion of a time trend term improves this outcome, since three of the seven test' statistics provides strong evidence of cointegration. On the other hand, within the Northern nations there is a strong evidence of cointegration among the variables since most of the test statistics provide evidence at 1% significance level with and without the trend term.

Additionally, the cointegration test results for the ICT service sector can be seen in Table 4. The ICT service industry in the Southern countries exhibits cointegration relation among the variables with the inclusion of a trend term since five of the seven test statistics are statistically significant at 1%. Nonetheless, with the removal of the trend term, it is not possible to strongly reject the null hypothesis of no cointegration. Considering the Northern regions, four of the test statistics confer that there is cointegration at a 5% significance level.

5.3. Panel ARDL Estimations

Table 1 exhibits the ARDL estimations of the macro-level analysis using the aggregate data. Firstly, the Hausman test was conducted to decide the more adequate estimator between the Pooled Mean Group (PMG), Mean Group (MG) and dynamic fixed effect (DFE). The MG and the DFE estimators allow for heterogeneity in the short and long-run estimators. On the other hand, the PMG estimator estimates error-variance allowing the differentiation of short-run' coefficients across countries while long-run' coefficients are equal. The DFE model considers the bias between the error term and the lagged dependent variable. According to the Hausman test, there is statistical evidence to use the DFE estimator when comparing p-values. Therefore, the DFE estimator is chosen to analyze aggregate data.

Considering the Southern group of countries, the ARDL (1, 1, 1, 1) model only provides evidence of a positive and significant effect of private investment (BERD) on GVA in the short term (Table 1), with the error correction term (ECT) being not significant. In the ICT sector (Table 2), ECT appears to be significant giving evidence of a long-run relation with the impact of BERD on GVA being positive and significant, both in the short and long term.

Table 1 - ***Panel ARDL using DFE Estimation***

	(1) [South]	(2) [North]
Long-run coefficients		
ECT	-0.11 (0.19)	-0.41** (0.01)
lnBERD	-0.41 (0.37)	0.47*** (0.00)
lnGBARD	-0.29 (0.52)	0.04 (0.81)
Short-run coefficients		
lnBERD	0.12* (0.06)	0.29*** (0.00)
lnGBARD	0.06 (0.17)	0.04 (0.73)
Constant	2.09* (0.08)	3.77** (0.02)

The asterisks ***, ** and * represents significance levels at 1%, 5% and 10% respectively.

Table 2 - ***Panel ARDL using DFE Estimation: ICT Service Sector***

	(1) [South]	(2) [North]
Long-run coefficients		
ECT	-0.43*** (0.00)	-0.20** (0.04)
lnBERD ICT Services	0.15** (0.02)	0.35** (0.02)
lnGBARD ICT Services	0.00 (0.99)	-0.18 (0.29)
Short-run coefficients		
lnBERD ICT Services	0.16*** (0.00)	0.04 (0.42)
lnGBARD ICT Services	0.01 (0.82)	0.03 (0.50)
Constant	3.80*** (0.00)	1.53 (0.10)

The asterisks ***, ** and * represents significance levels at 1%, 5% and 10% respectively.

Still, on a country basis[7] (Table 3), Italy and Greece reveal a long-run effect of BERD on GVA (0.27 and -1.37, respectively) while for Italy this positive effect also applies for the short run (0.94). Moreover, Italy and Portugal have positive elasticities of public investment (GBARD) in the short and in the long run, respectively.

Table 3 - ***Panel ARDL using DFE Estimation: Individual***

	Southern countries				Northern countries			
	PT	IT	GR	ES	UK	NL	FR	DE
Long-run Coefficients								
ECT	-0.12 (0.68)	-0.93*** (0.00)	-0.26** (0.01)	-0.04 (0.88)	-1.81*** (0.00)	-1.03** (0.04)	-0.31 (0.57)	-1.93** (0.03)
lnBERD	-1.64 (0.72)	0.27*** (0.00)	-1.37*** (0.00)	0.78 (0.88)	0.55*** (0.00)	0.23*** (0.00)	0.37 (0.21)	0.96*** (0.00)
lnGBARD	0.11 (0.88)	0.31* (0.06)	1.00 (0.15)	-1.81 (0.87)	0.23*** (0.00)	0.04 (0.96)	-1.16 (0.58)	-0.35*** (0.00)
Short-run Coefficients								
lnBERD	-0.17 (0.30)	0.94** (0.01)	-0.04 (0.84)	0.50** (0.01)	0.41*** (0.00)	0.10 (0.44)	1.00** (0.03)	1.24*** (0.00)
lnGBARD	0.12* (0.08)	-0.23 (0.49)	0.10 (0.44)	0.06 (0.44)	0.51** (0.01)	0.25 (0.70)	-0.16* (0.09)	-0.42 (0.44)
Constant	2.89 (0.39)	8.15** (0.03)	3.58* (0.06)	0.94 (0.67)	12.10*** (0.00)	11.22*** (0.00)	6.65 (0.19)	15.07** (0.03)

The asterisks ***, ** and * represents significance levels at 1%, 5% and 10% respectively.

For the Northern group, private R&D investment (BERD) has a positive (short and long run) effect on the dependent variable at 1% level (Table 1). The ECT coefficient is -0.41 with a 5% significance indicating the presence of a long run causal relationship. For this group of countries, public investment does not have a statistically significant influence on GVA.

On a country basis (Table 3), for all countries of the North, except France, in the long run, BERD has a positive and significant influence on GVA, with an elasticity between 0.23 (Netherlands) and 0.96 (Germany). They also seem to benefit for a short run positive effect of BERD on GVA (except for the Netherlands) with an elasticity that varies from 0.41 (United Kingdom) to 1.24 (Germany). Only France has a non-statistically significant coefficient of ECT.

[7] Furthermore, since the MG estimator is used to run the macro level model, it is possible to have each country's long and short-run coefficients and its respective ECT. This is because the MG estimator assumes that all the countries in the panel are heterogeneous.

In what relates to public investment, only the United Kingdom reveals a positive effect on GVA both in the short and in the long run. On the contrary, Germany and France have a negative elasticity of public investment in the long and in the short run respectively.

Table 4 - ***Panel ARDL using DFE Estimation: ICT Service Sector***

	Long-run coefficients: Southern countries				Long-run coefficients: Northern countries			
	PT	IT	GR	ES	UK	NL	FR	DE
ECT	-0.85** (0.02)	-0.81** (0.01)	-0.90** (0.03)	-0.33 (0.45)	-1.12* (0.06)	-1.71*** (0.00)	-0.36 (0.43)	-0.40 (0.14)
lnBERD ICT Servi-ces	-0.01 (0.85)	-0.19* (0.09)	0.28*** (0.00)	-0.46 (0.80)	0.12 (0.37)	0.02** (0.01)	0.17 (0.54)	-0.52** (0.00)
lnGBARD ICT Servi-ces	-0.01 (0.77)	0.20 (0.40)	0.01 (0.94)	-0.16 (0.52)	0.26*** (0.00)	-0.27*** (0.00)	-0.11 (0.74)	-0.39 (0.34)
	Short-run coefficients: Southern countries				Short-run coefficients: Northern countries			
	PT	IT	GR	ES	UK	NL	FR	DE
lnBERD ICT Servi-ces	0.10* (0.06)	-0.04 (0.77)	0.21** (0.01)	0.05 (0.87)	0.26 (0.15)	-0.11*** (0.00)	-0.30 (0.50)	0.00 (0.99)
lnGBARD ICT Servi-ces	-0.01 (0.77)	0.61** (0.02)	0.02 (0.81)	-0.04 (0.63)	0.20* (0.06)	-0.15** (0.01)	-0.05 (0.63)	-0.09 (0.62)
Constant	7.54** (0.01)	8.91** (0.01)	6.74** (0.03)	4.89 (0.11)	11.06* (0.06)	19.56*** (0.00)	3.86 (0.52)	4.04 (0.20)

The asterisks ***, ** and * represents significance levels at 1%, 5% and 10% respectively.

Looking at the ICT service sector (Table 4), only Netherlands have a positive and significant effect of private investment on GVA in the long run. However, in this country, both private and public investment seems to lead to negative outcomes in the short run. In line with the outcome for the global economy, the United Kingdom has a positive public investment' elasticity both in the short and in the long run (between 0.2 and 0.3, respectively). In what relates to Southern countries, there is evidence of positive private investment elasticities for Greece (0.21) and Portugal (0.10), in the short run, which in the case of Greece extends to the long run (0.28). Italy is the only country that has a positive effect of public investment on value-added but only for the short term.

5.4. Causality

Furthermore, it is also essential to analyze the direction of the causal effect of each variable on the dependent variable. This paper utilizes the panel Granger causality test proposed by Dumitrescu and Hurlin (2012) (Lopez & Weber, 2017). The results for this can be seen in Tables 5 and 6 (Appendix C).

Table 5 reveals that for the Southern regions there is a long-run causal effect from BERD to GVA, with only one country not benefiting from causal relation (Italy). The Northern countries show a bidirectional effect from BERD to GVA, which seems to be determined by France, although the Netherlands also has a positive effect of BERD on GVA. Looking at the ICT sector, this bidirectional effect also applies to the Southern region, although being determined by Portugal, with Greece only having a positive effect of private investment in ICT services valued added.

In regards to public investment (table 6), for the total economy, the evidence reveals that only Portugal benefit from these investments, with a positive effect from GBARD to GVA. Analyzing the ICT services sector, the same conclusion does not apply, with the northern countries benefiting from public investments (Netherlands and United Kingdom), in particular the United Kingdom which has a bidirectional effect of GBARD on GVA. In France, there is a long-run causal effect from GVA to GBARD. Portugal exhibits a causal long-run effect from GVA to public investment in the ICT service sector with no other causal relation for the other southern countries.

It is also possible to conclude that, in few countries, the public investment in the ICT services sector leads to private investment or vice-versa. For instance, in France and Netherlands there is a positive causal effect of private investment on public investment and the reverse occurs in Spain. For the economy as an all, this feedback effect between private and public investment only occurs in Italy[8].

6. Conclusion

This paper studies the impact of R&D on the GVA and seeks to determine the causal relationship between the public and private investment in R&D and economic growth.

Looking at the short and long run effects, we can conclude that the Northern countries considered in this analysis benefit from R&D private investments, both in the short and long run. This evidence is not so clear for the Southern countries under consideration.

Public investment only has a long run positive effect for two countries out of the eight, and for one country when looking at the ICT sector. For some countries, it seems that there is negative effect of public investment on GVA.

Looking at Granger causality, although some heterogeneity across countries persists, we found that in general there is a positive effect of private investment on the total GVA of the economy. Moreover, a bidirectional effect applies in the case of France. For the ICT sector, a bidirectional effects also applies for Netherlands and Portugal.

In regards to public investment, the evidence reveals that only Portugal has a positive effect of GBARD in GVA. Analyzing the ICT services sector, the same conclusion does not apply, with only Netherlands and United Kingdom benefiting from public investments, in particular the United Kingdom, which has a bidirectional effect of GBARD on GVA.

Despite the fact that this analysis is based on aggregate data, without capturing the characteristics of firms that benefit from those investments (neither the impact on those firms), it already gives some insights about the macro level impact of public and private investment in the value-added of a group of European countries. Investigation in this field seems to be crucial as investments, in particular public investments, should be calibrate in order to turn it more efficient, namely by exploring spillover effects.

A natural avenue of work would be to expand this dataset to cover more periods and countries and also to explore the relation between private and public investment and productivity since the country's distance to the frontier can determine the effect on GVA.

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APPENDIX A: Description of Variables

Table 1 - ***Description of variables used in macro level dataset***

Variable	Description
GVA	Gross value added in the economy expressed in millions of current euros (PPS values).
BERD	Business expenditure on Research and Development performed within business enterprise sector during a specific period. Expressed in millions of current euros (PPS values).
GBARD	Government budget allocations for Research and Development. Way of measuring government support for R&D activities. Expressed in millions of current euros (PPS values)

Table 2 - ***Description of variables used in ICT industry dataset***

Variable	Description
ICT GVA	Gross value added in the whole ICT industry expressed in millions of current euros (PPS values). This variable is split to include ICT service and ICT manufacturing.
GVA ICT Services	Gross value added in the ICT service industry expressed in millions of current euros (PPS values).
BERD ICT Services.	Business expenditure on Research and Development in the ICT sector performed within business enterprise sector during a specific period. This variable is split to include ICT service and ICT manufacturing.
GBARD ICT Services.	Government budget allocations for R&D in ICT service industries. Expressed in millions of current euros (PPS values).

APPENDIX B: Descriptive Statistics

Table 1 - ***Descriptive Statistics: Macro level for PT, ES, IT and GR (2006-2016)***

			Overall			Between			Within		
Variables	Obs	Mean	Std. Dev.	Min	Max	Std. Dev.	Min	Max	Std. Dev.	Min	Max
GVA	44	731509.60	558017.30	183826.40	1553293	635972.60	191935.50	1465775	31351.02	664266.50	819027.30
BERD	44	5235.93	4535.40	438.60	14352.83	5086.12	579.74	11079.21	846.85	2407.32	8509.55
GBARD	44	4664.05	3872.88	686.11	10110.71	4359.45	917.33	9148.83	643.53	3192.97	6216.43

Table 2 - ***Descriptive Statistics: Macro level for DE, FR, NL and UK (2006-2016)***

			Overall			Between			Within		
Variables	Obs	Mean	Std. Dev.	Min	Max	Std. Dev.	Min	Max	Std. Dev.	Min	Max
GVA	44	1550719	665866.10	493895.90	2679266	746494.90	536052.20	2335394	125367.90	1271872	1894591
BERD	44	24940.3	16191.78	4393.67	59273.17	17993.58	5909.66	48919.88	3701.33	16163.64	35293.59
GBARD	44	12701.51	6659.13	4025.32	25916.99	7399.05	4341.55	22065.03	1526.32	7814.09	16553.47

Table 3 - ***Descriptive Statistics: ICT industry for PT, ES, IT and GR (2006-2016)***

			Overall			Between			Within		
Variables	Obs	Mean	Std. Dev.	Min	Max	Std. Dev.	Min	Max	Std. Dev.	Min	Max
ICT GVA	44	29060.33	22848.5	5948.98	61959.97	26026.59	7130.57	58483.72	1483.79	24494.44	32536.58
ICT Manu. GVA	44	1876.72	1889.36	86.68	5374.78	2137.73	120.25	4867.36	250.14	1234.939	2384.14
ICT Ser. GVA	44	27183.61	21106.35	5828.08	56585.18	24044.58	6601.34	53616.36	1337.02	23259.50	30152.44
BERD ICT	44	881.64	732.67	89.87	2275.63	823.10	152.02	1967.11	129.87	293.20	1190.16
BERD ICT Manu.	44	261.51	334.71	11.33	931.19	377.69	31.55	820.67	50.60	127.08	431.54
BERD ICT Ser.	44	620.13	445.67	69.97	1521.60	483.62	120.47	1146.44	138.29	-.36	995.29
GBARD ICT Manu.	44	14.94	17.23	.15	49.41	18.88	.98	40.95	4.85	5.47	28.147
GBARD ICT Ser.	44	258.27	255.59	10.44	642.95	289.09	18.41	608.38	34.44	174.40	363.16

Table 4 - ***Descriptive Statistics: ICT industry for DE, FR, NL and UK (2006-2016)***

			Overall			Between			Within		
Variables	Obs	Mean	Std. Dev.	Min	Max	Std. Dev.	Min	Max	Std. Dev.	Min	Max
ICT GVA	44	75571.94	29262.19	26643.74	122766.80	32566.19	29010.41	104967.70	6508.44	62258.56	93371.07
ICT Manu. GVA	44	6355.95	5081.56	1220.67	21130.61	5504.91	1700.77	14270.59	1601.767	2921.072	13215.97
ICT Ser. GVA	44	69215.99	25835.12	25309.48	107964.90	28478.77	27309.64	90697.13	6710.219	54869.45	86483.72
BERD ICT	44	3645.62	1981.68	522.02	6535.38	2172.21	870.37	5874.53	553.04	2739.90	5379.85
BERD ICT Manu.	44	1492.64	1273.02	227.88	3914.19	1419.37	295.64	3315.95	272.92	779.46	2090.89
BERD ICT Ser.	44	2152.97	1047.40	269.45	4077.37	1057.57	574.73	2818.30	488.56	1183.96	3412.04
GBARD ICT Manu.	44	54.82	68.72	6.18	207.60	75.71	12.01	168.24	17.99	9.99	98.58
GBARD ICT Ser.	44	397.02	235.91	120.76	764.39	258.83	152.00	646.99	65.15	236.82	540.96

APPENDIX C: Results (Unit root and Cointegration Tests)

Table 1 - *IPS unit root test*

	Level Data				First Difference Data			
Variables	Southern Group		Northern Group		Southern Group		Northern Group	
	Cons-tant	Constant + Trend	Cons-tant	Cons-tant + Trend	Constant	Constant + Trend	Constant	Constant + Trend
GVA	-1.23 (0.109)	-2.42*** (0.007)	1.29 (0.902)	0.76 (0.776)	-4.98*** (0.000)	-5.55*** (0.000)	-3.24*** (0.000)	-3.91*** (0.000)
BERD	2.90 (0.998)	-0.29 (0.385)	1.73 (0.958)	0.81 (0.791)	-4.72*** (0.000)	-8.40*** (0.000)	-3.02*** (0.001)	-5.04*** (0.000)
GBARD	-1.93** (0.027)	0.58 (0.721)	0.36 (0.642)	0.92 (0.821)	-3.25*** (0.000)	-1.57* (0.059)	-2.75*** (0.003)	-2.81*** (0.002)

The asterisks ***, ** and * represents significance levels at 1%, 5% and 10% respectively.

Table 2 - *IPS unit root test: ICT Service Sector*

	Level Data				First Difference Data			
Variables	Southern Group		Northern Group		Southern Group		Northern Group	
	Constant	Constant + Trend	Constant	Constant + Trend	Constant	Constant + Trend	Constant	Constant + Trend
ICT Services GVA	-1.35* (0.088)	-2.13** (0.016)	1.26 (0.896)	0.25 (0.598)	-3.93*** (0.000)	-2.81*** (0.002)	-2.18** (0.014)	-1.32* (0.093)
BERD ICT Services	-2.14** (0.016)	-1.47* (0.070)	1.36 (0.912)	-0.07 (0.473)	-4.20*** (0.000)	-2.70*** (0.003)	-3.06*** (0.001)	-2.47*** (0.006)
GBARD ICT Services	-0.46 (0.322)	-0.35 (0.363)	-0.20 (0.422)	-0.41 (0.341)	-3.66*** (0.000)	-2.14** (0.016)	-4.20*** (0.000)	-2.64*** (0.004)

Table 3 **- *Pedroni Cointegration test***

Test statistics	Southern Group		Northern Group	
	Constant	Constant + Trend	Constant	Constant + Trend
Panel *v*	-1.36* (0.087)	-1.12 (0.132)	-2.21** (0.014)	-3.24*** (0.000)
Panel *p*	1.17 (0.121)	1.47 (0.071)	1.67** (0.048)	2.53*** (0.006)
Panel PP	-0.104 (0.457)	-1.12 (0.131)	-9.07*** (0.000)	-15.45*** (0.000)
Panel ADF	-1.28* (0.099)	-3.86*** (0.000)	-2.92*** (0.002)	-3.03*** (0.001)
Group *p*	1.98** (0.024)	2.21** (0.014)	1.62* (0.052)	2.37*** (0.009)
Group PP	-0.04 (0.486)	-1.34* (0.090)	-4.37*** (0.000)	-2.81*** (0.003)
Group ADF	-3.75*** (0.000)	-3.71*** (0.000)	-2.70*** (0.004)	-2.04** (0.021)

The asterisks ***, ** and * represents significance levels at 1%, 5% and 10% respectively.

Table 4 - *Pedroni Cointegration test: ICT Service Sector [demean]*

Test statistics	Southern Group		Northern Group	
	Constant	Constant + Trend	Constant	Constant + Trend
Panel *v*	-1.78** (0.038)	-2.50*** (0.006)	-1.71** (0.043)	-2.43*** (0.008)
Panel *p*	1.01 (0.155)	2.10** (0.018)	0.38 (0.352)	1.76** (0.039)
Panel PP	-0.72 (0.235)	-1.52* (0.065)	-1.94** (0.026)	-0.78 (0.217)
Panel ADF	-0.94 (0.175)	-3.72*** (0.000)	-2.04** (0.021)	-0.65 (0.257)
Group *p*	2.10** (0.018)	2.98*** (0.001)	1.66** (0.048)	2.65*** (0.004)
Group PP	0.11 (0.455)	-17.66*** (0.000)	-0.54 (0.295)	-0.03 (0.490)
Group ADF	-0.75 (0.227)	-3.08*** (0.001)	-0.50 (0.310)	-0.88 (0.190)

The asterisks ***, ** and * represents significance levels at 1%, 5% and 10% respectively.

Table 5 - *Granger Causality Test: GVA and BERD*

	Total economy		**ICT services**	
Region	GVA→BERD	BERD→GVA	GVA→BERD	BERD→GVA
North	Z-bar =8.8211 (0.000)***	Z-bar =6.0923 (0.000)***	Z-bar = 4.2599 (0.000)***	Z-bar = 3.1425 (0.002)***
South	Z-bar =-0.5580 (0.5768)	Z-bar =3.2001 (0.0014)***	Z-bar = 2.0281 (0.0426)**	Z-bar = 2.2823 (0.0225)**
	Total economy		**ICT services**	
Country	GVA→BERD	BERD→GVA	GVA→BERD	BERD→GVA
DE	Z-bar =-0.6550 (0.5125)	Z-bar =-0.3014 (0.7631)	Z-bar =-0.0283 (0.9774)	Z-bar =6.2650 (0.000)***
FR	Z-bar =19.6021 (0.000)***	Z-bar = 4.5251 (0.000)***	Z-bar = 1.5312 (0.1257)	Z-bar = 0.9991 (0.3178)
NL	Z-bar =-0.6002 (0.5483)	Z-bar = 6.8794 (0.000)***	Z-bar = 5.2679 (0.000)***	Z-bar = 3.7108 (0.0002)***
UK	Z-bar =-0.7046 (0.4810)	Z-bar =1.0815 (0.2795)	Z-bar =1.7489 (0.0803)*	Z-bar =0.3303 (0.7412)
ES	Z-bar =-0.6287 (0.5295)	Z-bar = 2.8723 (0.0041)***	Z-bar =-0.1542 (0.8775)	Z-bar = 0.6173 (0.5370)
GR	Z-bar =-0.6025 (0.5469)	Z-bar = 1.7891 (0.0736)*	Z-bar =-0.9724 (0.3309)	Z-bar = 5.0571 (0.000)***
IT	Z-bar =-0.3762 (0.7068)	Z-bar =0.0231 (0.9815)	Z-bar =1.5976 (0.1101)	Z-bar =-0.6524 (0.5142)
PT	Z-bar = 0.4914 (0.6232)	Z-bar = 1.7155 (0.0862)*	Z-bar = 5.0787 (0.000)***	Z-bar = 4.5191 (0.000)***

The asterisks ***, ** and * represents significance levels at 1%, 5% and 10% respectively.

Table 6 - *Granger Causality Test: GVA and GBARD*

	Total economy		ICT services	
Region	GVA→GBARD	GBARD→GVA	GVA→GBARD	GBARD→GVA
North	Z-bar =-0.0018 (0.9986)	Z-bar =-0.0991 (0.9210)	Z-bar = 5.1335 (0.000)***	Z-bar = 4.9161 (0.000)***
South	Z-bar = -0.7332 (0.4635)	Z-bar = 1.2676 (0.2049)	Z-bar = 1.3474 (0.1779)	Z-bar = 0.9279 (0.3535)
	Total economy		**ICT services**	
Country	GVA→GBARD	GBARD→GVA	GVA→GBARD	GBARD→GVA
DE	Z-bar =-0.2009 (0.8408)	Z-bar = 1.4306 (0.1525)	Z-bar =-0.7368 (0.4612)	Z-bar =-0.3409 (0.7331)
FR	Z-bar = 0.2064 (0.8365)	Z-bar =-0.3546 (0.7229)	Z-bar = 3.7361 (0.0002)***	Z-bar = 1.0066 (0.3141)
NL	Z-bar =-0.3411 (0.7330)	Z-bar =-0.6662 (0.5053)	Z-bar =-0.6449 (0.5190)	Z-bar = 4.6488 (0.0000)***
UK	Z-bar = 0.3321 (0.7398)	Z-bar =-0.6080 (0.5432)	Z-bar = 3.0136 (0.0026)***	Z-bar = 6.0855 (0.000)***
ES	Z-bar =-0.7062 (0.4801)	Z-bar = 0.0920 (0.9267)	Z-bar =-0.5759 (0.5647)	Z-bar = 0.5573 (0.5773)
GR	Z-bar = -0.0367 (0.9707)	Z-bar = -0.6884 (0.4912)	Z-bar =-0.6556 (0.5121)	Z-bar = 1.1101 (0.2669)
IT	Z-bar =-0.0533 (0.9575)	Z-bar = 1.3354 (0.1817)	Z-bar = 0.2110 (0.8329)	Z-bar = 0.1178 (0.9062)
PT	Z-bar =-0.6702 (0.5027)	Z-bar = 1.7962 (0.0725)*	Z-bar = 2.0956 (0.0361)**	Z-bar = 0.0705 (0.9438)

The asterisks ***, ** and * represents significance levels at 1%, 5% and 10% respectively.