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DIRECT AND INDIRECT EFFECTS OF UNIVERSITIES ON EUROPEAN REGIONAL PRODUCTIVITY

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Direct and indirect effects of universities on European regional productivity

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Abstract

For the first time we investigate the effects that Universities exert on Total Factor Productivity dynamics for a very ample sample of 270 European regions over the period 2000-2016. This novel contribution goes beyond the traditional human capital and technological capital *indirect* effects and proposes a sound empirical assessment of the highly differentiated "third mission" activities. These are unique to engaged academic institutions and shape the key role they play as societal development-promoting agencies. Our analysis provides evidence of sizeable and robust universities *direct* supply-side effects, which complement the traditional ones in driving European regional productivity growth.

Keywords: University; Regional Total Factor Productivity; Human capital; Technological capital; Universities' third mission.

Jel Classification: I23, I25, J24, 031, 047.

1. Introduction

Universities are fundamental actors in the current knowledge-based economy, not only for the generation of high-level human capital, the creation and diffusion of new knowledge and technological enhancements, but also for actively contributing to regional social and economic development. The awareness that universities play an essential role explains why higher education institutions (HEI) worldwide have significantly increased since the first university was founded in Bologna in 1088. The World Higher Education Database in 2021 records 20,000 HEI in 196 countries worldwide, almost 3,000 in Europe. These numbers have been growing steadily, especially in the post-World War II period, when the total of world HEI has quadrupled, and Europe almost tripled.

The literature has remarked that the functions carried out by universities are complex and highly differentiated as their roles have been changing over time to respond both to academic and societal needs in a multifaceted interplay with local and international stakeholders and institutions. The list of university functions is long, and it has been institutionalised in three missions: teaching, research and "third mission". While the first two are traditional missions, the latter has mainly developed in the last three decades, and it is still an evolving concept. Although its definition is characterised by a high degree of heterogeneity and vagueness, it includes a wide range of activities, like know-how and technological transfer, regional leadership, a hub of knowledge networks, entrepreneurship development, public engagement (Goldstein et al. 1995; Drucker and Goldstein, 2007).

As it is well known, the first two missions generate an expansion of human capital and technological capital. According to several scholars (refer, among others, to Romer, 1990b; Mankiw et al., 1992; Griliches, 1979), these two intangible factors are the key drivers of economic growth, although the literature has not focused on the role played by HEI as their main "supplier". This is especially the case in lagging regions, where R&D activities are almost entirely carried out by public universities due to the scarcity of large innovative firms. While an extensive theoretical and empirical literature has documented the effects of both human and technological capital, studies on the impacts of the third mission functions are still in their infancy because of the difficulties in providing clear definitions that allow for a rigorous empirical assessment (Uyarra, 2010; Varga, 2009; Brekke, 2021 for a recent ample review). Notwithstanding such difficulties, it is worth emphasising that the complex, diversified and growing set of societal functions is unique to universities because in combining the outcomes of their first two missions – teaching and research – they are the only institutions that can provide the local economy, government, and society at large with additional development-promoting services and support and act as an enduring reference of human and social values. Hence, the need to provide an assessment of the overall comprehensive impact that the existence of universities exerts on the local economy, over and above the one already accounted for by human capital and technological capital. This is the main aim of our study, which is posited at the intersection of two main streams of literature with the specific purpose of bridging them and thus provide a novel contribution that enhances the understanding on the role played by universities at the local level.

The empirical literature on the impact of HEI has mostly developed along two main research avenues: the first focusing mainly on demand-side effects, the "GDP approach", and the second emphasising the supply-side impact, the "Knowledge Production Function (KPF)" approach. Among the former, a few articles have explicitly investigated the universities' influence on local economic performance, measured mainly by GDP and employment, with a specific attention to regions within one country. Goldstein and Drucker (2006), Lendel (2010), Hausman (2012), Drucker (2016) focus on the US counties and states; Schubert and Kroll (2016) on German NUTS3 regions; Agasisti et al. (2019) on Italian labour market areas. To the best of our knowledge, only two empirical studies employ extensive cross-country comparisons to thoroughly investigate the contribution of HEI to regional development. The seminal contribution by Valero and Van Reenen (2019), who consider 1500 regions globally, and Agasisti and Bertoletti (2020) on 284 regions in Europe. Both studies assess the impact of universities on regional GDP per capita growth, thus considering the contribution to local demand arising from students and staff expenditures and universities' purchases and investments.

The second stream of the literature concentrates on the universities' effects on firms' and local systems productivity growth within the KPF framework. At the beginning, the main research purpose was to explicitly identify the extent to which university R&D spills over firms within the regional system of innovation (Acs et al., 1994; Varga, 2001). More recently, Buesa et al. (2010) have generalised the analysis by considering, not only R&D, but a broader set of indicators. Finally, Ponds et al. (2010) and Wanzenböck and Piribauer (2018) have extended the KPF model by including networks of different nature: university-industry collaborations and EU funded R&D partnerships, respectively.

So far, the two approaches on the role of HEI have mainly developed independently of each other. In this paper, we propose to bridge them by taking advantage of the merits of both and analysing how universities can act as a key driver of Total Factor Productivity (TFP) growth at the regional level. As TFP is a comprehensive measure of economic performance that encompasses the efficiency enhancing effects of knowledge-related processes, it allows us to focus on the long-run supply-side productivity effects that universities exert on the local economy. TFP is widely recognised as the main driver of economic growth, especially in mature economies (Easterly and Levine. 2001). A few studies have investigated TFP differentials (for EU regions see Marrocu et al., 2013; Männasoo et al., 2018; Siller et al., 2021), however none of them has focused on the TFP enhancing role of universities, and this paper tries to fill this gap.

We contribute to the literature in several ways as depicted in the conceptual framework in Figure 1. First, for the first time we assess the role of HEI on TFP dynamics for a very ample sample of European regions (270) at the NUTS2 level. Following Marrocu et al. (2013) we compute regional TFP levels over the period 2000-2016. This allows us to provide a thorough picture of regional productivity disparities in Europe, which, notwithstanding some convergence in the last two decades (EU Commission, 2017), are still a central issue in Europe (Rodríguez-Pose and Crescenzi, 2008; Iammarino et al., 2019). We then empirically assess the effect of HEI on TFP dynamics, once we account for human and technological capital, as well as a wide array of local characteristics that may affect the regional performance, such as the quality of the institutions, the territorial features, and the production structure.

Second, we provide novel evidence on disentangling the three effects that universities exert on the regional system in which they are located. The first two indirect effects are related to the creation of human capital and innovations by providing higher education and basic research. It is worth highlighting that local universities, especially in advanced territories, contribute to the enhancement of human capital jointly with external HEI thanks to graduate mobility (Corcoran and Faggian, 2017) and to the development of technological capital through universities-firms' collaborations. The third effect is unique and entirely due to the existence of the university itself, we can deem this as a "direct" university effect, which has no substitutes and does not exist in territories with no universities. It is intrinsically related to the core institutional features of the universities. As they carry out the ever evolving third-mission functions, universities are able to leverage multidimensional skills and capabilities, create synergies, promote value co-creation and, ultimately, act as a proper economic and cultural engine.

Third, in assessing the three possible university effects described above, we also investigate the role played by external factors that can influence regional productivity growth due to university knowledge spillovers from "proximate" regions. The existence of such externalities has relevant implications for both academic and public policies as far as university funding and the creation of new HEI are concerned.

Finally, we also contribute to the extant literature by investigating the two channels through which universities contribute to human and technological capital enhancement and, consequently, to productivity growth at the regional level.

Main results indicate that the "direct" impact of universities on regional productivity growth is positive and sizeable. It proves robust to the inclusion of other factors, such as institutional capital, agglomeration forces and production structure. This direct effect goes along with the more traditional "indirect" effects exerted by human and technological capital. Moreover, we have found robust evidence that the universities positively affect the regional growth rate of human and technological capital. These intangible assets represent, in turn, the key determinants of local productivity growth. Thus, universities play an essential role in enhancing, directly and indirectly, the productivity of regions in Europe. Finally, we show that the positive impact of universities may spread across regional boundaries and it is thus reinforced by spatial positive externalities from neighbouring territories.

The paper proceeds as follows. Section 2 outlines the literature background and offers the basic rationale of our research. The third section presents the dataset and the methodology for the TFP computation. The fourth section discusses the results of the baseline empirical analysis along with the robustness exercises. Section 5 examines the indirect channels through which universities influences the regional growth rates of human and technological capital. The final section summarises the findings and discusses their broader implications.

2. Literature review and conceptual background

Since the Second World War, there has been a considerable increase in higher education demand and the number of universities and HEI worldwide. This ever-increasing process is because universities are core agencies in contributing to economic growth and social development by forming human capital and high-quality skills, as well as prompting technological change by knowledge creation and diffusion. At the beginning of the 1900s only one in a hundred young people enrolled in universities; during the twentieth century, this proportion increased to one out of five. Over the years, the university density has also increased considerably. Nowadays, at least one university is located in almost every country globally, even though the distribution is remarkably skewed. Seven countries (United States, Brazil, Philippines, Mexico, Japan, Russia and India) are home to more than half of all existing universities.

It is widely recognised (Goldstein et al., 1995; Drucker and Goldstein, 2007) that universities play differentiated and complex functions, although all universities do not necessarily carry them out simultaneously. Over the last three decades, five different university engagements models have been identified (Uyarra, 2010), each advocating a different set of roles, various spatial aspects of interactions, as well as other mechanisms of university commitments[1]. Besides the institutional functions related to higher education and basic research, universities are involved in knowledge and technological transfer, in producing knowledge infrastructures and participating in related networks, in promoting entrepreneurship development, regional leadership, cohesion and democratic dialogue.

The literature has extensively examined the growth-enhancing effects of higher education, basic research and innovation, even though the university role as the main "supplier" of such assets is often remained behind the scenes. Several studies carefully examined the impact of human capital endowments on the economic growth processes (Romer 1990a, Mankiw et al. 1992, Benhabib and Spiegel 1994, Gennaioli et al. 2013 and 2014). At the same time, the knowledge-capital model (Griliches, 1979) has underlined the positive impact of technological capital on economic performance. As technology is, at least partly, a public good, higher investments in technological capital endowments increase local firms' productivity and, consequently, regional economic performance (Romer 1990b, Audretsch and Feldman 2004, Fischer et al. 2009, Rodriguez-Pose and Crescenzi 2008).

As for the other functions, which constitute the variegated and evolving third mission of HEI, the role played by universities in the last decades has changed considerably, and so have the expectations of policymakers and stakeholders. The rapid expansion of university education, the limited public funding, the increased competitiveness between universities, the challenges posed by the global emergences summarised in the Sustainable Development Goals and, more recently, by the Covid-19 pandemic are increasingly engaging universities for innovative modes of territorial intervention. Universities, therefore, have multiple impacts, not only on the production system but also in areas such as culture, environment, tourism, development and regeneration of local communities. Engaged universities are complex organisations that operate as nodes within multi-level institutional networks (international, national and local). They constantly aim at integrating teaching and research activities with the territory's needs in a global-regional innovation system (Bathelt et al. 2004, Benneworth and Hospers 2007, Arbo and Benneworth 2007). As a result, universities are significantly differentiated entities, even within the same national system, in terms of size, status, history, specialisation and organisation. These differences also make the ways and intensity with which universities play the role of growth-enhancer much differentiated (Agasisti et al. 2017). The evolution and transformation of universities, the high number of models they can select, and the heterogeneous nature of the regional economic and social environments that host these institutions have recently motivated a new wave of studies (see Bonaccorsi et al. 2019 and Brekke 2021, for recent reviews).

[1] The five models identified by Uyarra (2010) are: Knowledge factory, Relational university, Entrepreneurial university, Systemic university, Engaged university.

We identify two broad approaches within the empirical literature. The first focus mainly on demand-side effects and therefore analyses macroeconomic outcome measures, such as GDP and employment at the regional level. The second emphasises universities' long-run supply-side impact and focuses on technological advances and knowledge creation measures, such as patents. We refer to them as the *GDP* and the *KPF* approach, respectively.

Among the first stream, Goldstein and Renault (2004) explicitly investigate universities' impact on local economic performance. They employ a quasi-experimental approach to explain differentials in average earnings changes due to universities across 312 metropolitan statistical areas (MSA) in the USA. The same geographical setting is the focus of Goldstein and Drucker (2006), who study the influence of universities on local economic performance by explicitly differentiating their functions. They suggest that the presence of universities has the most substantial impact in small- and medium-sized regions and that such impact spills over neighbouring regions. Lendel (2010) follows this research track by introducing the business cycle dynamics into the analysis. She finds that research universities positively affect regional employment growth in the expansion period, while only top universities can still positively impact during the contraction. Moreover, results suggest a minimal necessary scale of university R&D expenditures to impact regional employment significantly. Drucker (2016) reconsider previous contributions to the USA by incorporating all degree-granting institutions and comparing multiple economic outcomes, including GDP, employment and entrepreneurship. As expected, the impact varies by outcome measures, but is substantially less relevant than in previous studies. There is evidence of spillovers across MSA but only up to almost 100 kilometres. Overall, by distinguishing universities' functions, the findings confirm that the traditional university missions of research and teaching are still crucial, together with general policies promoting entrepreneurship to support local economic performance.

More recently, the analysis has been extended to a few country studies in Europe. Schubert and Kroll (2016) use spatial panel-data models to investigate the impact of HEIs on GDP per capita and unemployment in NUTS3 German regions. They manage to identify cross-regional long-term effects of HEIs on knowledge generation, which go beyond direct demand-side effects. Moreover, they find that HEIs contribute in the long run to the reduction of regional unemployment. Agasisti et al. (2019) analyse the contribution of universities to economic growth for a selection of Italian labour market areas. They find a positive association between universities' efficiency and the economic development of the local production system in which the university operates, as well as in nearby regions accruing spillovers benefits.

All these studies focus on one country with the same institutional setting and other common specific features. This focus implies that results are not necessarily applicable to different situations. In the European context, a first partial attempt to go beyond country borders is the contribution by Lilles and Roigas (2017). They investigate the relationship between HEIs (measured by students in tertiary education) and economic growth in NUTS2 regions in Europe. Results highlight the importance of the indirect effects of human capital creation on knowledge-intensive sectors. More recently, Agasisti and Bertoletti (2020) investigate the impact of the dynamics of regional higher education systems (HES), rather than universities, on economic growth in 284 NUTS2 European regions from 2000 to 2017 paying specific attention to HES heterogeneity.

The seminal article by Valero and Van Reenen (2019) offers a more comprehensive assessment of universities' impact on GDP per capita growth differentials from 1950 to 2010 for 1500 regions in 78 countries. They find that increases in the number of universities are associated with higher GDP per capita at the regional level, with positive spillover effects from universities to neighbouring regions. These positive spillovers are mediated by increasing human capital, innovation and stronger pro-democratic attitudes.

Within the second stream of literature, the KPF approach, one pioneering contribution is Acs et al. (1994). They show that university research and development positively impact local small firms' performance, especially in specific sectors. Varga (2001) documents the importance of local agglomeration economies in allowing technology-intensive firms to take advantage of university research. Varga (2009) explores the themes of the geography of economic knowledge transfers mechanisms (both at regional and interregional levels) and university-based regional development. Ponds et al. (2010) and Wanzenböck and Piribauer (2018) follow this research avenue by extending the KPF model to consider the importance of networks in channelling knowledge spillovers across regions. The former focus on university-industry collaborations, while the latter analyses the role of EU funded R&D partnerships. Finally, Buesa et al. (2010) use a comprehensive set of variables to analyse the determinants of knowledge production in European regions. They offer robust empirical evidence that regional innovation systems consist of multiple and interconnected elements among which universities are crucially important.

In this paper, we propose a novel empirical framework which integrates the merits of the two approaches described above by focusing on the TFP enhancing effects of universities. Being a more comprehensive measure of economic performance, TFP encompasses all the changes resulting from creating, transmitting and absorbing knowledge, organisational and institutional changes, shifts in societal attitudes, or gains due to more efficient factor allocation (Isaksson, 2007; Del Gatto et al., 2011), which affect the long-term structure of the economy and, therefore, its ability to grow persistently.

From an empirical point of view, Rodríguez-Pose and Crescenzi (2008) show that innovation and growth in European regions result from a complex interaction between research and socio-economic and institutional conditions. Beugelsdijk et al. (2018), with development accounting techniques, find that the large and persistent differences in economic development across regions in the European Union can primarily derive from differences in TFP. A few papers have investigated these TFP differentials and their evolution in EU regions. Marrocu et al. (2013), Männasoo et al. (2018) and Siller et al. (2021) show that human capital endowment has a positive effect on TFP growth and that more robust TFP growth is associated with a more significant productivity gap. Moreover, they prove that spatial spillovers are a relevant component of TFP dynamics. However, none of them studies the specific role played by universities, and this paper tries to address this relevant issue.

Figure 1 attempts to provide a synthesis of the complex set of mechanisms and channels (Conway et al. 2009; Uyarra 2010) that link universities' activities to the final economic performance. This synthesis uses the distinction introduced by Florax (1992), who discriminate short-term, expenditure-based demand-side effects from long-term, knowledge-based supply-side effects. The core of our econometric analysis assesses the impacts of universities on TFP dynamics (Johansson and Arano, 2016, Pastor et al., 2018) while accounting for local characteristics, like the quality of the institutions, the territorial features, and the production structure. Universities can affect local economic performance along three channels: "directly" through their institutional third mission activities that the engaged universities conduct in favour of the local society; "indirectly" by contributing to the creation of human capital and innovation by forming high-skill graduates and providing basic research outcomes. Both direct and indirect channels can be reinforced by external factors due to knowledge spillovers from "proximate" regions (D'Este and Iammarino, 2010; D'Este et al., 2013). Our study aims to provide a thorough analysis of the supply-side effects considering together the three channels through which universities may affect regional productivity.

3. Data and methods

This section presents in detail the database used in our analysis. It refers to 270 NUTS2 regions in 28 European countries and comprises data to compute regional TFP levels, universities' activities variables and economic, social and territorial characteristics of the regions. Table A1 in the Appendix provides a complete description of all the variables and data sources.

3.1 Total factor productivity growth

The empirical evidence suggests that countries and regions, especially the most advanced ones, do not differ just in traditional factor endowments (labour and physical capital) but mainly in productivity, knowledge and technology (Isaksson, 2007). Beugelsdijk et al. (2018) found that the large and persistent divide across regions in Europe is mainly due to differences in total factor productivity. Therefore, it is crucial to provide an adequate measure of this phenomenon, both from a static and a dynamic perspective.

TFP is a measure of economic performance that focuses on both efficiency and technology. Its use is often hindered by missing data for the computation of capital stocks at the regional level. Nonetheless, there have been some recent studies on EU regions, such as Männasoo et al. (2018) and Siller et al. (2021), who use TFP regional measures following the pioneering research by Marrocu et al. (2013). We build upon this contribution by using the JRC EU Commission's Knowledge4Policy (K4P) platform.[2] The first step is to compute the annual stock of physical capital at time t by applying the perpetual inventory method to the flows of gross fixed capital formation in the previous year while assuming a yearly depreciation rate equal to 10 per cent. The capital stock value for the initial year 1999 is considered equivalent to the cumulative sum of investment flows over the ten years from 1990 to 1999.

We then compute TFP levels by following a quasi-growth accounting approach. We do not impose factor endowment elasticities, but we estimate them within a traditional Cobb-Douglas production function model. It is reported in (1) in its panel log-linearised form:

[2] This platform (https://knowledge4policy.ec.europa.eu/) builds upon another database created by the Cambridge Econometrics and provides a set of time series on regional value added, labour and capital formation disaggregated by sector.

$$\ln(VA_{it}) = \beta_K \ln(K_{it}) + \beta_L \ln(L_{it}) + \alpha_i + \delta_t + \varepsilon_{it} \quad (1)$$

where $i = 1, \ldots N = 270$ regions; $t = 2000, \ldots 2016$ (17 years); VA is value-added, K is capital stock, and L are units of labor; α_i are regional fixed effects, δ_t are times dummies, and ε_{it} is the error term. To deal with the usual production function endogeneity problem, we apply the Fixed Effects Two Stage Least Squares (2SLS) estimation method; as instrumental variables we employ the one year lagged input factors.[3] Estimated elasticities have the expected value based on theoretical and empirical literature: 0.34 for the capital stock and 0.60 for the labour input.

In the next step we calculate the TFP levels at the regional level for the years 2000-2016 by applying the growth accounting method using the estimated factors elasticities, assumed invariant over the period considered. Table 1 summarises the main results for different macro-regions and sub-periods. More specifically, we split our sample into the two sub-periods, 2000-2008 and 2008-2016, to analyse the effect of the financial crisis that hit the global economy in 2008. Moreover, we partition the regions into three groups. The first group includes the 13 New accession countries, which entered the EU in 2004-2013 (11 Eastern countries plus the Mediterranean islands of Cyprus and Malta).[4] The second group comprises the regions of the four Southern countries (Greece, Italy, Spain and Portugal), which have most severely suffered the sovereign debt crisis at the beginning of the century's second decade. The third group includes the regions of the remaining 11 countries in the West Centre and North Europe.

Some interesting results emerge. Considering the TFP index levels, with the European average equal to 100, the productivity divide still appears quite remarkable (see Map 1). The "old" prosperous Europe (West Centre and Northern regions) shows a TFP index equal to 120 in 2016 whilst the "new" Europe is slightly below half of that value with 58. However, there is a critical divide even within the "old" Europe: Northern countries have a lead of 20% with respect to Southern countries in 2000, which widens in the following sixteen years up to almost 30%.

Therefore, from a dynamic perspective, European productivity follows a triple path with diverse speed. Northern countries are stable and maintain their lead with respect to the average EU region. Eastern new accession countries move along a convergence path: their TFP average growth rate over the entire period is 1.69%, more than double compared to the western-northern countries (see Map2). Especially in the pre-crisis years, the New Europe has outperformed the Old Europe by growing at an average rate of 2.62 vs 0.96. Finally, Southern countries show a negative trend in their total productivity over the entire period (-0.08%), and in the final year 2016 they end up well below the European average. Most importantly, Southern countries have fallen behind more in the first years of the new century than after the financial breakdown in 2008: a sign of a structural rather than a contingent crisis. Thus, in the econometric analysis, we take these divergent TFP growth patterns -

[3] We have also considered longer lags and the results remained broadly unchanged.

[4] Malta is excluded from the econometric analysis due to the lack of data on value added.

across space and over time - into account by estimating specific regressions for macro-regions and sub-periods.

3.2 Measures for the presence of universities

Our analysis utilises the European Tertiary Education Register (ETER) dataset, which gives information on 2,764 HEI in 36 countries between 2000 and 2016. Notwithstanding the Bologna process, the national university systems are very different among the European countries. Therefore, the nature and classification of the HEI vary substantially across countries. For instance, Germany established a binary HEI, comprising both universities and *Fachhochschulen* (School of applied sciences), whose primary goal is to provide high professional training. On the other hand, Italy does not include these professional schools within the HEI (Agasisti and Gralka, 2019). Therefore, to provide comparability across countries, we restrict the analysis to the core category "universities", thus excluding the "universities of applied sciences" listed in the ETER database.[5]

In the year 2016, there were 1,005 active universities in the 28 EU countries. One hundred of them are very ancient institutions, created well before the 19th century starting with the first university, Alma Mater Studiorum, established in Bologna in 1088. Most of these institutions are located in Italy, Germany, Spain and the United Kingdom. From 1800 to 1944, 250 new universities were founded, spreading in most European countries. The reinforcement process of HEI has rapidly increased at the end of World War II. Universities show outstanding growth over the last 50 years, when almost half of the currently active institutions have been established (see Figure 2).

From the ETER dataset, we use the foundation year of each university to select the number of active institutions in year 2000, the initial time of our analysis, and in the following years until 2016. In the year 2000, the number of active universities in the 28 EU countries is 881. Most of them (71%) are public, while 16% are formally private but still dependent on government financing, while the remaining 12% are entirely private. In 2016 the number of universities increased by 12%, reaching the total number of 1,005. It is worth remarking that new universities arise nowadays in all European countries, signalling the vitality and the central role of this longstanding institution. To perform our econometric analysis, we have aggregated the universities individual data at the regional level. In 2000, among the 270 territorial units considered, only 23 regions lacked universities. Interestingly, the largest number of HEI is in Yugozapaden, the region of Bulgaria's capital city Sofia (20), followed by Inner London West (18) and Lisboa Metropolitan area (18). In 2016, at the end of the period considered, seven more regions had established a new university and therefore only 16 territorial units have remained without a higher education institute. These regions are, in general, small areas (1.9% of total EU population) contiguous to regions with well-established universities.

There are noticeable differences among the universities in terms of size, nature and quality, and the "university presence" variable described above is not able to account for these features. Therefore, in the econometric analysis, we try to control these differences by

[5] We have also excluded other typologies of HEIs in Italy (the online universities) and Poland (the Academies of National Defence Ministry, Maritime and Theological) given their specificities.

using additional information from the ETER database, which also contains data on staff, finances, educational offer, research, students, Erasmus mobility. Unfortunately, these variables present several missing data, and thus, we can use only a small set of additional indicators. We consider the research universities, the number of staff (both academic and administrative), the number of students and graduates (5-7 ISCED) and the incoming Erasmus students. Finally, we compute the universities' average size (average number of enrolled students per university in the region), which allows assessing the existence of either economies or diseconomies of scale.

3.3 Transmission channels

As discussed in the previous sessions, universities indirectly influence regional economic performance through two channels. In the first one, universities contribute to the formation of human capital by providing graduates and postgraduates individuals. Thus, we measure human capital by the share of the population, aged 25-64 years, with tertiary education (ISCED 5-8) over the total population. In the second transmission channel, universities are the leading producer of basic research and innovation, which contribute to increase the endowment of technological capital in the economy and, consequently, its productivity. The technological capital of each region is measured in terms of R&D expenditure over GDP. Although we also considered the stock of patents, we prefer to account for technological capital by means of R&D, an innovation input rather than an output one, because it is a more comprehensive measure of firms' innovative efforts, tacit knowledge exchange and collaborative interactions between firms and universities (Uyarra, 2010). Moreover, patenting activity is rare in regions with economic structures characterised by small businesses (Santarelli and Sterlacchini, 1990) or specialised in traditional low-tech productions.

3.4 Regional contextual variables

The extent to which universities' activities affect regional economic performance depends on several other local system characteristics. To control for these factors, we include three sets of contextual variables: the intangible assets, the production structure, and the geographical features.

Among the intangible assets, given that human capital and technological capital are already included to account for the indirect universities' effects, we consider the regional institutional capital. More precisely, we include the quality of the local institutions using the European Quality of Government Index, computed by Gothenburg University (Charron et al., 2015). This measure is a composite index based on three main dimensions: high impartiality, public service delivery quality and low corruption.

The literature has also emphasised how differences in the production structure impact regional performance (Marrocu et al., 2013). Therefore, we include an indicator that measures the relative importance of traditional sectors and it is based on the Revealed Comparative Advantage (RCA) index in Low-technology manufacturing (LTM). We expect that regions specialised in LTM show a relatively lower productivity growth. In the econometric analyses we also consider other indexes based on the relative specialisation in High- and medium high-technology manufacturing and Knowledge-intensive services.

The last set of controls are related to the geographical characteristics of the regions. We consider the Settlement Structure Typology (SST) index, which distinguishes six categories of regions according to two dimensions, density and city size. The less densely populated areas without centres take value one, while the densely populated regions with large centres take the maximum value of six. In the preliminary analysis, we have also considered other territorial controls, like an accessibility measure, the population density, and the country's capital. However, they were consistently outperformed by the SST index, thanks to its multidimensionality.

3.5 Spatial spillovers

The literature has highlighted the importance of spatial spillovers,[6] which make the growth process in one region dependent on the performance of the other proximate regional systems. Therefore, the productivity growth rate of a specific region may be affected by the presence of other universities in nearby areas, which may favour human capital mobility and the transmission of knowledge externalities (Drucker and Goldstein 2007, D'Este et al. 2013, Valero and Van Reenen, 2019).

We account for university spatial spillovers by considering as additional regressors the spatial lag of the corresponding explanatory variables. Spatial lags are computed by means of a weight matrix whose elements are given by the inverse of the Euclidean geographical distance for any pair of regions in our sample. For robustness we also consider a first-order contiguity matrix. Following Keleijan and Prucha (2010), all matrices are max-eigenvalue normalised; such normalisation avoid the imposition of strong undue restrictions, preserves symmetry and the absolute, rather than relative, notion of distance.

4. Explaining the regional productivity growth process

This section discusses the main results of the econometric analysis. In section 4.1 we focus on the long-term supply-side model of TFP growth, which allows us to provide novel evidence on the role of universities as key drivers of regional productivity. Our preferred model specification is then subject to robustness checks by performing sub-sample analysis (section 4.2) and by taking into account university heterogeneity in terms of size and quality (section 4.3).

4.1. The baseline spatial model of productivity growth

The most general specification of our productivity growth model is formulated as:

$$\Delta TFP_i = \beta_0 + \beta_1 university_i + \beta_2 hk_i + \beta_3 tk_i + \beta_4 ik_i + \beta_5 TFP_i + \beta_6 W\_univ_i + \upsilon_i \qquad (2)$$

where the dependent variable (ΔTFP_i) is the annual average growth rate of regional TFP computed over the period 2000-2016 for 270 territorial units. The initial level of TFP and all

[6] We are aware that in spatial econometrics it is customary to refer to spatial spillovers effects as "indirect" effects, as opposed to the "direct" ones which are due to changes in one's territorial unit own variables. In this paper to avoid confusion with the university direct/indirect effects we will refrain from using them when referring to spatial spillovers.

the explanatory variables – number of universities in the region (*university*), human capital (*hk*), technological capital (*tk*) and institutional capital (*ik*) refer to the year 2000 and are log-transformed.[7] Following Elhorst (2014), we account for university spillovers, by including the variable W_Univ_i, which is the spatial lag of the number of universities, computed as explained in section 3.2.[8]

Table 2 reports our baseline results. In column 1, we propose the simplest model that includes the three productivity-enhancing channels previously discussed: the university, human capital and technological capital. As expected, the university variable shows a positive and significant effect on regional efficiency growth with an estimated coefficient equal to 0.30. This is a remarkable result because, also in the case of productivity, we find evidence of a direct effect of universities, which is additional with respect to the well-documented effects due to the two indirect channels – human and technological capital. All three growth-enhancing channels are effective in driving regional economic productivity. The initial level of the dependent variable is negative, signalling a convergence process among the European regions: regions which are initially less efficient show a higher growth rate.

Column 2 includes the institutional quality variable and two controls for the production structure and the region's geographical features. The institutional capital shows the expected positive impact on regional productivity growth, while other results are maintained. The third model of Table 2 accounts for the possibility of regional cross border effects by including the spatial lag of universities. Results show that this variable exhibits a positive and significant coefficient (0.727), much larger than the own region's one (0.403).

It is important to remark that our variable of interest, the number of universities in the region, maintains a positive and significant effect in all the specifications. Considering our most general model of column 3, this implies that, on average, a 10% increase in the number of universities in a region produces a long-run impact on TFP levels equal to 1.8%. Moreover, when one considers the combination of the home region effect along with the one due to spatial externalities, an increase of 10% in the number of universities would produce a rise of around 5.2% in the TFP level. It is worth noting that such an effect would results if the 10% in the number of universities occurred in each region and a comparable increase has been recorded in Europe over the period 2000-2008.

Moreover, the other two indirect channels, related to the productivity-enhancing impact of the universities, are also positive and significant. All the three channels are therefore effective: in addition to the indirect effects through education and the scientific research activity, the presence of universities in a region favours its economic growth, supporting the diffusion of the innovations, entrepreneurship promotion, leadership formation and the cultural enhancement.

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[7] The number of universities is augmented by 1 to also keep the regions with zero universities when taking logs.

[8] Model 2 is a parsimonious SLX (spatial lag of X) specification, which allows for a straightforward estimation and identification of the the spatial spillovers, as these correspond to the estimated coefficient of the spatially lagged explanatory variables (Elhorst, 2014). This is remarkable advantage with respect to sptial autoregressive counterparts which entail more stringent requirements on the weight matrix to achieve spillovers identification.

Estimation results for the other explanatory variables are unchanged. More precisely, high institutional quality enhances local economic performance. Moreover, the territorial control variable SST is positive and significant, implying that a very densely populated area with large urban poles fosters regional productivity growth. When we look at the production structure, the estimation results show that specialisation in low tech manufacturing is detrimental to productivity dynamics.

To examine in more detail the effect of spatial spillovers, we construct two spatial lags for the university variable. In the first case the inverse distance matrix exhibits a cut-off at 300 km, while in the second one the distances considered are in the range 300-600 km, in this way we account for universities located in long-distance regions without considering the too remote ones.[9] Results reported in column 4 allow us to assess how the impact of universities changes as the distance increases. Interestingly, the magnitude of universities spatially lagged coefficient is equal to 0.54 for a distance up to 300 km, while it decreases to 0.26 for those in the range 300-600. Moreover, as expected, the significance levels decline from 1% to 10% for the regions distant up to 600 km. After this threshold distance, the lagged value of the universities is no longer significant. This result confirms that spillovers are bounded in space, and their effect decay with distance. For robustness, in column 5 we report results for the model which includes the university spatial lag based on the first order contiguity matrix. The main results are qualitatively unchanged, thus confirming the spatially bounded nature of spillovers.

The spatial analysis indicates that the universities have an influence not only in the region where they are located, but also in nearby territories. This finding points out that, not only there are no competitive processes among regional university systems, but that beneficial externalities are reinforcing each region's own efforts. This spillover effect may be directly due to the university *per se* or it might also work through the channels of human capital and technological capital spatial interactions. We also estimated models including, alternatively, the spatial lag of these two intangible assets and they turn out to produce positive and significant externalities. Due to multicollinearity issues, arising because of the high correlation of spatially lagged variables (correlation coefficients above 0.92), we cannot include them in the same model.[10]

Finally, for comparison with previous literature, we have estimated equation (2) replacing TFP with per capita GDP. The results, reported in Table A2 in the Appendix, show that the universities' variable has a positive and highly significant coefficient, signaling a demand-side effect on the local economy. All results are robust to the inclusion of production structure, territorial characteristics and spatial effects. Our results can be directly compared with those reported by Valero and Van Reenen (2019) in their estimation of a Barro long-run relationship. They state that a 10% increase in the number of universities generates a 1.6% increase in long-run GDP per capita at the world level. In our estimates for the European regions, the long-run impact (1.9%) is slightly lower. Moreover, when we

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[9] To choose the spatial ranges length, we have considered that the average distance across the EU regions is around 1200 km. Therefore, our benchmarks of 300 and 600 km represent, the first quartile and the median of the distance distribution.

[10] Estimations are available from authors.

consider the total effect, which also includes the spatial spillovers, the overall impact goes up to a remarkable 6.8% higher GDP per capita in the long run.

4.2 Robustness analysis: time and geography

In this section we present the robustness analysis carried out to check the stability of the baseline results on the universities' impact on regional productivity over time and across macro-regions. We consider two periods sub-samples by splitting the observations to account for the structural break of the global financial crisis in 2008. The first two columns of Table 3 report the results for the 2000-2008 and 2008-2016 sub-periods, while the last three columns refer to the macro-regions, namely Centre-North, South and New.

The most important result is that our variable of interest, the number of universities, exhibits a positive and significant coefficient across all periods and macro-regions. However, relevant differences in the magnitude of its impact among countries emerge. More specifically, the enhancing growth effect of the universities is more substantial for the new accession countries where the coefficient reaches the value of 0.63. Interestingly, in this model, the human capital coefficient is significant with a negative sign. This result suggests that the universities direct effect on the productivity growth of their own area is more effective than the indirect effect via the endowments of a highly educated population. Apart from the new accession countries, the human capital variable confirms its positive and significant role in all other specifications. The technological capital appears to positively affect the regional efficiency growth in the first period, before the financial crises. Moreover, looking at the geographical breakdown, it shows a positive impact for the new accession countries.

The local institutions' quality coefficient, which was positive and significant in the preferred model for the whole period (model 3 of Table 2), now appears not significant in the pre-crisis years, when the market forces worked more effectively. Nonetheless, it turns out to be highly significant in the post-crisis period when the need for a public intervention in the economy to assure the recovery phase was essential. Among the other determinants, it is worth remarking that we corroborate a convergence process of the TFP levels in all models, even though with some notable differences. More specifically, the convergence process is almost halved in the post-crisis period.

4.3 Robustness analysis: accounting for quality and size of universities

As we have previously discussed, the number of universities in a specific region is a simple proxy for the complex role of universities. However, this measure is the only one that is consistently available for the largest possible number of EU regions. If the analysis is focused on reduced samples of regions, we are able to account also for some specific university features by considering additional indicators. Namely, the number of universities' graduates, enrolled students, academic and administrative staff (all measured as ratios to thousands of regional inhabitants), the attractiveness for the Erasmus programme students, the average universities size (average number of enrolled students per university in the region), and the prevailing specialisation in research activities. Table 4 reports the results for models including these additional indicators of universities' activities. Since the number of graduates, students, and staff are highly correlated (correlation coefficients in the range 0.82-0.90), we include them one by one to avoid multicollinearity and Table 4 reports only the number of university graduates since the number of staff or enrolled students yields the same results.

In column 1, together with all the explanatory variables and controls included in the preferred specification (model 3 in Table 2), we also consider the effects of the universities' average size and the number of graduates. We also include a variable − the share of incoming Erasmus students over total enrolled students − which aims to feature, albeit roughly, the quality of the host institution and the vitality of the local economy, which are recognised as beneficial elements for economic growth.

Only the average size has a negative and significant coefficient, implying the absence of economy of scale along the university dimension. In other words, on average, regional productivity growth is enhanced by smaller universities, which are, possibly, more interconnected with the local community. The other two additional indicators for the universities' activities do not seem to be relevant in driving productivity growth. It is important to remark that our primary variable of interest – the number of universities in the region – maintains its positive and significant role despite the inclusion of these additional regressors.

In model 2 we substitute the universities' measure so far used, with the number of universities specialised in research, which may be considered an indicator of higher quality. The estimated coefficient turns out to be positive and significant showing, however, a magnitude slightly smaller (0.379) than the one in the baseline model (0.403 in column 3 Table 2). This result might reasonably indicate that universities are most effective when both their main functions – teaching and research – are jointly performed. The university "production" process is a very complex one, which entails a continuous and intertwined relationship between higher education and research, which allows to exploit a wide set of economies of scope and variety.

5. Universities and the transmission channels

As discussed in the previous sections, HEI in a specific region directly foster productivity growth, and we have provided novel and robust evidence on such an impact. At the same time, universities are the institutions responsible for creating highly skilled graduates and scientific research, consequently increasing the region's human and technological capital endowments. These two intangible factors, in turn, enhance regional efficiency growth, as we have shown in the previous sections. Therefore, in the following two sections, we further investigate the mechanisms that connect universities' presence with the human and technological capital dynamics at the regional level.

5.1 The human capital channel

Table 5 presents a model where the dependent variable is the regional growth rate of human capital over 2000-2016. Our variable of interest is, as before, the number of universities because we aim at testing the functioning of this transmission channel. As usual, we also include the initial level of human capital to control for convergence dynamics.

Column 1 reports the estimation results of a simple specification for the entire sample of the 270 EU regions. As expected, the number of universities exerts a positive and significant impact on the subsequent growth of the graduates share with a relatively high coefficient at 0.52. Moreover, the initial level of human capital shows a negative coefficient, implying a catch-up process in the high education endowments.

A region's capacity to increase the share of graduates may also be positively influenced by the quality of local institutions that oversee the educational system, which exhibits a positive and significant coefficient, meaning that local institutions with a higher quality promote human capital accumulation. Although graduates' endowments in a specific region might be affected by the geographical spillovers coming from other areas, results in column (2) and (3) indicate no significance evidence of such externalities for both cases considered, all neighbouring regions allowing for distance decay or just the contiguous ones.[11] Remarkably, the effect of the universities maintain its positive influence and shows an even higher coefficient (0.75) with respect to the models for the TFP growth.

In columns 4-6 we report the results by macro-regions. The most important finding is that university positive effect on human capital accumulation is generally confirmed. The only exception is model 4 for the Centre-North regions, where the university coefficient is only marginally significant (pvalue 0.150). A possible explanation is that we use the number of graduate residents in the region to measure human capital. These more advanced Centre-North regions often attract a relevant part of their graduates from universities located in other areas and countries.[12] Interestingly, the Southern and the New accession regions show a high impact of universities on human capital accumulation with a coefficient equal, respectively, to 0.61 and 1.35. The results for the other regressors are maintained in most specifications.

5.2 The technological channel

The second transmission mechanism of the university effects on productivity growth is the technological capital channel. Universities are the leading creators of basic research and technological innovation, favouring the accumulation of technological capital and enhancing local productivity growth. In this section, we aim to investigate the role of universities in promoting technological capital growth at the regional level. We start with a simple model where technological capital growth over the period 2000-2016 depends on the number of universities located in the region and the initial level of R&D expenditure to control for the convergence process.

Column 1 in Table 6 shows that universities exert a positive and significant effect on technological capital growth. This is in contrast with the non-significant role of universities found by Valero and Van Reenen (2019). It is worth noting that they proxied technological capital by the stock of patents, which – compared to R&D investments – is a too restrictive measure of innovative efforts as it accounts only for codified-higher quality inventions.

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[11] The results are confirmed also in the case of the inverse distance matrices computed for the 0-300 and 300-600 distances.

[12] Also, in the case of the macro-regions models we find no evidence of spatial externalities. A more sophisticated model with graduates' migration flows is needed to control for regions' different levels of attractiveness (see, for example, Abreu et al. 2014 for UK and Giambona et al., 2017 for Italy). This relevant issue is left for future research.

Our result is confirmed when we include other explanatory variables, like the initial endowment of human capital and the quality of the local institutions. We also control for spatial spillovers by including the universities spatial lag alternatively based on the inverse distance matrix (model 2) or the contiguity matrix (model 3).

The initial level of human capital endowments appears positive and significant in model, while it turns out only marginally significant (p-value 0.160) in model 2. Institutional capital is never significant, contrary to the human capital growth model previously analysed. The educational system in Europe is mainly public, and therefore the role of local institutions is crucial for its expansion. On the other hand, the technological capital accumulation process features both local and international traits, the role of private firms is more decisive, and therefore there is less room for the quality of public institutions. The initial level of R&D expenditures is always negative, meaning that the convergence process in the technological endowments across the European regions is ongoing.

Finally, we find evidence of sizeable universities externalities (coefficient equal to 3.5 in the second column and 2.5 in the third one) which point to the relevance of research inter-regional networks in driving technological advances and the need for coordinated policies at the European level to make them larger, denser and more interconnected.

In columns 4-6, we split our sample by the geographical breakdown. The main results are all confirmed. Most importantly, universities positively impact technological growth in all areas, with the partial exceptions of the Centre-North regions where the universities' effect is only marginally significant (pvalue 0.150). The strong positive effect of the initial level of human capital on the technological accumulation in the New accession countries is worth noting.

6. Concluding remarks

The role of universities in enhancing regional development has evolved over the last decades in quantitative and qualitative terms. Along with a remarkable rise in university students and graduates associated with a sizeable proliferation and diffusion of universities worldwide, their role is being increasingly conceived as an essential engine to cultural, entrepreneurial and civic development (Mowery and Sampat, 2005; Uyarra, 2010). Besides a demand-side effect, a supply-side impact appears to be the result of various functions which stem from the key ones of human capital formation and research. Namely, know-how and technological transfer, regional leadership, entrepreneurship development, public engagement (Florax, 1992; Goldstein et al. 1995; Drucker and Goldstein, 2007).

In this paper, we have proposed a new empirical framework that bridges the KPF and the GDP approaches mainly adopted in the extant literature to investigate the university effects. We focus on the supply-side effects by focusing on TFP and assessing the distinct influence of three universities' growth-enhancing channels: the two indirect channels through higher education and basic research and the direct channel of the third mission activities. Moreover, we also estimate growth models for human and technological capital to assess the university key role in enhancing the local stock of such valuable intangible assets.

The first important result of our analysis is that the long-run impact of universities on regional TFP is always positive and sizeable. This direct effect supplements the indirect one generated through human and technological capital. The university role proves robust to the inclusion of other variables, such as institutional capital, agglomeration forces and production structures indices. Moreover, we find that universities may spread their effects across regional boundaries, although with a significant distance decay. We show that a 10% increase in universities is associated with a 1.8% rise in the long-run TFP in a region. An expansion that rises to more than 5% when this internal impact is reinforced by the external ones accruing from neighbouring regions.

Finally, we show that universities are essential drivers of local human and technological capital growth, thus confirming their productivity-enhancing indirect effects. Although expected and usually taken for granted, this last outcome was not always found in previous studies. In general, universities play an essential role in increasing the productivity of the European regions, which complements and integrates that of other growth determinants. We have also tested the relevance of universities in regional economic performance by employing the usual GDP model. Our results are compatible with previous research showing that there is also a demand-side effect other than the supply-side one.

Overall, these results demonstrate the several and differentiated ways in which universities enhance economic performance and support the society as a whole. Universities facilitate the private and public agents engaged in innovation and production with novel entrepreneurship and organisational models. We offer robust evidence that universities produce beneficial externalities within and beyond the local economic system in which they are located. Even though this might appear an obvious conclusion, it is worth remarking that this outcome strongly calls for policies favouring more advanced education as a means towards vigorous productivity enhancements and enduring economic growth. Therefore, strong support of the higher education institutions represents a crucial policy to reduce the development gap across regions, which is still a primary objective of the European cohesion policies, especially now in a time of pandemics. It is worth remarking that the Next Generation EU aims at modernising traditional policies to maximise their contribution to the Union priorities and, for this reason, allocates 60% of the resources to the heading of "cohesion, resilience and values".

Although we find clear evidence on the direct effect of university activities on local performance, further research is needed to disentangle this channel usually summarised under the heading of third mission: business-academy linkages, movements of researchers and other personnel, and other collaborations favouring knowledge exchange and diffusion, regional leadership, and entrepreneurial culture. This research line requires homogeneous micro-data, which are not readily available for the whole of Europe.

Another critical area which deserves further exploration concerns the map of interactions among regions and universities. We have started exploring this map by focusing on geography. Still, we know that other dimensions may prove essential (Boschma, 2005, Basile et al., 2012, Paci et al. 2014), especially for the collaborations between universities and industry (Alpaydin and Fitjar, 2021), since spillovers may travel through many channels, such as student and researchers' mobility or collaborative networks within cognitive communities.

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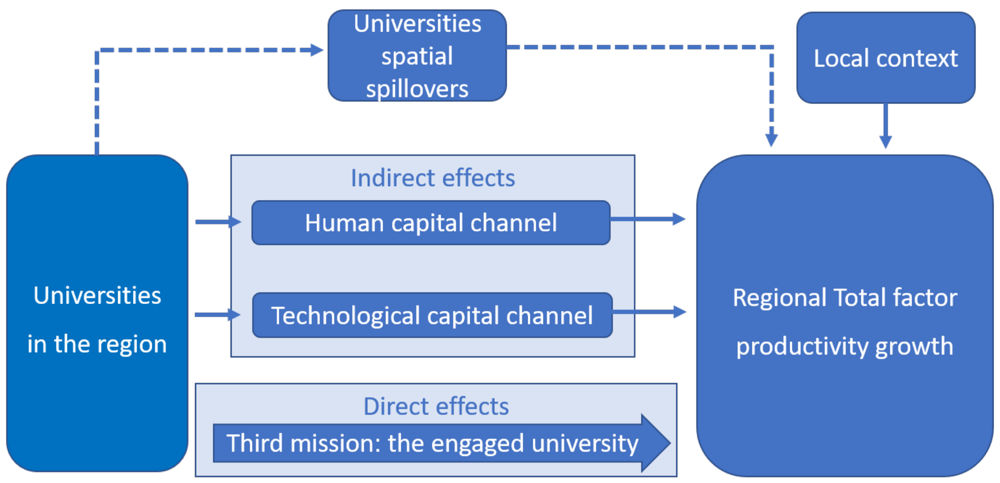
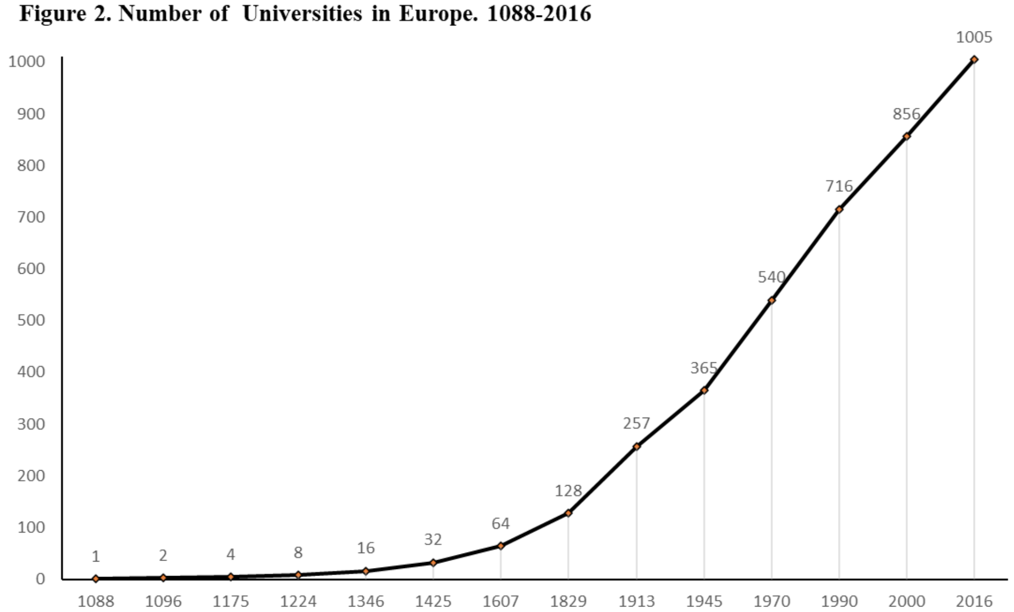
Figure 1. The long-run supply-side productivity-enhancing effects of universities

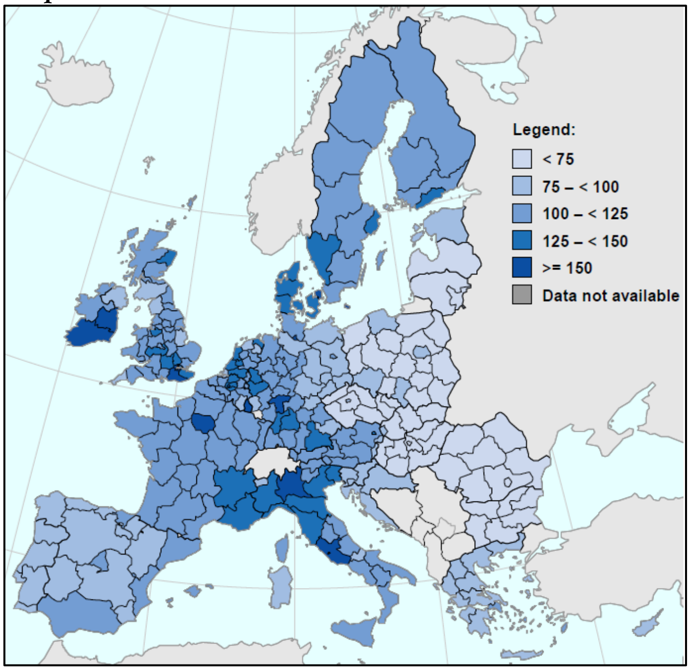


Source: own elaborations

Figure 2. Number of Universities in Europe. 1088-2016



Map 1. TFP levels. Index EU=100. Year 2000



Map 2. TFP annual average growth rates. 2000-2016

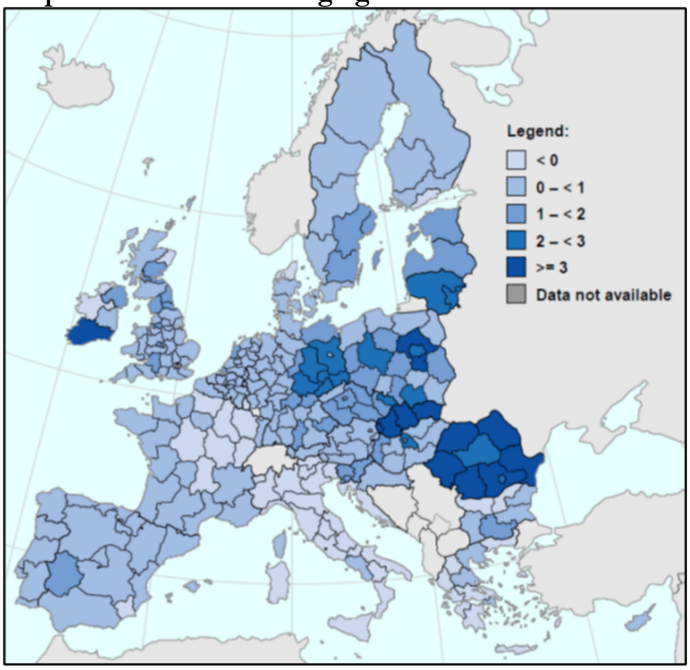


Table 1. Total Factor Productivity in the EU countries

	West-Northern countries	Southern countries	New accession countries	European Union
Index TFP level, EU=100				
2000	119	101	51	
2008	119	93	57	
2016	120	90	58	
TFP average annual growth rate				
2000-2016	0.67	-0.08	1.69	0.74
2000-2008	0.96	-0.06	2.62	1.12
2008-2016	0.36	-0.08	0.62	0.33

South: Italy, Spain, Greece, Portugal
New: 12 new accession countries (Malta is excluded)
West-North: remaining 11 Western Central and Northern countries

Table 2. Universities and regional efficiency growth. Baseline results
Dependent variable: growth rate of TFP, annual average 2000-2016

Model	1		2		3		4		5	
Spatial matrix	NO		NO		distance		distance		contiguity	
Number of universities	0.302	***	0.309	***	0.403	***	0.411	***	0.296	***
	(0.072)		(0.079)		(0.076)		(0.085)		(0.080)	
Human capital	0.573	***	0.335	**	0.303	**	0.294	**	0.398	***
	(0.128)		(0.137)		(0.126)		(0.137)		(0.137)	
Technological capital	0.234	***	0.151	**	0.137	***	0.132	**	0.148	**
	(0.066)		(0.060)		(0.051)		(0.063)		(0.058)	
Institutional capital			0.603	***	0.512	**	0.493	**	0.561	**
			(0.220)		(0.209)		(0.211)		(0.231)	
TFP initial level	-1.795	***	-2.294	***	-2.184	***	-2.143	***	-2.237	***
	(0.208)		(0.207)		(0.198)		(0.210)		(0.199)	
Spatial lag of universities					0.727	***			0.250	***
					(0.156)				(0.089)	
Spatial lag 0-300 km of universities							0.540	***		
							(0.158)			
Spatial lag 300-600 km of universities							0.264	*		
							(0.137)			
Actual-fitted values square correlation	0.418		0.418		0.548		0.548		0.523	
(a) Controls for production structure	NO		YES		YES		YES		YES	
(b) Controls for geographical features	NO		YES		YES		YES		YES	

Notes
Number of regions 270
Estimation method: Least squares
Robust standard errors in parentheses; *** indicates significance at the 1% level, ** at the 5% level and * at the 10% lev
Exogenous variables are defined for year 2000 and are in natural logs
(a) RCA for Low technology manufacturing
(b) Settlement structure typology
See Table A1 for variables' definition

Table 3. Robustness for time periods and territorial samples

Dependent variable: growth rate of TFP, annual average

Model	1		2		3		4		5	
Growth rate years	2000-08		2008-16		2000-16		2000-16		2000-16	
Territorial sample	All		All		Centre-North		South		New	
Number of regions	270		270		155		55		60	
Number of universities	0.428	***	0.339	***	0.333	***	0.243	**	0.628	**
	(0.138)		(0.079)		(0.071)		(0.113)		(0.279)	
Human capital	0.484	**	0.433	**	0.541	***	0.319	*	-1.101	**
	(0.244)		(0.175)		(0.151)		(0.164)		(0.456)	
Technological capital	0.220	**	0.083		-0.003		0.075		0.574	***
	(0.092)		(0.071)		(0.050)		(0.107)		(0.207)	
Institutional capital	0.368		0.679	***	0.452		0.630	***	0.227	
	(0.409)		(0.123)		(0.291)		(0.224)		(0.217)	
Initial level of TFP	-3.172	***	-1.467	***	-1.875	***	-1.375	***	-2.045	***
	(0.310)		(0.304)		(0.394)		(0.407)		(0.681)	
Actual-fitted values square correlation	0.491		0.194		0.398		0.512		0.467	
(a) Controls for production structure	YES		YES		YES		YES		YES	
(b) Controls for geographical features	YES		YES		YES		YES		YES	
(c) Controls for spatial dependence	YES		YES		YES		YES		YES	

Notes

Number of regions 270

Estimation method: Least squares

Robust standard errors in parentheses; ∗∗∗ indicates significance at the 1% level, ∗∗ at the 5% level and * at the 10% le

Exogenous variables are defined for year 2000 and are in natural logs

(a) RCA for Low technology manufacturing

(b) Settlement structure typology

(c) Spatial lag of universities, distance matrix

South: Italy, Spain, Greece, Portugal

New: 12 new accession countries (Malta is excluded)

Centre-North: remaining 11 western central and northern countries

See Table A1 for variables' definition

Table 4. The role of universities' quality and size
Dependent variable: growth rate of TFP, annual average 2000-2016

Model	1	2
Number of regions	261	259
Number of universities	0.334 ***	
	(0.079)	
Number of research universities		0.379 ***
		(0.088)
Universities average size	-0.046 *	-0.046 *
	(0.026)	(0.026)
Universities graduates	0.095	0.073
	(0.079)	(0.081)
University attractiveness - Erasmus students	0.067	0.064
	(0.071)	(0.074)
Actual-fitted values square correlation	0.562	0.563
(a) Controls for production structure	YES	YES
(b) Controls for geographical features	YES	YES
(c) Controls for spatial dependence	YES	YES

Notes
Estimation method: Least squares
Robust standard errors in parentheses;
*** indicates significance at the 1% level, ** at the 5% level and * at the 10% level
Exogenous variables are defined for year 2000 and are in natural logs
Spatial lag computed with distance matrix
(a) RCA for Low technology manufacturing
(b) Settlement structure typology
(c) Spatial lag of universities, distance matrix
See Table A1 for variables' definition

Table 5. Universities and human capital growth

Dependent variable: growth rate of human capital share, annual average 2000-2016

Model	1	2	3	4	5	6
Territorial sample	All	All	All	Centre-North	South	New
Spatial matrix	NO	distance	contiguity	distance	distance	distance
Number of regions	270	270	270	155	55	60
Number of universities	0.519 ***	0.722 ***	0.750 ***	0.318	0.611 **	1.353 ***
	(0.190)	(0.191)	(0.188)	(0.224)	(0.275)	(0.518)
Institutional capital		1.011 ***	1.006 ***	-0.406	3.564 ***	1.180 **
		(0.398)	(0.380)	(1.334)	(0.741)	(0.508)
Initial level of human capital	-4.234 ***	-4.685 ***	-4.793 ***	-4.470 ***	-5.487 ***	-3.333 ***
	(0.317)	(0.369)	(0.381)	(0.614)	(0.803)	(0.821)
Spatial lag of universities		-0.232	-0.214	-0.419	-4.943 ***	3.010 **
		(0.362)	(0.262)	(0.491)	(1.655)	(1.330)
Actual-fitted values square correlation	0.519	0.542	0.543	0.383	0.691	0.418

Notes

Estimation method: Least squares

Robust standard errors in parentheses; *** indicates significance at the 1% level, ** at the 5% level and * at the 10% level

Exogenous variables are defined for year 2000 and are in natural logs

South: Italy, Spain, Greece, Portugal

New: 11 new accession countries (Malta is excluded)

Centre-North: remaining 12 western central and northern countries

See Table A1 for variables' definition

Table 6. Universities and technological capital growth
Dependent variable: growth rate of R&D, annual average 2000-2016

Model	1		2		3		4		5		6	
Territorial sample	All		All		All		Centre-North		South		New	
Spatial matrix	NO		distance		contiguity		distance		distance		distance	
Number of regions	270		270		270		155		55		60	
Number of universities	5.244	***	5.542	***	5.051	***	1.841		9.668	**	7.295	***
	(0.914)		(1.128)		(1.105)		(1.293)		(4.428)		(2.691)	
Human capital			2.154		3.401	**	-0.655		1.767		9.961	***
			(1.532)		(1.657)		(1.887)		(3.138)		(3.586)	
Institutional capital			-0.756		-0.825		4.170		1.235		0.650	
			(1.656)		(1.578)		(3.981)		(2.507)		(1.990)	
Initial level of R&D	-3.387	***	-3.786	***	-3.664	***	-1.896	**	-4.951	***	-6.896	***
	(0.390)		(0.516)		(0.497)		(0.977)		(1.633)		(1.671)	
Spatial lag of universities			3.472	**	2.540	***	2.757	*	12.202	**	11.009	*
			(1.556)		(0.968)		(1.625)		(6.159)		(6.725)	
Actual-fitted values square correlation	0.375		0.395		0.398		0.096		0.346		0.346	

Notes
Estimation method: Least squares
Robust standard errors in parentheses; *** indicates significance at the 1% level, ** at the 5% level and * at the 10% level
Exogenous variables are defined for year 2000 and are in natural logs
South: Italy, Spain, Greece, Portugal
New: 11 new accession countries (Malta is excluded)
Centre-North: remaining 12 western central and northern countries
See Table A1 for variables' definition

Appendix. Table A1. Data sources and definition

Variable	Primary Source	Years	Definition
Value added	JRC, EU science hub	2000-2016	Millions euros, constant price 2015
Units of labour	JRC, EU science hub	2000-2016	Thousands
Gross fixed capital formation	JRC, EU science hub	1990-2016	Millions euros, constant price 2015
Total Factor Productivity	Own calculation	2000-2016	Estimated levels
TFP growth rate	Own calculation	2000-2016	Growth rate tfp 2000-2016, % annual average
Capital stock	Own calculation	2000-2016	Millions euros, constant price 2015
GDP per capita	Eurostat	2000-2016	Real gdp per capita, thousands euro
GDP pc growth rate	Eurostat	2000-2016	Growth rate of GDP per capita, % annual average
University	ETER	2000-2012	Number of universities in the region
Research university	ETER	2000-2012	Number of research active universities in the region
University Graduates	ETER	2000-2012	University graduates (Isced 5-7) per thousand inhabitants
University Students	ETER	2000-2012	University students (Isced 5-7) per thousand inhabitants
University Staff	ETER	2000-2012	University staff (FTE) per thousand inhabitants
University attractiveness	ETER	2000-2012	Share of incoming Erasmus students over total enrolled students (Isced 5-7)
University size	ETER	2000-2012	Average number of enrolled students (Isced 5-7) over number of university in the region
Human Capital	Eurostat	2000-2016	Population aged 25-64 with tertiary education (Isced 5-8) over total population 25-64, %
Technological capital	Eurostat	2000-2016	R&D expenditure over GDP, %
Quality of Institution	Gothenburg University	2010	Index based on citizens' perceptions on impartiality, quality of public service, corruption.
HMM specialisation	Eurostat, Labour forces	2000-2016	Normalised RCA, Employment in High- and Medium high- technology manufacturing
LTM specialisation	Eurostat, Labour forces	2000-2016	Normalised RCA, Employment in Low-technology manufacturing
KIS specialisation	Eurostat, Labour forces	2000-2016	Normalised RCA, Employment in Knowledge-intensive services
Population density	Eurostat	2000-2016	Population per km2
Settlement Structure Typology	ESPON project 3.1 BBR	2000	1=less densely populated without centres, 2=less densely populated with centres, 3=densely populated without large centers, 4=less densely populated with large centres, 5= densely populated with large centres, 6=very densely populated with large centres
Accessibility by road, rail, air	ESPON project 2.4.2	2000	1=highly below average; 2=below average; 3=average; 4=above average; 5=highly above average

Appendix. Table A2. Universities and regional economic growth

Dependent variable: growth rate of GDP per capita, annual average 2000-2016

Model	1		2		3	
Number of universities	0.558	***	0.522	***	0.678	***
	(0.159)		(0.179)		(0.182)	
Human capital	1.095	***	1.077	***	1.032	***
	(0.263)		(0.286)		(0.270)	
Technological capital	0.382	***	0.378	***	0.353	***
	(0.109)		(0.109)		(0.104)	
Institutional capital	0.081		0.099		-0.049	
	(0.509)		(0.515)		(0.496)	
Initial level of GDPpc	-2.784	***	-2.799	***	-2.707	***
	(0.331)		(0.347)		(0.324)	
Spatial lag of universities number					1.163	***
					(0.365)	
Actual-fitted values square correlation	0.573		0.573		0.592	
(a) Controls for production structure	NO		YES		YES	
(b) Controls for territorial features	NO		YES		YES	

Notes

Number of regions 270

Estimation method: Least squares

Robust standard errors in parentheses;

*** indicates significance at the 1% level, ** at the 5% level and * at the 10% level

Exogenous variables are defined for year 2000 and are in natural logs

Spatial lag computed with distance matrix

(a) RCA for Low technology manufacturing

(b) Settlement structure typology

See Table A1 for variables' definition

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