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Public Investment, Convergence and Productivity Growth in European regions

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Public investment, convergence and productivity growth in European regions

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Abstract

This paper estimates an augmented growth model to analyse the contribution of public investment to productivity growth for European regions. The empirical model accounts for the accumulation of public capital, the stock of infrastructure and the creation of knowledge by the government sector, alongside other growth determinants, as institutions, education, and business R&D. Convergence dynamics are also explored. Data include 273 NUTS2 European regions from 27 countries from 1999 to 2018. The empirical evidence presented suggests that public investment is positively associated with productivity growth and complementarities with business investment are in place. Furthermore, returns on both types of investments are larger in the regions of the Southern periphery, flagging policy space for further public and private productive spending. No significant effect is found for the stock of infrastructure. Public R&D has an indirect impact on productivity growth through the mediating effect of business R&D, while institutional quality is a horizontal determinant of growth.

1 Introduction

The empirical growth literature has attempted to explain whether and why countries or regions do converge to a level of productivity, identifying those

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factors supposedly shaping productivity growth dynamics and eventually determining the evolution of cross-country and regional disparities. Analysing the process of convergence means assessing whether less developed economies are catching-up with the more developed ones, as implied by the neoclassical growth model. The theoretical foundations of this prediction date back to Gerschenkron (1962) and the pioneering contribution by Solow (1956), to which the empirical literature on growth and convergence implicitly or explicitly refers to. While the original theoretical model implies unconditional (*absolute*) convergence regardless of economy and society-wide conditions, this is hardly reflected in the data (Barro and Sala-i Martin, 1992; Rodrik, 2013; Johnson and Papageorgiou, 2020). In those cases where unconditional convergence is observed, it takes place as a nonlinear process (Fiaschi and Lavezzi, 2007a; Martino, 2015) limited either to specific sectors (McMillan and Rodrik, 2011; Rodrik, 2013; Martino, 2015) or groups (clubs) of economies (Quah, 1996; Corrado et al., 2005; Fiaschi et al., 2018; Johnson and Papageorgiou, 2020)Therefore, the literature has turned onto the identification of those factors favouring economic and productivity growth, enabling or deterring the process of (conditional) convergence and eventually shaping cross-country and regional disparities. In order to do so, a common empirical approach is to augment a standard growth regression *à la Solow* with additional variables economic theory suggests they may affect growth. In other terms, the concept of exogenous technological progress is endogenised by allowing for the creation and accumulation of knowledge through investments in education and training, research, development and innovative activities (Aghion and Howitt, 1992; Crescenzi, 2005). Furthermore, local endowments other than labour and capital are introduced together with economy-wide factors, in the attempt to *reduce* the magnitude of the residual. The contributions by Barro and Sala-i Martin (1992); Mankiw et al. (1992) set the way for later work. Earlier studies focus on different measures of educational attainment to capture the concept of human capital (Bernanke and Gürkaynak, 2001). Since then, the empirical literature has further expanded to the analysis of additional factors consistently with economic theory, including most notably: institutions (Rodrik et al., 2004; Acemoglu et al., 2005; Rodríguez-Pose, 2013; Acemoglu et al., 2014; Rodríguez-Pose and Ketterer, 2020; Rodríguez-Pose et al., 2021), research and innovation efforts (Bilbao-Osorio and Rodríguez-Pose, 2004; Crescenzi, 2005; Rodríguez-Pose and Crescenzi, 2008; Fagerberg et al., 2010; Crescenzi and Rodríguez-Pose, 2011; Soete et al., 2020a), public investment (Romp and De Haan, 2007), and infrastructure (Crescenzi and Rodríguez-Pose, 2008, 2012; Crescenzi et al., 2016).

Against this backdrop, this paper contributes to the existing literature by analysing the contribution of public investments to productivity growth in the case of the EU regions. The empirical approach applies the insights from cross-country studies on public investment to the literature on growth empirics in Europe and its regions, accounting for public capital accumulation, infrastructure and the creation of knowledge by the government sector, in the attempt to measure their relevance for productivity dynamics in the European Union (EU). The analysis is relevant for both the empirical literature and for its policy implications.

For what concerns the empirical literature, the growth model estimated in this paper brings together different sources of productive public spending, namely total public investment, public R&D and the stock of infrastructure, using data on European regions in the last two decades. While the importance of public investment for productivity growth and development is acknowledged in the cross-country empirical literature, when it comes to regional analysis, and in particular in the case of European regions, there is less emphasis on the role of the government sector. Capital accumulation usually enters empirical models as total (gross) investment, without distinguish between its public and private components, Gonzalez-Paramo and Martinez (2003) and León-González and Montolio (2004) being an exception in their investigation of the impact of public capital spending on growth across Spanish regions. Some research focuses on infrastructure, as a physical measure of a specific type of public capital stock, as for instance in Crescenzi and Rodríguez-Pose (2008) and Crescenzi and Rodríguez-Pose (2012). Furthermore, despite the increasing importance attributed to intangible investment, research and development (R&D) mostly enter growth models as an aggregate figure. Even though public R&D is very different in nature and scope than its counterpart in the business sector[1], one needs to look at different strands of the literature to find accounts of public R&D efforts and their impacts on productivity (Verspagen, 2005; Van Elk et al., 2015; Soete et al., 2020a,b).

From a policy perspective, the paper aims to contribute to fill the gap between available evidence and the most recent policy changes. Indeed, while the empirical literature has given little attention to the role of government productive spending, the relevance of public investments has come back to the forefront of the policy debate in Europe, most notably following the latest Covid-19 pandemics. The European Commission has put forward its strategy

[1]See Archibugi and Filippetti (2018) on the characteristics of public R&D *vis à vis* business R&D and on the reason why public efforts are needed for knowledge creation and adoption.

to favour the recovery from the pandemics crisis, accelerating the process of transformation of the EU economies to make them more sustainable and resilient. The NextGen EU plan and the new multiannual budget for the period 2021-2027 foresee a renewed policy framework aiming to foster and accelerate the digital and green transitions, providing a stimulus package of over € 2 trillion. Hence, national and subnationl governments, under the guidance of and in cooperation with the European institutions, will have a key role in the implementation of the plan, through the implementation of reforms and investments (Commission, 2020). Heterogeneity in the capacity of regional governments and economies to implement and absorb investments is likely to be key.

The remainder of this paper is structured as follows. Section 2 introduces the context of the analysis and presents the related literature. Section 3 presents the data used and the empirical framework. Section 4 reports the distribution dynamics for labour productivity across European regions. Unconditional convergence is also investigated applying a non parametric regression. The main results of the growth regression are in Section 5, while Section 6 concludes.

2 Related literature

The analysis sets at the crossroads of different and yet interlinked strands of the empirical literature on productivity growth and its determinants.

First, it builds on the literature on public investment assessing the impact of productive government spending on growth at least since Barro (1990). If public investment is understood in a similar way as private investment is, then it is expected to impact growth directly as a *production factor* (Bayraktar, 2019). However, public investment is also likely to affect the relationship between economic performance and private investment, building the base for business engagement, complementing private capital spending, or lowering production costs of the business sector (Romp and De Haan, 2007; Bayraktar, 2019). Therefore, empirical studies take different approaches to investigate the relationship between the accumulation of public capital and growth. From a methodological perspective, the estimation of either a production function or a growth regression is the most common approach in the literature, due to the pragmatic flexibility of the empirical specifications (Romp and De Haan, 2007). Although the range of estimates varies with sample composition and time period, available cross-country evidence suggests that the contribution of public sector investments to economic performance tends to be positive, independently of the empirical specification and the measure used[2] (Romp and De Haan, 2007; Bom and Ligthart, 2014). Capital accumulation, i.e. investment, usually enters empirical models as total (gross) investment, without distinguish between its public and private components (Rodríguez-Pose and Ketterer, 2020), with few exceptions as for instance Gonzalez-Paramo and Martinez (2003) and León-González and Montolio (2004) in their analysis of Spanish regions. Furthermore, growth policies worldwide have historically focused on infrastructure as a driver of economic performance, due to its direct effects on the stock of capital, the spillovers on the rest of the economy, the reduction of the cost of private investments, the network effects and the increased accessibility to regional and global markets (Égert et al., 2009). Regional policies in the EU have had a similar focus on infrastructure. Therefore, empirical studies have analysed to what extent regional or national infrastructure endowments affect productivity growth dynamics. This is also true for studies on European regions, whose recent findings reveal no significant contribution of infrastructure to growth in Europe (Crescenzi and Rodríguez-Pose, 2012; Rodríguez-Pose, 2020), while the cross-country literature provides no straightforward results (Bom and Ligthart, 2014). The approach of this paper applies the insights from cross-country studies on public "capital" to the literature on growth empirics in Europe and its regions, accounting for public investment, infrastructure and the creation of knowledge by the government sector, in the attempt to measure their relevance for productivity dynamics in the EU.

Second, the analysis contributes to the existing evidence on convergence, by assessing its dynamics across EU regions in the last two decades. Other than *testing* the validity of the neoclassical prediction, analysing convergence allows to trace the trend in regional disparities that are of crucial importance for the overall objective of cohesion, as foreseen by the EU treaties[3]. Are Eu-

[2]Different measures for public capital spending are used. For instance, in the case of the production function, a value for public capital stock is estimated, while growth regressions make use of public investment consistently with the derivation in the theoretical literature as in Solow (1956) or Mankiw et al. (1992). Capital stock has the disadvantage of neither being readily available from national and international statistical sources, nor straightforwardly usable for international comparisons (Romp and De Haan, 2007; Bom and Ligthart, 2014). Differently, investment statistics are routinely produced by National Statistical Offices and their use for cross-country comparisons is more straightforward (Romp and De Haan, 2007). See Romp and De Haan (2007) and Bom and Ligthart (2014) for a review of the literature.

[3]Empirical work is increasingly assessing the impact of the European Cohesion Policy on the reduction of regional disparities. The Cohesion Policy foresees the engagement of national and regional governments, which are involved in its design and implementation and hence allowing for potential differences in final outcomes. For instance, Crescenzi and

ropean regions converging? Or, alternatively, which regions are catching up and which are lagging behind? Existing evidence shows that EU regions are not converging or, when they are, they do cluster in *convergence clubs* and the overall trend is mostly driven by Central-Eastern and Eastern regions (Fiaschi and Lavezzi, 2007b; Marelli, 2007; Martino, 2015; Fiaschi et al., 2018). This analysis builds on previous work by providing distribution dynamics of labour productivity for NUTS2 regions using the latest available data. Results will serve as building block for the growth regressions.

Finally, the paper draws from and contributes to the empirical research assessing the role of regional specific factors in shaping productivity growth dynamics. Research on this topic has a long lasting tradition in growth empirics, Mankiw et al. (1992) and Barro and Sala-i Martin (1992) being pioneering studies in a cross-country setting. Since then, both theoretical and empirical analyses have explored the role of additional factors. The search for other variables affecting economic performance is mainly due to the acknowledgement that the standard framework was less and less capable to explain growth disparities across regions and countries, and more so when assessing regional dynamics in Europe (Rodríguez-Pose and Ketterer, 2020). Indeed, the EU is characterised by a high degree of heterogeneity that translates into significant gaps in terms of economic performance between the more and the less developed countries, but also in terms of endowments of human capital, infrastructure and the capacity to produce and adopt knowledge. Further to cross-country heterogeneity, regional disparities are widespread between and within countries. In the past years economies of agglomeration have characterised the global production of goods and knowledge creation, clustering economic and innovation activities, and firms' headquarters in a few global and regional hubs, as for instance in capitals or main metropolitan areas (Rosenthal and Strange, 2004; Puga, 2010; Crescenzi et al., 2020; Verginer and Riccaboni, 2021). Agglomeration economies coupled with the increasing productivity gap between frontier firms and the *laggards*, fuelled by the concentration of knowledge creation and the failure in the process of innovation diffusion and take-up (Andrews et al., 2016; McGowan et al., 2017; Autor et al., 2020). These trends contributed to the widening of already existing regional divides and fostered new disparities along the capitals and metropolitan areas *vis à vis* peripheral areas dimension (Rodríguez-Pose,

Giua (2020) point out that the positive effects of the Cohesion policy tend to concentrate in German regions, with limited and short lived benefits accruing to Southern Europe. Regional and national characteristics are key for understanding such differences in impact. While the assessment of Cohesion Policy is not the scope of this paper, it has implications for convergence dynamics. See, among others, Crescenzi and Giua (2017) or Crescenzi and Giua (2020) on the subject.

2018). Therefore, researchers have been exploring several factors whose relationship with growth is supported on a theoretical grounding[4]. R&D and innovative investments usually come first on the list of drivers. They are fundamental for the generation or adoption of new knowledge, fuelling technological progress that is the key engine of productivity gains and sustained growth in the medium and long term (Romer, 1994). Consistently with an evolutionary view of technological change, where path dependency and uncertainty are the main features of innovation (Dosi et al., 1988), knowledge creation and innovative activities are unevenly distributed and geographically concentrated (Mazzucato and Perez, 2015). In order to properly model growth dynamics, differences in regional capacities to produce, take-up and apply new knowledge need to be accounted for (Bilbao-Osorio and Rodríguez-Pose, 2004; Crescenzi, 2005; Rodríguez-Pose and Crescenzi, 2008). Therefore, empirical work includes R&D intensity - defined as R&D expenditure over output - among the productivity growth determinants[5]. Within the focus on public investment of this paper, this analysis also assesses the contribution of R&D undertaken in the public sector vis à vis the business sector is analysed. Following Mankiw et al. (1992) and the related literature, educational attainment is another factor usually included in growth empirics to represent the availability of human capital, and it complements R&D efforts as a measure of the regional knowledge base and adoption capacity. Then, institutions have become one of the most investigated factors in growth empirics. In the original definition by North (1991), institutions are socially devised constructs determining the incentives for individuals and groups to engage in economic (and innovation) activities. *Good* institutions ensure an efficient delivery of public goods and services, a lower level of corruption and a fair and generalised protection of property rights for all social and economic actors (Acemoglu et al., 2002; Ogilvie and Carus, 2014). Empirical applications attempt to capture these characteristics by using variables related to efficiency, efficacy and impartiality in the delivery of public good and services, as well as the general protection of property rights. In the last decade, the

[4]A parallel strand of literature has developed the concept of *territorial capital*, blending together a series of factors within and beyond the firm's boundaries. They include the growth determinants discussed in this section and add further variables, as for instance the artistic, natural or financial capital of the region (Castelnovo et al., 2020), or relational and behavioural factors (Fratesi and Perucca, 2019). As in the standard growth regression framework, territorial capital is then used to study the contribution of place-specific characteristics to regional growth and the impact of development policies. See Camagni (2017) for further details.

[5]Patents could be used as an alternative measure. However, due to the skewness of patenting across sectors and firms and because of the investment focus of this paper, R&D intensity is usually preferred.

increased availability of data on institutional quality both at the country and subnational level has spurred empirical work on the quality of local and national institutions and their contribution to prosperity and development. In particular, data has increased substantially for what concerns Europe, whose heterogeneity is also reflected in the different degree of institutional quality across its regions (Charron et al., 2014, 2019). While still incomplete in the time dimension, the substantial increase in data availability on institutional quality at the regional (NUTS2) level made it easier to investigate institutions and their relationship with economic performance (Charron et al., 2014; Annoni et al., 2016; Charron et al., 2019). An increasing literature assessing the impact of institutions on regional (productivity) growth in Europe has provided support to the theoretical claim that institutional quality is a key driver of development dynamics (Rodríguez-Pose and Ketterer, 2020; Rodríguez-Pose, 2020; Rodríguez-Pose and Ganau, 2021). Findings suggest that institutions are key drivers of productivity growth and development, not only as a direct enhancer of economic performance: returns on investment tend to be higher where good institutions are in place. This is true for investment, in general (Rodríguez-Pose and Garcilazo, 2015; Rodríguez-Pose, 2020) and for the specific case of public investment (Bayraktar, 2019) or infrastructure endowments (Esfahani and Ramirez, 2003; Crescenzi et al., 2016), research and innovation efforts[6] (Tebaldi and Elmslie, 2013; Boschma, 2015; Rodríguez-Pose and Di Cataldo, 2015; Rodríguez-Pose, 2020), and human capital (Acemoglu et al., 2014). The main takeaway is that empirical assessments need to "control for" institutions when estimating a growth regression. (Acemoglu et al., 2014; Rodríguez-Pose and Ganau, 2021).

3 Methodology and data

3.1 Methodology

As a preliminary step to investigate productivity growth dynamics, a non-parametric convergence regression is estimated in search for evidence of absolute convergence of labour productivity, defined as gross value added (GVA) per worker, as in equation ((1)).

$$\bar{g}_{ri} = a + s(y_{i,0}) \tag{1}$$

[6]However, research and innovation policies may deliver positive outcomes also under weaker institutional regimes, as for instance in the case of R&D subsidies (Bianchini et al., 2019).

$\bar{gr}_i$ is the average growth rate of labour productivity for each region i, $y_{i,0}$ is the level of labour productivity at the beginning of the period, and s is the smooth term. Based on earlier results in the literature, a non linear relationship is expected to be in place, driven mostly by Eastern and Central Eastern economies (Fiaschi and Lavezzi, 2007a; Marelli, 2007; Martino, 2015). The non-parametric setting serves the scope of identifying non-linearities.

The main analysis implements a growth regression framework, building on the approach popularised by Barro (1991), Mankiw et al. (1992) and Barro (1996) among others. The standard growth equation, based on the original model by Solow (1956), is augmented with additional factors to assess whether and how they contribute to determine the growth rate of labour productivity and disparities across economies. In particular, one can assume a standard Cobb-Douglas production function

$$Y_{it} = A_{it} K_{it}^{\beta_k} G_{it}^{\beta_g} H_{it}^{\beta_h} L_{it}^{\beta_l} \tag{2}$$

where Y is the GVA of region i at time t, K, G, and L are private capital, public capital and employment, while H represents human capital. Equation (2) can be augmented with additional factors by specifying the composition of the "technological component", or residual, A as for instance:

$$A_{it} = A_0 e^{Z'_{it}\vartheta} \tag{3}$$

where A_0 is an exogenous shock and Z'_{it} is a vector of economy-specific characteristics, in this case including institutional quality, infrastructure, and R&D[7]. After transforming equation (2) in per worker terms and taking the logs, the resulting empirical model for labour productivity growth is as follows (see Mankiw et al. (1992); Islam (1995); Rodríguez-Pose (2020)) :

[7]Public capital may enter the production function as part of Z in equation (3), rather than decomposing the capital stock in its private and public components. The advantage of doing may be to allow its impact to go through different channels, as for instance a reduction of private production costs, positive externalities and network effects, in the same way R&D increases the global stock of knowledge available to companies to drawn upon (i.e. shifting the production function upwards). Alternatively, treating public capital stock as a production factor provides the "rationale" for interaction and complementarities with the business investment, without any loss of generality. As noted by (Romp and De Haan, 2007), the resulting growth regression would be equivalent in either case, with no empirical implications.

$$
\begin{aligned}
ln(y_{i,t}) - ln(y_{i,t-1}) = {} & \beta_1 ln(y_{i,t-1}) + \beta_2 ln(priv\_investment_{i,t-n}) + \\
& \beta_3 ln(pub\_investment_{i,t-n}) + \\
& \beta_4 ln(priv\_investment_{i,t-n}) x ln(pub\_investment_{i,t-n}) + \\
& \beta_5 ln(h\_capital_{i,t-n}) + \beta_6 ln(n_{i,t} + g + \delta) + \vartheta_1 R\&D_{i,t-n} + \\
& \vartheta_2 institutions_{i,t} + \vartheta_3 infrastructure_{i,t} + \mu_i + v_t + u_{i,t}
\end{aligned}
\tag{4}
$$

The dependent variable on the left hand side of equation (4) is the growth rate of labour productivity, which is the variable of interest. The right hand side includes the value of labour productivity in the previous period, $y_{i,t-1}$, to investigate for convergence dynamics (Islam, 1995), *priv_investment* and *pub_investment* are gross private and public investment respectively, while *h_capital* is the human capital investment proxied by the secondary education attainment. $ln(n_{i,t} + g + \delta)$ is the last term of the standard non augmented model, where n is population growth, g and δ are unaccounted technological shock and capital depreciation respectively, their sum assumed to be equal to 5% (Rodríguez-Pose, 2020). *Institutions*, *R&D* (intensity) and *infrastructure* are the additional regional specific factors of interest, with the above caveats. The model is estimated via fixed effect in a panel setting, using a within transformation model with the package *plm* in the software *R*. The model includes a time effect v_t and a fixed effect μ_i. However, since the panel is unbalanced and there are a few variables with low within variations, e.g. institutions and the infrastructure stock, country fixed effects are used for μ_i. Concerning the lag structure of the growth regression, on the one hand, empirical specifications usually include lagged independent variables to control for omitted variables, endogeneity and reverse causality issues and, on the other hand, to account for lagged and long term impact of some factors, most notably investment. In this paper, a three years moving average is used for $t-n$ in the estimation of equation (4) for what concerns the investment-related variables, including human capital and R&D. Differently, *infrastructure*, *institutions* and $ln(n_{i,t} + g + \delta)$ enter at time t[8].

The further research question of interest is whether public R&D has any

[8] Infrastructure and institutional quality may be considered as *stock* variables with little variation overtime, the former being a physical measure of a specific type of capital stock resulting from past public investment. The model already accounts for the "flow" variable in the form of public investment, which also includes (new) infrastructure spending. Institutions are characterised by high cross -country and -region heterogeneity but limited variation overtime, due to persistence and path dependency, as discussed in North (1991), Charron et al. (2019), and Bianchini et al. (2019).

impact on labour productivity growth. Theoretical (Archibugi and Filippetti, 2018) and empirical (Soete et al., 2020b,a) work suggests that public efforts in knowledge creation, because of their nature and characteristics as "far from the market" investments, may have both a direct and indirect impact on productivity growth. Therefore, the main specification is complemented by a 2SLS model in a panel setting. In particular, in the first step business R&D, $R\&D^b_{i,t}$, is regressed on public R&D, $R\&D^p_{i,t}$, and the share of knowledge intensive sectors on gross value added, $Knowledge\_Share_{i,t}$, the latter used as external instrument together with all the remaining regressors, $W_{i,t}$ (equation (5)). Then the fitted values of business R&D, $\hat{R\&D}^b_{i,t}$, are used in the second stage together with public R&D and the other variables included in the original model (equation (6)) .

$$\begin{aligned} R\&D^b_{i,t} = &\beta_0 + \gamma_1 R\&D^p_{i,t-n} + \gamma_2 Knowledge\_Share_{i,t} \\ &+ W^{'}_{i,t}\gamma_w + \mu_i + v_t + u_{i,t} \end{aligned} \tag{5}$$

$$\begin{aligned} ln(y_{i,t}) - ln(y_{i,t-1}) = &\beta_1 ln(y_{i,t-1}) + \beta_2 ln(priv\_investment_{i,t-n}) + \\ &\beta_3 ln(pub\_investment_{i,t-n}) + \\ &\beta_4 ln(priv\_investment_{i,t-n}) x ln(pub\_investment_{i,t-n}) + \\ &\beta_5 ln(h\_capital_{i,t-n}) + \beta_6 ln(n_{i,t} + g + \delta) + \\ &\phi_1 \hat{R\&D}^b_{i,t-n} + \phi_2 R\&D^p_{i,t-n} + \phi_3 institutions_{i,t} + \\ &\phi_4 infrastructure_{i,t} + \mu_i + v_t + u_{i,t} \end{aligned} \tag{6}$$

On the one hand, such a mediating model allows to estimate the relationship between business R&D and labour productivity growth. On the other hand, it provides estimates of the direct and indirect relationship between public R&D and labour productivity growth, the direct effect given by ϕ_2, and the indirect effect being equal to the product of γ_1 and ϕ_1.

3.2 Data

Data are drawn from three sources. The ARDECO dataset, managed by the Directorate General for Regional and Urban Policy (DG REGIO) of the European Commission, provides data on gross value added, gross fixed capital formation and employment figures. The European Social Progress Index is used for the indicator on institutional quality, using and updating the index proposed by Bianchini et al. (2019). The Eurostat regional database provides

	Mean	25%	Median	75%	Complete rate
Labour productivity	52256	34113	57144	65966	1.00
Investment share	0.24	0.20	0.24	0.26	1.00
Public investment share	0.04	0.03	0.04	0.05	0.83
Quality of Institutions	59.08	49.77	61.28	68.50	0.90
Total R&D intensity	1.29	0.55	1.02	1.63	0.54
Public R&D intensity	0.55	0.26	0.46	0.71	0.53
Education	72.57	64.50	76.30	83.70	0.81
Motorways (km)	293.61	69.00	204.00	411.00	0.54

Table 1: Descriptive statistics

information for the remaining variables. The analysis uses data on European regions for the period from 1999 to 2018. Regions are defined at the NUTS-2 territorial level, representing the second finest level of disaggregation of subnational data in the Eurostat classification. Because of data availability, the NUTS-0 territorial unit (national level) is used for Latvia, Luxembourg, and Cyprus, while most of the data is reported only at the NUTS-1 level in the case of Belgium. Hence, the regional information for these countries is aggregated accordingly. Overall, the dataset includes 273 regional observations spanning a period of twenty years. It is worth noting that the final sample is unbalanced due to missing data for a few independent variables, most notably R&D intensity, infrastructure and, to a lesser extent, education.

The main descriptive statistics for the pooled sample are reported in table 1. The mean and median of labour productivity - obtained as the ratio between GVA and employment - are around 52.000 and 57.000 euros[9] per worker. Public investment represents on average about 17% of total investment, amounting to 4% of GVA vis à vis the total investment share of 24%, without significant variation across the distribution, as shown by the 1st and 3rd quartiles. However, a certain degree of variation can be observed overtime, as shown in figure 1. The share of public investment has fluctuated between 3.3% and 4.3%, recording its higher value in the aftermath of the economic crisis in 2009 and its lowest in 2016.

R&D intensity is more unevenly distributed, as revealed by the difference between its mean value (1.29%) and the median (1.02%) and the gap between the 1st and 3rd quartile (1.8 percentage points). This is not surprising, as research and development activities tend to be concentrated in a few hubs, as do companies that invest the most in research and innovation (Crescenzi et al., 2020). This translates in the geographical pattern in figure

[9] All monetary values are at constant 2015 prices.

Figure 1: Evolution of the share of public investment over GVA

2, revealing a core-periphery dynamics and the emergence of *agglomerations* in the centre of Europe, Southern France, Nordic regions and the South of the United Kingdom. Public R&D intensity tends to follow the same pattern, with a mean and a median of 0.55% and 0.46%, corresponding to around 42-43% of total R&D intensity. Data on post-secondary education attainment in the 25-64 years age range is used to proxy human capital. On average, 72.6% of the population have completed post-secondary studies, while the interquartile range amounts to about 20 percentage points. For what concerns infrastructure endowment, physical data on motorways (kilometres) is used due to their relevance in connecting regional economies, following (Crescenzi and Rodríguez-Pose, 2012). In the empirical model, kilometres are normalised by population size (thousands of inhabitants) to account for different demographics and 'needs' for transport infrastructure.

Finally, institutional quality is proxied by the Quality of Institutions index (INSTQ) developed by Bianchini et al. (2019) and updated using the most recent data. The Index draws from a targeted subset of the EU regional Social Progress Index (SPI), developed by DG REGIO of the European Commission, which itself is based on different sources, including Eurostat,

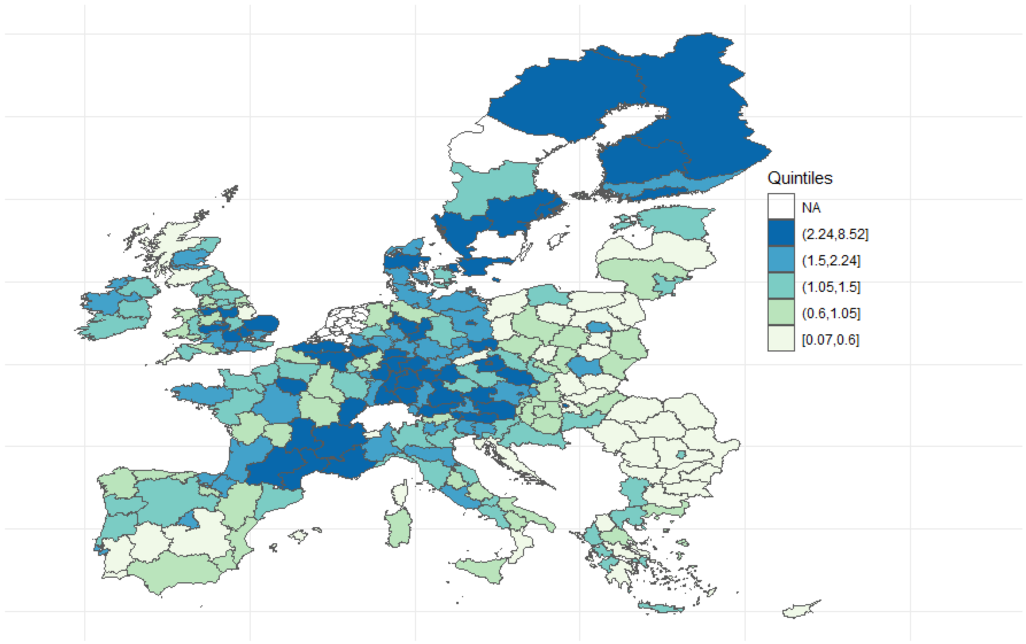

Figure 2: Total R&D intensity

EU-SILC and the European Quality of Institutions Index (EQI)[10], among others. Overall, the index is the result of the aggregation of 13 sub-indicators grouped in two main dimensions representing i) the generalised protection of property rights and the delivery of public goods and services, and ii) the capacity of a region to produce and absorb knowledge, consistently with the recent theoretical and empirical literature (Acemoglu et al., 2005; Ogilvie and Carus, 2014; Rodríguez-Pose and Ketterer, 2020). It is worth noting that INSTQ is based on the so-called "formal institutions", following the original definition by (North, 1991). This choice leaves informal institutions out, most notably trust, which sometimes is used in the literature as either a proxy or a component of institutional quality. A definition based on formal institutions has the advantage of focusing on aspects that can be the target of policy interventions, as the accountability and quality of local governments and the impartiality and efficacy in the delivery of public goods and services. Institutional quality tends to be higher in more developed economies, and Europe is not exception. Furthermore, regional variation within European

[10]The EQI is the most used institutional index in empirical work assessing the impact of institutions on growth across European regions. It strongly correlates (0.9) with the INSTQ used in this paper and results are consistent regardless of the index used.

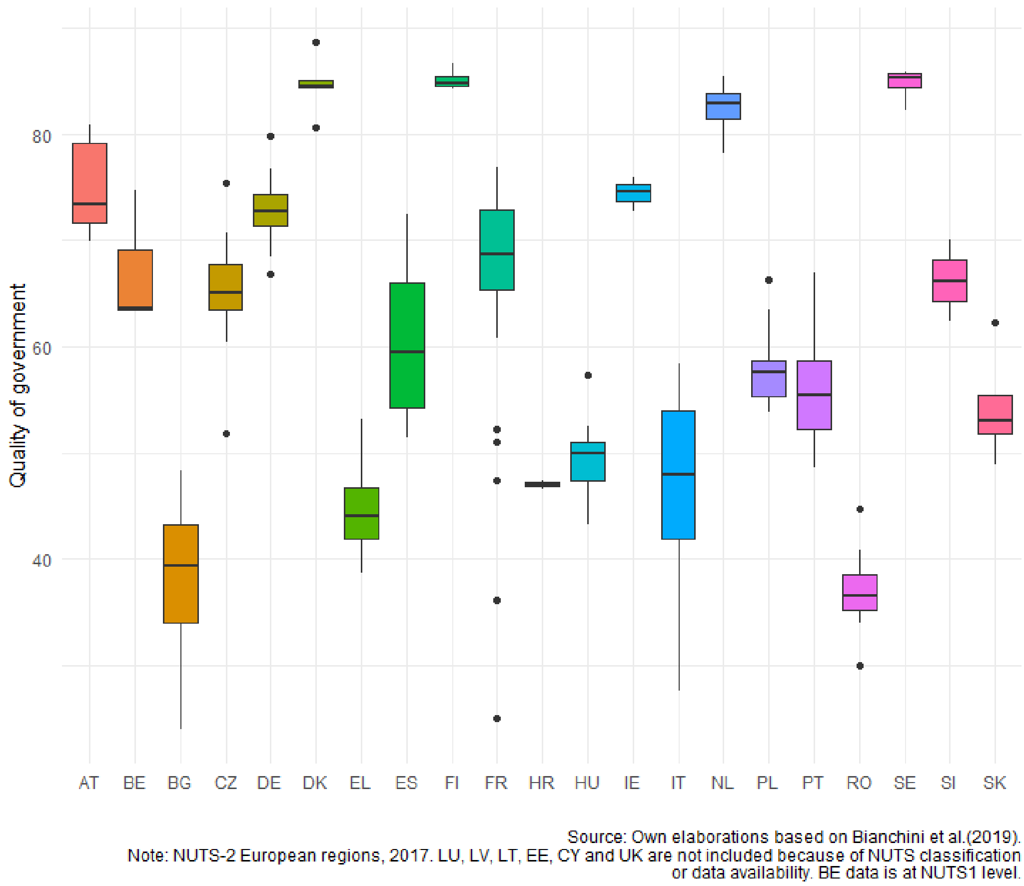

Figure 3: Regional variation in institutional quality

countries is substantial, most notably in Italy, Bulgaria, Spain, Portugal and France, as shown in Figure 3. Differently, overtime variation tends to be lower, since institutions are characterised by embeddedness, path dependency and stickiness, slowing down their process of change and increasing their persistence[11].

[11]There is also a data driven issue, as indicators on institutional quality for European regions are available with a gap of around 3 years between each instance and data goes back in time until the beginning of the 2010s only. This implies that values need to be assumed for the years in between instances and before the first release of the indicator. The analysis makes the standard assumption that institutional quality is consistent overtime, applying the closest available value to the years for which the information is missing. Institutional theory and the fact that most indicators are built using two or three years averages support this empirical choice (Bianchini et al., 2019)

4 Productivity distribution and convergence

Over the years, convergence has been investigated by applying parametric (Le Gallo et al., 2003; Marelli, 2007) and non parametric methods (Fiaschi and Lavezzi, 2007b; Azomahou et al., 2011; Martino, 2015; Fiaschi et al., 2018). European regions are of particular interest because of their heterogeneity in terms of labour productivity levels and growth rates. Figure 4 maps the distribution of the log of labour productivity in 2018, revealing a sharp divide between the "core" of the EU and the economies in the South and the East. Most of the regions in the two lowest quintiles are located in the South of Europe and in the Eastern countries accessing the EU with the enlargements after 2004. Central and northern regions tend to belong to the first three quintiles.

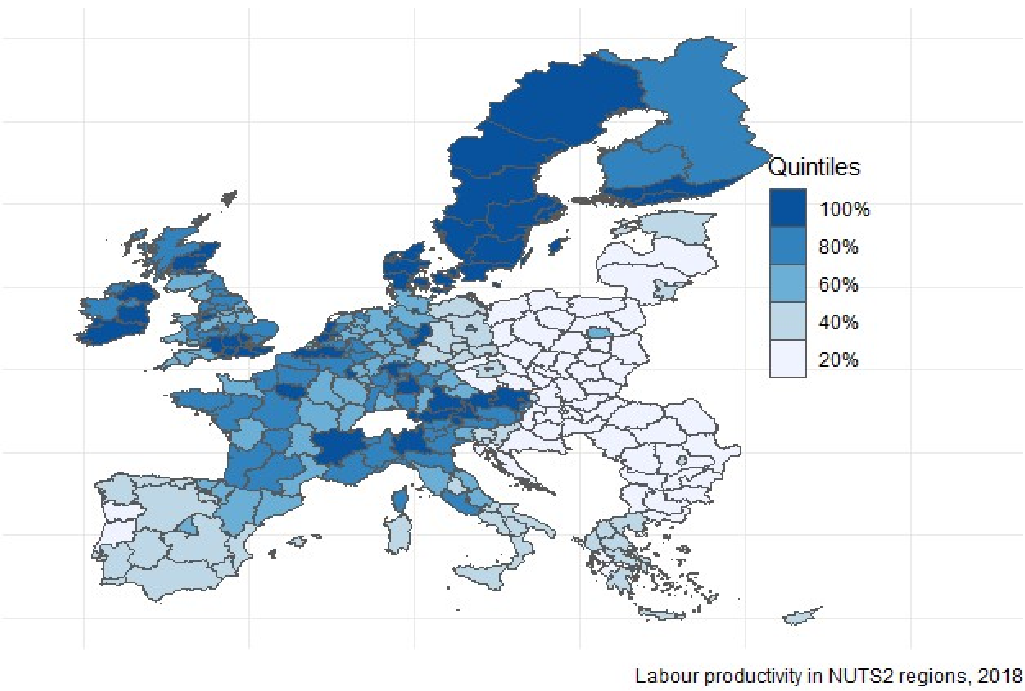

Figure 4: Distribution of labour productivity in Europe

The distribution changes considerably when considering productivity growth over the period (Figure 5). Eastern economies have been growing the most in the last two decades, in between 1.9% and 5.7%, followed by some regions in Eastern Germany, the United Kingdom, Portugal and Northern Europe whose productivity grew in between 1% and 2%. Differently, with a few exceptions, labour productivity growth in Southern Europe and France has been underwhelming. In particular, almost all regions in Italy and Greece

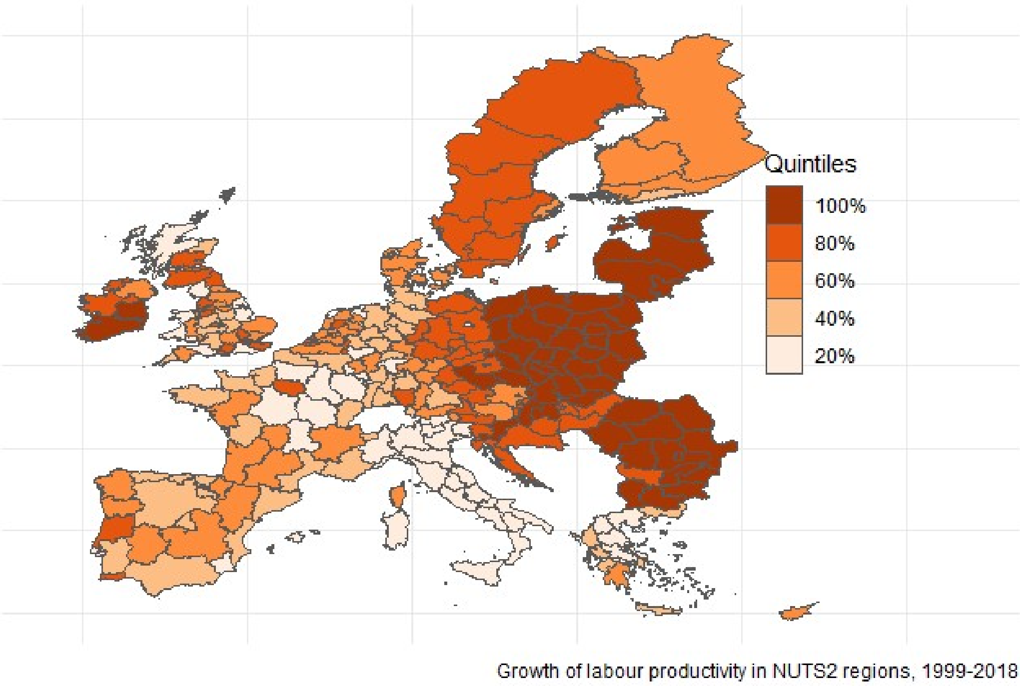

Figure 5: Distribution of the average growth rate of labour productivity in Europe

have had zero or negative productivity growth, while Spanish and French regions experienced an average growth below 1% with the exception of the region of Île de France. These trends have interesting implications for convergence and cohesion in the EU. First, it is clear that if a process of convergence is in place, this is driven by Central-Eastern Europe, which is slowly narrowing the productivity gap with the richer regions. This is particularly true when comparing their performance with Southern Europe, most notably Greece, Spain and the Italian Mezzogiorno. These regions seem to be unable to keep the pace with the more productive regions and have failed to improve their productivity prospects in the last two decades. A similar argument applies to the majority of French regions and to Northern Italy despite having higher levels of labour productivity. Taken together, Figures 4 and 5 reveal a pattern that is consistent with the narrative of a 'middle income' trap. Indeed, the regions with the lowest productivity growth rates are the same that Iammarino et al. (2020) identify as having the highest probability of falling in a middle (or high) income trap. At the same time, some of the regions at the top of the productivity distribution are in the top two quintiles of the productivity growth distribution, as for instance in the United Kingdom, Northern Europe and Nordic countries.

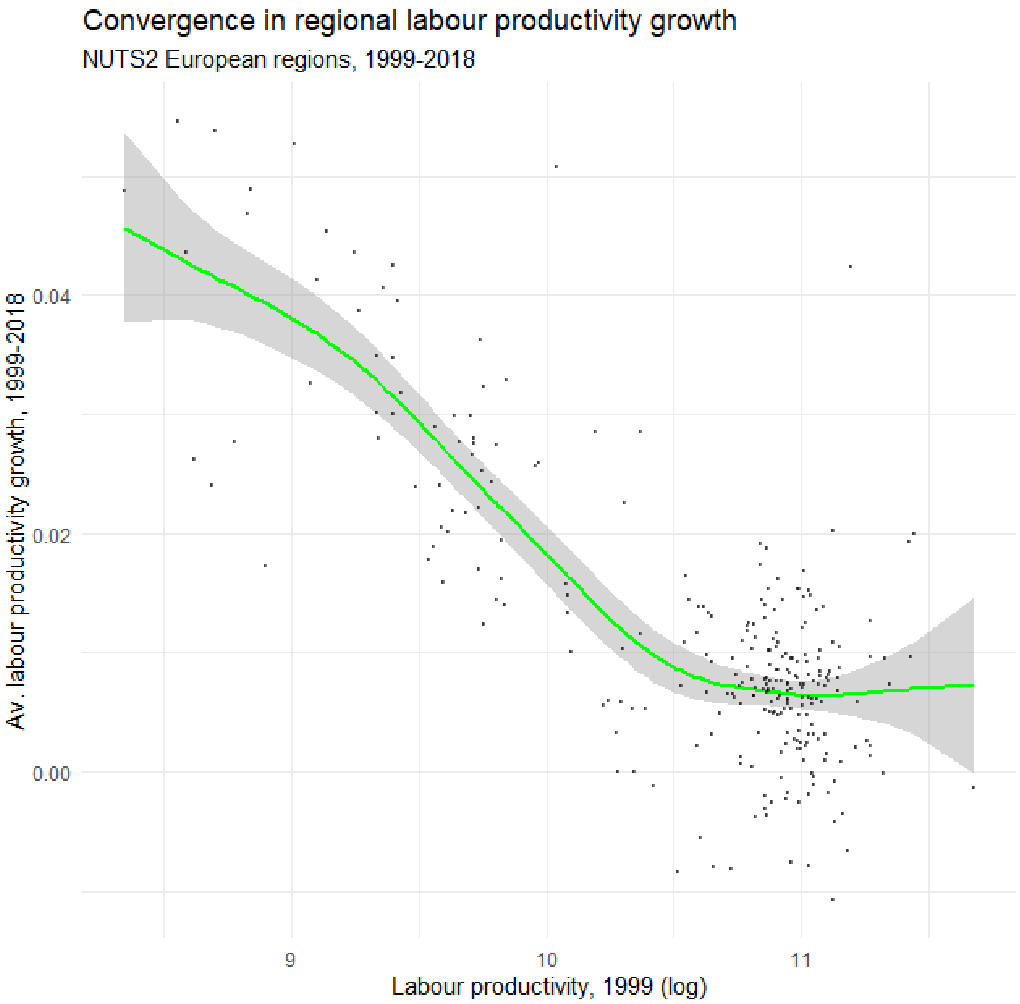

Figure 6: Convergence

In terms of convergence, the above suggests that a nonlinear unconditional convergence process should be in place, mostly driven by the regions at the bottom of the labour productivity distribution. To formally test this hypothesis, Equation (1) is estimated regressing the average labour productivity growth on its initial level, for each region. The results are plotted in Figure 6 and are consistent with previous evidence (Martino, 2015). The negative shape of the curve stops at a value of log of labour productivity of around 10.5, being flat thereafter with a slight tendency upwards. This confirms the hypothesis that convergence is only in place for the less productive regions, i.e. Eastern economies, while it does not seem to hold for the rest of the distribution because of the low growth path of the 'middle-income' regions. These findings raise the question of which have been the drivers of productivity growth across European regions in the last two decades and what has (not) contributed to productivity growth in some middle and high income regions. To further explore these issues, a growth model is estimated in Section 5.

5 Growth regressions

Table 2 reports the estimates for the full sample using three model specifications. The first column implements the standard growth regression *à la* Mankiw-Romer-Weil (MWR) as in Mankiw et al. (1992) and Bernanke and Gürkaynak (2001): it corresponds to the augmented version of the MWR model. As outlined in Section 3.1, the investment variables - including education and R&D - enter the model as a three year moving average, to allow for lagged impact and to deal with potential endogeneity issues. The model is also estimated using a different lag structure, whose results are reported in Appendix 7. The model in the second column adds infrastructure per capita as a physical measure of the endowment of public capital. The third column sets out the full model that includes public investment and its interaction with private capital accumulation. This specification is meant to bridge the most recent growth empirics with the analysis of the role of public investment, which gets renewed attention in the post-Covid scenario, most notably in Europe.

The results of the augmented *MRW* model in column 1 are consistent with expectations and the evidence in previous research. The negative and significant coefficient on lagged labour productivity suggests that European regional economies are converging. The distribution analysis in Section 1 indicates that this process is mainly driven by the growth rates of Central-Eastern regions. The coefficient for the investment rate is positive and significant, albeit very limited in magnitude. This is perhaps surprising, but it is consistent with the recent findings by Rodríguez-Pose and Ketterer (2020) on a similar sample of European regions. They interpret the results as evidence that investment rate is not a determining driver of productivity growth starting from the last decade of the last century. More generally, there is some evidence reporting a 'decoupling' between investment and economic performance, suggesting that an investment-less growth may be in place following the economic crisis in 2008 (Arrighetti and Landini, 2021). The coefficient on $n + g + \delta$ is negative and significant, as implied by the theoretical model, while education does not seem to be a driver of growth in the sample. R&D

is found to be positively associated with labour productivity growth, as institutions are, consistently with the findings of most of the literature.

The specification in column 2 is a first attempt at accounting for the role of public investment, taking a "capital stock" perspective by including infrastructure in the model (Romp and De Haan, 2007). Consistently with previous empirical work, as in Crescenzi and Rodríguez-Pose (2008) and Crescenzi and Rodríguez-Pose (2012), results do not suggest any significant role for infrastructure in shaping labour productivity growth. This may be due to this kind of public capital stock having exhausted its productive boost (Crescenzi and Rodríguez-Pose, 2012), while other factors - e.g. institutions - have a more prominent role. Including infrastructure does not inform about the contribution of public investment, which adds to the existing capital stock and of which infrastructure is just a subset. Focusing on public investment also allows to make business investment explicit and investigate the complementarities between the two sources, which may be relevant given the nature of public investment and its effect on the return of private activities (Bayraktar, 2019)

Therefore, column 3 reports the full specification, where public and business investment enter the model separately. An interaction term is also included in order to capture complementarities. Both the public and the private investment rate are found to be significantly and positively correlated with labour productivity growth. The magnitude of the coefficient of business investment is about twice (0.088) as large than the one of public investment (0.04). Furthermore, the positive and significant coefficient of the interaction term (0.026) supports the existence of complementarities between public and private investment efforts, as for instance positive externalities of public investment on the returns of private activities. The quality of local institutions remains an important driver of productivity growth, while the coefficient on post-secondary education turns significant.

The heterogeneity of the EU economies calls for a more detailed analysis of regional dynamics. As the convergence findings show that Eastern regions have been undertaking a different growth path with respect to the rest of the EU, drivers of productivity growth may differ across groups of regions. In order to investigate such regional differences, regions are divided in three main groups, corresponding to countries in the South, East and North-West of Europe[12]. Then, the full model is estimated for four subsamples as reported

[12]In particular, the Southern group includes regions in Portugal, Italy, Greece and Spain; the Eastern group includes regions in Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Croatia, Latvia, Lithuania, Poland, Romania, Slovenia and Slovakia; and the

	Augmented 'MWR' model	'MWR'+ infrastructure	Full model
Labour productivity, t-1	-0.029^{***}	-0.038^{***}	-0.036^{***}
	(0.004)	(0.006)	(0.006)
Investment	0.006^{*}	0.004	
	(0.003)	(0.005)	
Business Investment			0.088^{**}
			(0.035)
Public Investment			0.040^{**}
			(0.018)
Business x Public Investment			0.026^{**}
			(0.011)
$(n + g + \delta)$	-0.312^{***}	-0.314^{***}	-0.321^{***}
	(0.085)	(0.101)	(0.103)
Institutional Quality	0.013^{***}	0.017^{***}	0.014^{**}
	(0.005)	(0.006)	(0.006)
Education	0.002	0.008	0.010^{*}
	(0.004)	(0.006)	(0.006)
R&D intensity	0.002^{***}	0.002^{***}	0.002^{**}
	(0.001)	(0.001)	(0.001)
Infrastructure		3.473	2.362
		(4.333)	(4.900)
Fixed effects			
Country	Yes	Yes	Yes
Time	Yes	Yes	Yes
R^2	0.185	0.217	0.219
Adj. R^2	0.175	0.203	0.204
Num. obs.	4282	2931	2796

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

Table 2: Growth model

in Table 3. The subsamples East (column 1) and South (column 2) are intended to inform about the growth dynamics of two homogeneous groups of economies, the former with low initial productivity levels and faster growth rates, with a specific growth model based on inflows of foreign investments, and the latter being a middle income - low growth group. Then, columns 3 and 4 report the results for two heterogeneous subsamples, namely 'South and West' and 'East and South'. While the results may suffer from the high internal heterogeneity of these two subsamples, it may still of interest to see whether relevant insights do emerge for what could be understood as the former "Western block" (South and West) and the periphery of Europe (East and South).

Estimates suggest that convergence is in place in all subsamples, in particular in those in which Eastern regional economies are included. Indeed, Eastern economies are driving the convergence process and catching up with the slow (zero) growing Southern regions (column 4), while an internal (and faster) convergence path is in place also if only the East group is considered (column 1). Convergence in the 'South' subsample is the result of *club* convergence in two groups of regions, a low productivity and a mid-high productivity one, the latter including Northern Italian and a few Spanish regions[13]. A similar argument holds for the 'South, West' subsample (column 3), in which less productive (Southern) regions are clustering at the bottom of the distribution. Interestingly, education is a positive driver of productivity growth for Eastern regions, while a negative relationship is found for Southern economies. This suggests that higher productivity growth was not related to the availability of educated labour force in the South of Europe. It follows, that the positive and coefficient on education in the 'East, South' subsample in column 4 is driven by the predominant effect of eastern regions.

When it comes to the investment shares, results show that they are positively correlated with productivity growth across the subsamples. It is worth noting that the magnitude of the effect of public investment is larger in the Southern subsample (column 2), highlighting its importance in the low-growth regions in the South of Europe. Differently, its magnitude is the lowest in the 'East' subsample, albeit still positive, consistently with recent evidence showing that productivity growth in CESEE countries is based on business investments fuelled by capital inflows and technology imports from abroad (Gattini et al., 2021). The complementarities between the two sources

North-Western group includes Austria, Belgium, Germany, Denmark, Finland, France, Ireland, Luxembourg, the Netherlands, Sweden and the United Kingdom. See Section 3.2 for further details about sample composition and the definition of the territorial units.

[13]A bimodal distribution for labour productivity in the 'South' group can be obtained, corresponding to the above regions. It is not reported for the sake of space.

	East	South	South, West	East, South
Labour productivity, t-1	-0.062^{***}	-0.022^{**}	-0.026^{***}	-0.049^{***}
	(0.011)	(0.011)	(0.008)	(0.007)
Business investment	0.102^{**}	0.134^{***}	0.096^{***}	0.106^{***}
	(0.044)	(0.019)	(0.034)	(0.028)
Public investment	0.036^{**}	0.071^{***}	0.051^{***}	0.048^{***}
	(0.018)	(0.011)	(0.018)	(0.013)
Business x Public investment	0.023^{*}	0.040^{***}	0.031^{***}	0.028^{***}
	(0.012)	(0.007)	(0.011)	(0.008)
$(n + g + \delta)$	-0.614^{**}	-0.167^{*}	-0.106	-0.454^{***}
	(0.254)	(0.094)	(0.083)	(0.161)
Institutional quality	0.022^{*}	0.011^{**}	0.011^{*}	0.010
	(0.011)	(0.005)	(0.006)	(0.007)
Education	0.124^{***}	-0.013^{**}	0.003	0.017^{**}
	(0.031)	(0.006)	(0.006)	(0.008)
R&D intensity	0.007^{**}	0.007^{***}	0.001	0.008^{***}
	(0.003)	(0.002)	(0.001)	(0.002)
Infrastructure	-1.774	-2.629	5.164	2.298
	(27.812)	(3.867)	(3.767)	(6.095)
Fixed effects				
Country	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
R^2	0.147	0.226	0.092	0.274
Adj. R^2	0.108	0.194	0.074	0.255
Num. obs.	832	709	1964	1541

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

Table 3: Full model: regional subsamples

of investments are also confirmed. Furthermore, it is interesting to highlight that overall the magnitude of the coefficients on the investments shares is larger in the 'South' subsample: this may be interpreted as evidence of larger marginal returns on investment, due to the lower initial stock of public and private capital in these regions. This is a relevant finding from a policy perspective, as it flags the insufficiency of past efforts and calls for further productive investments to fuel productivity patterns in the Southern periphery.

5.1 Focus on public and private R&D

The results in section 5 suggest that research and innovation investments, proxied by R&D intensity, have a positive yet limited impact on labour productivity growth. Research, development and innovation efforts are of particular interest due to the prominent position they have in the latest strategies and policies adopted and implemented in the EU, first with Horizon 2020 and then with the green and digital transitions envisioned within the Green Deal and the NextGenEU policy package. Particular emphasis has been put on the role of public research. As already mentioned, whether public R&D investment can be justified by its impact on productivity growth is a question that has already received research and policy attention (Van Elk et al., 2015; Soete et al., 2020a,b). The analysis by Van Elk et al. (2015) of the relationship between public R&D and growth yield ambiguous results which, overall, did not support the case for public R&D efforts as an engine of growth. However, as extensively discussed in the economics of innovation literature, public R&D is different in nature and scope with respect to business R&D, the latter being 'closer' to the market than the former and aimed at increasing business productivity. The direct creation of output is not the main scope of public R&D, which mostly aims at generating and diffusing new (basic) knowledge, on the basis of which additional knowledge and innovations can be produced elsewhere. Furthermore, as noted by Archibugi and Filippetti (2018), public R&D matters not only for the creation and diffusion of knowledge, but also for the directionality of new research and innovations because of the political process behind the allocation of resources.

Overall, the above implies that public research may impact productivity growth indirectly, through its impact on private activities, most notably business investments in R&D. In order to capture this channel, a 'mediating model' is estimated in two steps, first estimating the impact of public R&D on business R&D, for then estimating the full model as in column 3 in Table 2.

The results are reported in Table 4. The first column shows the estimates of the first step, in which business R&D is regressed upon all the variables in the main model, as in equation (5). The interest is mainly in the coefficient on the 'mediated' variable, public R&D, and on the external instrument, the *High-Tech sectors' share*. For what concerns the instrument, the coefficient is positive and significant. Coming to public R&D, unsurprisingly a positive and significant relationship with business R&D is in place, as suggested by the positive value of the coefficient (0.127). The latter represents the indirect effect of public R&D on productivity growth, going through the 'mediating' factor business R&D. The interpretation follows the economic rationale ex-

dep. var:	First Step business R&D	Second Step prod. growth
Labour productivity, t-1	-0.3866^{***}	-0.0453^{***}
	(0.1086)	(0.0055)
Investment	0.0134	0.0116^{**}
	(0.0865)	(0.0050)
$(n + g + \delta)$	1.5929	-0.6553^{***}
	(1.8861)	(0.1116)
Institutional quality	0.6723^{***}	-0.0098
	(0.1388)	(0.0085)
Education	0.1573	0.0151
	(0.1855)	(0.0111)
Public R&D	0.1270^{***}	-0.0013
	(0.0457)	(0.0030)
Business R&D (Fitted)		0.0256^{***}
		(0.0049)
External Instrument		
High-Tech sectors' share	0.1399^{***}	
	(0.0117)	
Fixed Effects		
Country	Yes	Yes
Time	Yes	Yes
R^2	0.604	0.273
Adj. R^2	0.592	0.252
Num. obs.	1565	1565

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

Table 4: Two steps mediating model for public and private R&D

plained above: research, development and innovation efforts in the public sector have a leverage effect on the same activities in the business sector, because of the effect of the expansion of the pool of basic knowledge available to private research and development.

The second column reports the results of the second step. Business now R&D enters the model and it is positively and significantly related to labour productivity growth (0.0256). No significant direct relationship can be found for public R&D, meaning that, in the sample, it affects productivity growth only indirectly. It is also wroth noting that the institutional quality is no more significant in the second step, while it impacts positively business R&D in the first step. This may be surprising, but it is consistent with the institutionalist theory. Indeed, good (generalised) institutions are considered as 'root causes' of growth and prosperity as they set the incentives for economic and social interactions, ensuring that individuals and firms can reap the benefits of their investments, and provide essential public goods and service. As such, good institutions support innovative investments that are riskier than 'standard' activities with more uncertainity in returns. (Ogilvie and Carus, 2014). This is exactly what the findings in the first step suggest: higher institutional quality is associated with higher R&D intensity in the private sector and, as such, they are an engine of productivity growth.

6 Conclusions

Institutions, investment, R&D and innovation are at the core of both empirical research and policy discourse as drivers of regional growth and prosperity. This is especially true for European economies, and more so after the outbreak of the Covid-19 pandemics that accelerated the process of inclusion of digital and the green policies within the European and national agendas. The "twin" transitions have brought back the role of the public sector into the spotlight, calling for targeted interventions to provide directionality to economic and societal change. In practical terms, the European Green Deal and the NextGenEU package foresee new investments from governments at all levels throughout the EU, to transform the European economies and make them more productive, resilient, inclusive and green.

This paper analysed the contribution of public investment, public R&D and institutional quality to productivity growth in the last two decades for NUTS2 European regions. A standard growth model was augmented by including the variables of interest, positioning the analysis at the crossroads between growth empirics, economics of innovation, and regional economics. The results show that public investment is associated with higher productivity growth for European regions in the last two decades. As expected, the magnitude of its contribution is lower than that of business investment, yet the estimates reveal complementarities between public and private efforts, supporting previous theoretical and empirical arguments for the role of productive government spending. An important finding is that investment is overall 'more productive' in the Southern periphery of Europe, flagging larger marginal returns from additional effort. This is a key finding from a policy perspective, especially in view of the upcoming investments within the Green

Deal and the NextGenEU policy plans. In this respect, the characteristics of the data do not allow to assess the role of specific types of investments, as for instance in the fields relevant to the Green Deal and the NextGenEU policies, hence one may expect the contribution to vary depending on the domain and the type of investment. What the data allowed to do was to analyse a specific type - while still relatively broad - of public investment, namely in R&D. Because of its characteristics, public research expands the knowledge base on which companies can build on for their own research and innovation activities, eventually leading to productivity improvements on the firms' side. As long as this is true, public R&D should have at least an indirect impact on productivity growth. The analysis supports such a hypothesis.

Furthermore, the empirical and theoretical literature has identified the quality of public institutions as crucial driver of economic performance at all levels, from local to national governments. Such an acknowledgement has led to policy discussions on whether capacity-building at the local level is a prerequisite for the efficient delivery of public policies and, similarly, whether public efforts, as for instance in the case of research and innovation policy, should be focused where "good" institutions already exist or whether they should target also regions where they are not in place (Bilbao-Osorio and Rodríguez-Pose, 2004; Bianchini et al., 2019). The analysis of this paper confirms the general result that institutional quality is indeed a key factor driving productivity growth. While this is not surprising, it is worth noting how a similar exercise performed by Rodríguez-Pose and Ketterer (2020) led to different results for a similar sample. In their analysis, the authors find that it is not institutional quality, but rather institutional change the key factor explaining growth in EU regions. In a related work, Rodríguez-Pose (2020) discusses the issue from a theoretical perspective, arguing that while institutions are "sticky" and resistant to change due to path dependency, those systems that successfully undertake "positive" change are performing better than others. It would be interesting to investigate whether institutional change has any relevant effect in the context of this paper. Unfortunately the data at hand do not allow to test such a hypothesis. Indeed, while the availability and quality of of institutional data has increased substantially in recent years, they have very limited within-region and overtime variation. The data generating process itself only allows a couple observations along the whole time period. While this is a well known issue in the empirical literature, it also makes any computation of institutional change arbitrary and with limited (and "artificial") variation. To the best of my knowledge, the analysis by Rodríguez-Pose and Ketterer (2020) is the only attempt in estimating the impact of institutional change on growth, using the EQI for a panel of European regions, but it is not clear how the above issues are dealt with in their paper. Notwithstanding the above remarks, the results of the growth regressions in this paper are still a relevant finding, especially due to their validity across subsamples in less developed EU economies.

This paper contributed to the understanding of productivity growth and its determinants in the EU in the last two decades. Yet, the discussion has highlighted further avenues for future research that are of interest both for the empirical literature and to better inform and support policy making. First, different typologies of public investments may have different outcomes, hence it would be useful to understand which these are using available data. This would be useful also in future perspective in the context of the new EU digital and green policy scenario and could be done exploiting past available information on policies and impacts, as for instance done by (Crescenzi et al., 2021). Second, new source of data would benefit the analysis of the contribution of some determinants, as for instance institutions and their change. Available data has already very much improved over the last couple of decades, yet current technologies and data generation processes may allow to use administrative or private information to generate institutional data built from the bottom-up. Such a process would make it easier to get data at smaller intervals and to trace changes across shorter period of times, picking up the research recommendations put forward by (Rodríguez-Pose and Ganau, 2021). Of course, such an agenda would imply research beyond the growth regressions approach used in this paper, and would require searching for alternative and more granular data sources. Yet, it would definitely benefit policy support.

7 Appendix

Empirical applications of the standard growth model *à la* 'MRW' deviate from the theoretical foundations by implementing a lag structure for the independent variables. The justification is usually twofold. First, investment may take time to bear fruits in terms of productivity improvements, and investment taking place in the past may still have an impact on output today. Second, implementing a lag structure may also be useful to address endogeneity problems, as for instance concerning investment decisions (including R&D) and output. Indeed, while theory usually provide the foundation for the direction of the relationship, as for instance for institutions and productivity growth, lagging the independent variable is a convenient shortcut. In this paper, the empirical specification uses a right-sided moving average considering the latest three years from t to $t-3$, somehow taking on board some of the recommendations in Islam (1995). In this section, alternative estimations are reported as a robustness check, using three alternatives for the lag structure, i.e. $t-0$ (as of the theoretical model), $t-1$ and $t-3$.

	ma	t	$t-1$	$t-3$
Labour productivity, t-1	-0.0292^{***}	-0.0332^{***}	-0.0274^{***}	-0.0243^{***}
	(0.0044)	(0.0053)	(0.0050)	(0.0054)
Investment	0.0056^{*}	0.0044	0.0043	0.0062^{*}
	(0.0034)	(0.0038)	(0.0036)	(0.0035)
$(n+g+\delta)$	-0.3120^{***}	-0.2681^{***}	-0.3975^{***}	-0.3302^{***}
	(0.0850)	(0.0995)	(0.0936)	(0.0901)
Institutional quality	0.0131^{***}	0.0148^{***}	0.0082^{*}	0.0103^{**}
	(0.0047)	(0.0055)	(0.0049)	(0.0048)
Education	0.0021	0.0031	0.0049	0.0092^{**}
	(0.0042)	(0.0049)	(0.0044)	(0.0044)
R&D Intensity	0.0024^{***}	0.0018^{***}	0.0028^{***}	0.0021^{***}
	(0.0005)	(0.0006)	(0.0007)	(0.0007)
Fixed effects				
Country	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
R^2	0.1853	0.1860	0.2017	0.1778
Adj. R^2	0.1753	0.1732	0.1891	0.1642
Num. obs.	4282	3233	3200	3009

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

Table 5: Robustness check: different lags structure

Table 5 shows the results for the base 'MRW' model and compare them with the specification in the main text (column 1). The coefficient on the investment rate becomes insignificant when 0 or 1 lags are used, while the estimate for $t-3$ is virtually unchanged with respect to the moving average specification. Interesting, R&D intensity remains significant across the four specifications. It is worth noting how this is true also for institutional quality, providing support to the choice of not taking any lagged value in the main model, consistently with the data characteristics and the theoretical groundings.

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