Gabinete de Estratégia e Estudos

REPÚBLICA PORTUGUESA
ECONOMIA E MAR

GEE Paper

175

Julho de 2023

# Science and productivity in European firms: How do regional innovation modes matter?

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**www.gee.gov.pt**
ISSN (online): 1647-6212

# Science and productivity in European Firms: How do regional innovation modes matter? [1]

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**Abstract**

Productivity disparities in the European regions tend to persist. In order to understand the underlying sources of this phenomenon we assess the importance of science and regional innovation modes on firms' productivity growth on a sample of 150,712 firms across 161 NUTSII European regions, over the period 2012-2017. We find that science is a major source of firms' productivity growth, and it has been particularly important to firms located in Southern Europe and, to less extent, in Eastern EU regions, indicating that a science-push convergence process is at work in the EU peripheral regions. Our findings also show that the fast-growing productivity firms are those who benefit more from external knowledge and innovation. Growth by imitation seems to be a viable strategy restricted to the slow-growing productivity firms. These results help to conciliate contentious evidence regarding firms' benefits from spillovers, namely from scientific knowledge.

**JEL Classification:** O33, O38, L25, R11

**Keywords:** Territorial innovation patterns, Firm productivity, Europe, Quantile regression



[1] Award-winning work by the Call for Papers on the "Impact of Science on Economy and Society in Portugal: Investment, scientific employment and knowledge enhancement", a partnership between the Office for Strategy and Studies of the Ministry of Economy and Maritime Affairs (GEE) and the Foundation for Science and Technology (FCT).

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## 1. Introduction

Productivity is one of the main determinants of economic growth, yet it is a highly dispersed phenomenon. Productivity dispersion can be observed not only across firms and industries but also across space, i.e., between and within countries. Recently, OECD (2018) estimated that between-country differences account for 57% of total variation in productivity among European countries, while the remaining 43% is due to within-country variation. After a period of some economic convergence, regional productivity disparities in the European regions tend to persist (Camagni & Capello 2017, Cortinovis & Van Oort 2019, Capello & Cerisola 2021, Cartone et al. 2021). These results highlight the importance of local conditions on determining productivity.

There is now overwhelming evidence showing that knowledge spillovers are an important source of productivity growth, namely at the regional level (Krugman 1991, Jaffe et al. 1993, Howitt & Aghion 1998, Storper 2011). As knowledge spillovers are geographically bound (Audretsch & Feldman 1996) local sources of knowledge play a key role in enhancing firms' innovation and productivity (Chen et al. 2016, Pfister et al. 2021, Lehmann et al. 2022). However, the importance of local knowledge sources has been heavily challenged in the literature. Studies show that closeness is not always beneficial to firms. In some cases, firms obtain larger benefits from networking with non-local partners in order to avoid lock-in effects (Fitjar & Rodríguez-Pose 2013), or from being located in more isolated places in order to contain spillovers or leakage effects (Hervas-Oliver et al. 2018). There is also evidence that other proximity dimensions, such as cognitive and cultural, can be more important than geographical proximity for firms to access external knowledge (Boschma 2005, Breschi & Lenzi 2016).

One possible explanation for these contentions is that the impact of local knowledge sources is moderated by firms' internal resources. However, empirical evidence is conflicting at times as are the assumptions behind it. On one hand, it has been argued and corroborated that weaker firms benefit more from external sources, which act as substitutes for internal endowments (Busom & Vélez-Ospina 2017, Caloghirou et al. 2021). On the other hand, it has also been proposed that stronger firms will benefit more through complementarity as they have more internal capabilities (Cohen & Levinthal 1990, Audretsch & Belitski 2020). To further complicate the matter, it has also been argued that moderately strong firms benefit the most as they have sufficient internal capabilities to enjoy complementarity while being less exposed to knowledge leakage (Hervas-Oliver et al. 2018).

In order to address the above contradictory theoretical assumptions and results, researchers (see, e.g., Speldekamp et al. 2020) have been focusing on the ways innovation can take place and on the different roles that internal and external knowledge sources can have on firms' productivity. The notion that innovation can be attained through several ways (Pavitt 1984, Malerba 2002, Jensen et al. 2007) has been receiving recent attention from scholars of the geography of innovation (Asheim & Coenen 2005, Iammarino 2005, Tödtling et al. 2011, Capello & Lenzi 2013a, Marrocu et al. 2013), who argue that learning, knowledge exchange and innovation follow certain behaviors that are region-specific. Therefore, it is possible to identify territorial patterns of innovation that help to understand differences in innovation capabilities and their impact on firms' productivity and, hence, on the local economy.

In this paper, we investigate to what extent scientific knowledge and different territorial innovation patterns are important to explain firms' productivity, and if some patterns lead to higher productivity gains than others. In order to do so, we apply Capello & Lenzi (2013a)´s taxonomy to a sample of 150,712 manufacturing firms that are located across 161 NUTSII European regions. To our knowledge, this is the first study to investigate the relationship between territorial patterns of innovation and productivity at the firm-level and across multiple European Regions. Capello & Lenzi (2015) investigated the role of territorial modes of innovation on regional productivity. However, their analysis only describes the average behavior of the region, which is largely dependent on the regions´ productive structure, and does not reveal heterogenous effects on firms. In turn, by applying quantile regression to firm-level data, we are able to analyze if and how the impact of regional innovation mode on firms' productivity differs across firms. By linking regional innovation modes with firm-level data, we contribute to the understanding of how geography and science are related to productivity, via an R&D and innovation mechanism. We also test the robustness of our results against the possibility that differences in main geo-economic groups of regions can affect the impact of innovation patterns (Crowley & McCann 2018). As regional innovation patterns contribute to explain regional differences in economic development, our study provides grounds for public intervention.

Furthermore, based on empirical findings across EU, we analyse some specific characteristics of Portuguese regional innovation modes and their recent evolution in order to disclose the potential role of science in shaping Portuguese firms' productivity. By assessing the main components of the Portuguese regional innovation modes, we offer a prospective analysis of the role of science in the Portuguese case and add to the ongoing debate on the interplay between science and economic development.

The paper is organized as follows. In Section 2 we discuss the use of internal and external knowledge sources and innovation modes, and describe the taxonomy of territorial innovation patterns. In Section 3 we describe the data, variables and econometric strategy employed. Our estimation results are reported and discussed in Section 4. In Section 5 we offer a detailed analysis on the recent evolution of indicators characterizing the Portuguese regional innovation modes in order to disclose the complex nature of regional knowledge production and the role of science. At the end, Section 6 gives some concluding remarks and policy recommendations.

## 2. Science, innovation mode and firm productivity

Economic theory (see, e.g., Krugman 1991, Jaffe et al. 1993, Howitt & Aghion 1998, Storper 2011) has long recognized that innovation and technological change are key drivers of productivity and that the local generation of knowledge, accumulation and spillovers are a main source of regional differences in productivity and economic growth. The key idea in this line of thought is that some knowledge is tacit and hard to acquire without direct expertise. The flow of knowledge either through collaborations or unintended spillovers is facilitated by geographic proximity. Innovation and technological change can occur not only by the introduction of new products and processes but also through imitation or technology transfer, allowing firms behind the technological frontier to benefit from the knowledge flows as well.

In order to innovate and grow, firms need to use various sources of external knowledge and combine them with internal resources, namely R&D capabilities (Antonelli 2006, Teece 2010). Beyond contributing to productivity, R&D investment can also increase the returns to knowledge spillovers, generating a string of innovations developed in-house, co-created with partners or developed by other firms (van Rijnsoever et al. 2017, Baum et al. 2019).

Firms can access external knowledge in many different ways. The knowledge may be purchased or transferred according to a license contract; acquired through new employees who bring with them know-how about technical solutions; obtained from collaborative efforts with other firms and research organizations such as universities, or accessed through spillovers from other economic agents. These external sources can be local or distant (national or international), such as links to international networks, international suppliers or customers abroad and trans-national links for R&D collaboration with firms abroad (Fitjar & Rodríguez-Pose 2011, Tödtling & Grillitsch 2014, Yeung 2021). In turn, the engagement with external sources of knowledge is related to the firms' innovation mode (Fitjar & Rodríguez-Pose 2013), namely as advanced by Jensen et al. (2007) the "Science and Technology Innovation" (STI) and the Doing-Using-Interacting (DUI) innovation mode, which are region-specific.

Among the various regional innovation taxonomies proposed by the literature, the Capello & Lenzi (2013a) is the one that best represents possible ways of doing innovation, and of the relative importance of external sources of knowledge. Capello & Lenzi (2013a) territorial innovation taxonomy includes five groups of regions: (i) the Science-Based; (ii) the Applied-Science; (iii) the Applied Smart-Technological; (iv) the Applied Smart-Creative and Diversification; and (v) the Imitative Innovation region allowing for different regional economic growth paths. The Science-Based region, composed of strong knowledge and innovation-producing regions. The Applied-Science region, similarly made up of strong knowledge-producing regions, albeit characterized by a local knowledge base of an applied nature. The Smart-Technological Application region has a high product innovation rate, with a limited degree of local basic science, but a high level of creativity. A Smart-Creative Application region, has a low degree of local science in the form of patents and R&D, a non-negligible internal innovation capacity, and a high degree of local capabilities. The Imitative Innovation region is characterized by a low knowledge and innovation intensity but high entrepreneurship, creativity, attractiveness and innovation potentials (see, also, Capello & Lenzi 2013b, 2015).

Each conceptual pattern is the result of specific structural characteristics of the region and of specific relational structures supporting knowledge and innovation creation and acquisition. The taxonomy acknowledges that innovation may be attained through different paths other than the knowledge intensive and science-based one, and allows for the acquisition of knowledge and innovation from outside the region. Thus, even the imitative innovation approaches, typical of peripheral areas and declining industrial regions, are taken into consideration. Regional innovation patterns differ significantly in terms of intensity, mix of knowledge, and innovation activities. They also differ in the relational structure supporting knowledge and innovation creation and acquisition (Capello & Lenzi 2013b, 2015). As a result, productivity differentials are not just determined by the regional endowment level, but also by the way firms are able to take advantage of existing resources (Cartone et al. 2021), with some regions being better at converting R&D into productivity gains than others (Fernandez-Vazquez & Rubiera-Morollon 2013).

According to the Capello & Lenzi (2013a) framework, regions characterized by a higher intensity of scientific knowledge creation achieve higher productivity gains from this knowledge than less knowledge intensive regions, consistent with the absorptive capacity argument (Cohen & Levinthal 1990). Regions innovating through non-scientific knowledge or through knowledge spillovers achieve productivity gains from both non-scientific knowledge and innovation, particularly when creativity and entrepreneurship are present in a region. No a priori exists for the effects of innovation on the economic performance of imitative regions. In fact, the efficiency of imitation is expected to rest on the degree of novelty attained during the imitation processes (Capello & Lenzi 2013a).

Recent evidence seems to support this view. For instance, Evangelista et al. (2018) found that less innovative and peripheral EU regions have been increasing their specialization in key enabling technologies (KETs) at the expense of the most advanced regions. Likewise, Mewes & Broekel (2020) show that many non-metropolitan European regions are able to develop complex technologies, Tödtling et al. (2022) found that metropolitan regions are not more beneficial to innovation than other regions and Pfister et al. (2021) found that what works for the major innovation centres, which often draw upon many top-ranked academic research institutions and large research-intensive companies, might not work for other types of regions. Nevertheless, there is also strong evidence (Mewes & Broekel 2020) showing that technological complexity is a key driver of regional growth.

## 3. Data source, variables and econometric approach

### 3.1 Data sources and variables

Our main data source is the Amadeus database where we collected firm-level data.[4] The database provides detailed data on firms' financial and productive activities from balance sheets and income statements, and has been widely used by scholars to study firm level performance, financial activity and macro analysis (Kalemli-Ozcan et al. 2015). Despite having a missing values limitation and poor representation of small firms, recent vintages of the database provide wider coverage, which in some countries are closer to the population than older vintages. In order to avoid possible structural changes in the regions' innovation mode, we restricted the analysis to a time frame – from 2012 to 2017, that is close to Capello & Lenzi (2013*a*) publication. Also, we restricted our sample to the manufacturing industries, because older vintages of the database have poor coverage of the service industries.

We began by downloading information for all firms, and after a cleaning procedure due to missing data on firms' location and economic data, we ended up with 150,712 firms distributed across 161 NUTS II regions and 19 European countries.[5] In order to classify the 161 NUTS II regions regarding their innovation mode, we followed Capello & Lenzi (2013*a*).

With these data we constructed the variables that enter in the regressions. Our dependent variable is firm productivity growth. We use the value added per worker, which is a measure of labour productivity and we calculate the log difference of the value added per worker between *t* and *t-1*. Value added was deflated by the country-specific GDP deflator collected from the Eurostat portal. Our main explicative variables are the regional innovation mode, namely the five types as identified by Capello & Lenzi (2013*a*), and for each of them an indicator variable was created.

As control variables, we included the lagged value of firm's productivity, specifically in *t-2*, as productivity growth is largely determined by past productivity, firm size, measured by the log of the number of employees in *t-1* and the log of firm age (Coad et al. 2016) in order to control for differences in firms' resources, capabilities and experience. By lagging the variables, we expect to mitigate potential endogeneity problems. We also add dummy variables for the sector in which the firm operates by using Bogliacino & Pianta (2016) revised version of Pavitt (1984) sectoral taxonomy, as well as controls for time effects. Table 1 shows the descriptive statistics of the sample.

[4] The Amadeus database is now the Orbis Europe database.

[5] The countries in the sample are: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Finland, France, Germany, Italy, Lithuania, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden.

Table 1: Descriptive Statistics

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Dependent variable | | | | | |
| Productivity Growth | 274,439 | 0.553 | 0.904 | -7.646 | 8.041 |
| Regional innovation mode | | | | | |
| Science-based | 274,439 | 0.051 | 0.220 | 0 | 1 |
| Applied-science | 274,439 | 0.103 | 0.304 | 0 | 1 |
| Applied-Smart-Tech | 274,439 | 0.031 | 0.174 | 0 | 1 |
| Applied-Smart-Creative | 274,439 | 0.322 | 0.467 | 0 | 1 |
| Imitative | 274,439 | 0.492 | 0.499 | 0 | 1 |
| Control variables | | | | | |
| Productivity *t-2* | 274,439 | 3.026 | 1.272 | -7.674 | 12.509 |
| Size *t-1* | 274,439 | 2.343 | 1.262 | 0.693 | 12.133 |
| Age | 274,439 | 2.926 | 0.681 | 0 | 6.574 |
| Science-dominated industries | 274,439 | 0.072 | 0.259 | 0 | 1 |
| Specialised-supplier industries | 274,439 | 0.160 | 0.366 | 0 | 1 |
| Scale and information-intensive industries | 274,439 | 0.215 | 0.412 | 0 | 1 |
| Supplier-dominated industries | 274,439 | 0.552 | 0.497 | 0 | 1 |

It is worth noting the large variation in the mean and standard deviation of the firm level variables Productivity and Size, which are larger than the corresponding statistics of the dependent variable. On one hand, these statistics show strong heterogeneity across firms, as expected, and, on the other hand, that productivity growth has a lower dispersion than productivity level. The great variability in terms of firm's size, age and efficiency suggests that firms follow different paths of performance, which should affect productivity growth.

Regarding the distribution across industries, there is a good balance in the representation of each industry type in the sample in that the distribution of our sample follows what has been found in previous studies (Bogliacino & Pianta 2016), with Science-dominated industries being less frequent and the Supplier-dominated industries more frequent. Regarding the sample the distribution across regions we observe a similar pattern, that is, the more scientific intensive regions are less frequent, 5% of the regions, and the Imitative regions are the most frequent, nearly 50% of the regions in the sample.

Table 2 shows the t-tests of mean differences for the dependent variable and the control variables firm Size and Age across regional innovation modes. Overall, the findings indicate that firms located in different regions are significantly diverse in terms of size, age and performance, measured by productivity growth.

Table 2: T-tests of mean differences of main variables by regional innovation mode

| Variable | Regional innovation mode | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Science-Based | Applied-Science | | Applied-Smart-Tech | | Applied-Smart-Creative | | Imitative | |
| | | Mean | Diff | Mean | Diff | Mean | Diff | Mean | Diff |
| Productivity Growth | -0.079 | 0.480 | -0.559*** | 0.201 | -0.280*** | 0.388 | -0.467*** | 0.505 | -0584*** |
| | (1.031) | (1.057) | | (0.568) | | (0.941) | | (0.939) | |
| Size *t-1* | 2.674 | 2.236 | 0.438*** | 2.925 | -0.251*** | 2.216 | 0.458*** | 2.383 | 0.291*** |
| | (1.503) | (1.266) | | (1.549) | | (1.182) | | (1.249) | |
| Age | 2.650 | 2.577 | 0.073*** | 3.492 | -0.842*** | 2.855 | -0.205*** | 2.507 | 0.143*** |
| | (1.064) | (0.644) | | (0.833) | | (0.833) | | (0.995) | |

Notes: standard deviations are in parenthesis. The t-tests are performed against the Science-based regional innovation mode.

*** 1% significance level

We can observe that the mean productivity growth in the Science-Based regions has a negative value over the 2012-2017 period. The Imitative mode is the one with the highest mean value, with 0.505, followed by the Applied-Science mode with a mean growth of 0.480. This shows clear differences in productivity growth across regions and that applied and imitative modes of innovation may well be playing a key role on firms' productivity.

Regarding the remaining variables, we also observe statistically significant differences between each region and the Science-Based one, showing clear differences across regions. In our sample, firms in the Applied-Smart-Tech regions are larger and older than the entire sample. In turn, firms in Applied Science, Applied Smart-creative and Imitative regions are, on average, smaller, younger and with less internal scientific knowledge capabilities than firms in Science-Based regions, suggesting that productivity differentials may well be explained by the way firms are able to take advantage of existing resources and potential knowledge spillovers.

### 3.2 Econometric approach

In order to analyze the role of regional innovation mode on firms' productivity we apply a quantile regression technique. Quantile regression has been frequently used in studies that aim to investigate firms' performance overall (Barbosa & Louri 2005) or in particular the distribution of returns to innovation (Coad et al. 2016, Barbosa & Faria 2022). Quantile regression is adequate to investigate phenomena in which it is relevant to analyze the full (conditional) distribution of the dependent variable, instead of just focusing on the average effects of independent variables. In the case of productivity analysis and innovation related productivity variations, one should expect innovation induced heterogenous effects across the productivity distribution. Thus, quantile regression may show whether being located in a region with a particular innovation mode exerts a significant influence on one tail of the distribution but not on the other. In particular, it allows us to assess whether a productivity gap between laggard and frontier firms is being widened or shortened (Barbosa & Faria 2022). The standard least-squares assumption of normally distributed errors does not hold for data with such characteristics.

Although quantile regression computation requires linear programming methods, the quantile regression estimator is asymptotically normally distributed, more robust to outliers than the OLS regression, and its semi-parametric nature avoids assumptions about the parametric distribution of the error process (Barbosa & Faria 2022, Koenker et al. 2018). To deal with non-normally distributed errors we apply a bootstrap resampling approach, based on 100 replications, to estimate the entire variance-covariance matrix of the estimators. Another important point is that the full sample is used for every quantile regression and not just the observations belonging to marginal quantiles. This implies that all covariates are valid predictors in all quantiles.

## 4. Impact of regional innovation mode on firms' productivity

In this section, the empirical results related to the relationship between regional innovation mode and firms' productivity are shown. We begin by presenting empirical results based on all firms, regions, and countries. Our focus is on the direct impact of the Capello & Lenzi (2013a) regional innovation taxonomy in explaining variability on productivity at firm-level, controlling for other factors with power to drive firms' productivity.

We proceed to address and discuss the robustness of the results. For that, the models are re-estimated using several different partitions of the data, which allows us to uncover potentially heterogeneous relationships between regional innovation mode and productivity and, hence, to enlarge our knowledge on the mechanisms by which regional innovation modes foster productivity gains. These partitions are based on macroeconomic context, firms' size, and firms' age.

### 4.1 All firms and regions

Table 3 presents the OLS regression estimates in the first column, followed by the quantile regression estimates of the impact of the regional innovation mode on the firms' distribution of labour productivity growth. A first conclusion is that the quantile regression is in fact a better estimation strategy than merely looking at the average value of the distribution. While OLS estimates show a negative effect of each regional innovation mode, quantile regression estimates uncover hidden effects.

Table 3: Estimates of the impact of regional innovation mode on productivity growth in European

| | | Quantiles | | | | |
|---|---|---|---|---|---|---|
| | OLS | 10 | 25 | 50 | 75 | 90 |
| **Regional Innovation modes** | | | | | | |
| Science-based | -0.144*** (0.006) | -0.251*** (0.004) | 0.344*** (0.004) | -0.254*** (0.008) | 0.019** (0.009) | 0.280*** (0.009) |
| Applied-science | -0.126*** (0.005) | -0.436*** (0.011) | -0.165*** (0.005) | -0.006** (0.003) | 0.053*** (0.004) | 0.064*** (0.005) |
| Applied-smart-tech | -0.135*** (0.006) | -0.198*** (0.005) | -0.370*** (0.005) | -0.389*** (0.009) | 0.043*** (0.007) | 0.275*** (0.006) |
| Applied-smart-creative | -0.058*** (0.003) | -0.239*** (0.008) | -0.119*** (0.003) | -0.017*** (0.003) | 0.056*** (0.003) | 0.218*** (0.005) |
| Control variables | | | | | | |
| Productivity$_{t-2}$ | -0.102*** (0.002) | -0.060*** (0.002) | -0.043*** (0.001) | -0.072*** (0.001) | -0.105*** (0.001) | -0.170*** (0.003) |
| Age | 0.018*** (0.002) | 0.056*** (0.004) | 0.016*** (0.002) | 0.011*** (0.001) | -0.001 (0.002) | -0.005 (0.003) |
| Size$_{t-1}$ | -0.001 (0.001) | -0.001 (0.001) | 0.000 (0.001) | -0.001 (0.001) | 0.000 (0.001) | -0.001* (0.001) |
| Constant | -0.062*** (0.008) | -0.838*** (0.012) | -0.502*** (0.011) | -0.184*** (0.007) | 0.225*** (0.007) | 0.741*** (0.018) |
| R2 / Pseudo-R2 | 0.533 | 0.31 | 0.37 | 0.40 | 0.41 | 0.34 |
| N | 274,439 | 274,439 | 274,439 | 274,439 | 274,439 | 274,439 |

Notes: Standard errors are computed by bootstrap based on 100 replications. Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. *Imitative* is the innovation type omitted. Time and sectoral dummies are included. Manufacturing firms.

Our results show that the regional innovation mode has explanatory power over firms' productivity growth, thereby, confirming the conceptual relevance of the Capello & Lenzi (2013a) framework. Specifically, we found that the benefits from the local innovation mode are heterogenous across the productivity distribution, with fast-growing productivity firms, located in the right end of the distribution, being those that are reaping the benefits from local innovation conditions, comparatively to firms located in imitative regions. Thus, our results corroborate recent extant evidence (Chen et al. 2016, Guarascio & Tamagni 2019, Audretsch & Belitski 2020, Caloghirou et al. 2021, Barbosa & Faria 2022, Lehmann et al. 2022) in that R&D and innovation activities have heterogenous effects across firms.

Moreover, our estimates provide support to the importance of scientific knowledge to induce productivity gains, as shown in previous studies (Chen et al. 2016, Pfister et al. 2021). Our estimates show that the Science-based innovation mode has positive and significant impact, notably among the fast-growing productivity firms. In this regard, our findings provide strong support to the link between science and productivity, as advocated in recent studies of regional growth (Mewes & Broekel 2020), at least in the case of manufacturing industries.

Estimates in Table 3 also provide support to the contention that other modes of doing innovation, namely by Smart-Tech and Smart-Creative applications can also be a viable path to economic growth as advocated by Capello & Lenzi (2013a). In all, the estimates show that productivity gains are larger from more innovative ways of doing innovation than from mere imitation, but these gains are only being attained by the most efficient, hence capable firms (i.e., firms in the higher quantiles of the productivity growth distribution). Performance level and capabilities are an a priori condition to benefit from those innovation regional modes. These results are consistent with the argument that firms with more internal capabilities benefit more from knowledge spillovers (Cohen & Levinthal 1990). In turn, slow and medium-growing productivity firms seems to be able to reap benefits when located in imitative regions, indicating that in these regions a kind of caching-up process could be at work. In these regions, slow or medium-growing productivity firms appear to profit, comparatively more than other firms, from high entrepreneurship, creativity, attractiveness and imitative innovation. This suggests that regions of an imitative mode of doing innovation are a fertile space to generate productivity gains for slow and medium-growing productivity firms.

Another important finding relates to the moderating role of firm-specific effects. Age and internal capabilities proxied by ex-ante productivity level seem to be significant drivers of productivity growth, regardless of the innovation regional mode where the firm is located. Ex-ante better performing firms attain small productivity growth rate, regardless of its position on the productivity growth distribution, suggesting that a productivity catching-up process is at work over the entire distribution of productivity growth. Moreover, the positive role of age in driving productivity growth fades away for fast-growing productivity firms, suggesting that the pool of knowledge and innovation capabilities at regional level could have more power in engendering productivity gains. These findings corroborate the importance of regional innovation mode of doing innovation in engendering heterogenous productivity gains.

### 4.2 Robustness checks

Some previous research has found that differences of impact of innovation on productivity can also be explained by the macro-economic context in which regions are located (Crowley & McCann 2018, Hashi & Stojčić 2013). Therefore, we test for the robustness of our results by dividing our sample in three main areas: dynamic innovation regions (regions in Northern and Central Europe); Mediterranean regions (regions in Spain, Portugal, Italy); and transition regions (regions in Eastern European countries that joined the EU after 2004 and Eastern Germany regions). Table 4 shows the estimates for these three main areas.

Overall, the results indicate that the macro-economic context affects the way firms reap benefits from external knowledge at regional level. There is a clear divide between Northern and Centre regions vis-a-vis the other European regions, either Southern and Eastern. In the case of the Northern and Centre regions, which are mostly characterized by the Science-Based territorial innovation mode, we do not observe productivity gains linked to their territorial innovation pattern. The only exception being the slow-growing productivity firms located in the Applied-Science regions. This is in line with previous studies that found that smaller firms are more dependent on external knowledge sources (Busom & Vélez-Ospina 2017, Speldekamp et al. 2020, Caloghirou et al. 2021). High performers, i.e., firms located in the upper band of the productivity distribution do not show up as benefiting from local spillovers associated to the innovation regional mode, comparatively to the Imitative mode. This is consistent with the idea that larger firms relying more on scientific knowledge are less dependent on local knowledge (Fitjar & Rodríguez-Pose 2013, Baum et al. 2019).

Regarding the other European regions Southern and Eastern-, our estimates show a different outcome, one in which the more innovative territorial innovation modes are playing an important part in influencing local firms' productivity. While we observe differences in the relative importance of each innovation mode across main economic region, we also find that benefits are not equally distributed across firms. In general, only the fast-growing productivity firms are enjoying benefits from local spillovers, comparatively to similar firms located in Imitative regions. An exception are the firms located in the Science-Based innovation mode regions located in the Mediterranean countries. Here, all firms, i.e., across the entire productivity distribution are enjoying productivity gains. This result not only shows the power of local conditions in shaping firms' growth but also the importance of science to do so, and providing supporting evidence to previous studies such as Mewes & Broekel (2020), Tödtling et al. (2022) or Pfister et al. (2021).

Table 4: Estimates of the impact of regional innovation mode on productivity growth in European firms by main economic region

| | Quantiles | | | | |
|---|---|---|---|---|---|
| **Panel A: Northern and Centre regions** | 10 | 25 | 50 | 75 | 90 |
| Science-based | -0.066*** | -0.169*** | -0.204*** | -0.135*** | -0.137*** |
| | (0.009) | (0.009) | (0.005) | (0.011) | (0.010) |
| Applied-science | 0.345* | 0.057 | 0.070 | -0.762*** | -1.077*** |
| | (0.190) | (0.179) | (0.266) | (0.211) | (0.229) |
| Applied-smart-tech | -0.034*** | -0.152*** | -0.180*** | -0.117*** | -0.132*** |
| | (0.009) | (0.010) | (0.009) | (0.011) | (0.013) |
| Applied-smart-creative | -0.074*** | -0.174*** | -0.081*** | -0.040*** | -0.076*** |
| | (0.010) | (0.007) | (0.006) | (0.008) | (0.008) |
| Constant | -0.287*** | 0.286*** | 0.673*** | 1.017*** | 1.167*** |
| | (0.026) | (0.039) | (0.022) | (0.016) | (0.017) |
| Pseudo R2 | 0.37 | 0.34 | 0.25 | 0.22 | 0.35 |
| N | 54,858 | 54,858 | 54,858 | 54,858 | 54,858 |
| **Panel B: Mediterranean regions** | | | | | |
| Science-based | 0.272*** | 0.319*** | 0.447*** | 0.658*** | 0.462*** |
| | (0.035) | (0.012) | (0.051) | (0.016) | (0.021) |
| Applied-science | -0.140*** | -0.074*** | -0.036*** | -0.015*** | 0.010*** |
| | (0.015) | (0.005) | (0.003) | (0.004) | (0.007) |
| Applied-smart-creative | -0.079*** | -0.056*** | -0.024*** | -0.006** | 0.017*** |
| | (0.005) | (0.003) | (0.001) | (0.003) | (0.004) |
| Constant | -0.948*** | -0.550*** | -0.213*** | 0.167*** | 0.803*** |
| | (0.014) | (0.008) | (0.007) | (0.010) | (0.014) |
| Pseudo R2 | 0.45 | 0.53 | 0.56 | 0.55 | 0.43 |
| N | 174,197 | 174,197 | 174,197 | 174,197 | 174,197 |
| **Panel C: Transition economy regions** | | | | | |
| Science-based | -0.057** | -0.030 | 0.003 | 0.026* | 0.068* |
| | (0.025) | (0.021) | (0.020) | (0.014) | (0.036) |
| Applied-science | -0.347*** | -0.104*** | 0.059*** | 0.301*** | 0.324*** |
| | (0.016) | (0.012) | (0.009) | (0.010) | (0.012) |
| Applied-smart-creative | -0.313*** | -0.142*** | -0.074*** | 0.219*** | 0.206*** |
| | (0.017) | (0.013) | (0.009) | (0.009) | (0.012) |
| Constant | -1.239*** | -0.518*** | -0.107*** | 0.067*** | 0.496*** |
| | (0.054) | (0.021) | (0.019) | (0.018) | (0.040) |
| Pseudo R2 | 0.24 | 0.27 | 0.32 | 0.35 | 0.33 |
| N | 45,384 | 45,384 | 45,384 | 45,384 | 45,384 |

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Standard errors are computed by bootstrap based on 100 replications. Significance levels: *, 10%; **, 5%; ***, 1%. *Imitative* is the innovation mode omitted. Time and sectoral dummies are included. Applied Smart-Tech region is omitted due to lack of observations. Manufacturing firms.

In order to check further the robustness of our results, the model was re-estimated for additional sub-samples. Tables 5 and 6 present the results with the sample divide by firm size and firm age, respectively, as important drivers of firms' innovation and growth (Coad et al. 2016). Firm size sample partition was divided in three categories: small size firms when the firm has between 1 and 10 employees, medium size firm when it has between 11 and 250 employees, and large size firm when it has 251 or more employees. We defined young firms as those with 10 years old or less, and as old firms all the others.

Table 5: Estimates for productivity growth in European firms by firm size

| | Quantiles | | | | |
|---|---|---|---|---|---|
| **Panel A: Small-size firms** | 10 | 25 | 50 | 75 | 90 |
| Science-based | -0.301*** | -0.238*** | -0.059** | 0.202*** | 0.465*** |
| | (0.018) | (0.024) | (0.025) | (0.054) | (0.025) |
| Applied-science | -0.560*** | -0.244*** | -0.059*** | 0.013 | 0.085*** |
| | (0.017) | (0.008) | (0.004) | (0.010) | (0.014) |
| Applied-smart-tech | -0.215 | -0.366*** | -0.364*** | 0.007 | 0.379** |
| | (0.183) | (0.053) | (0.042) | (0.206) | (0.160) |
| Applied-smart-creative | -0.279*** | -0.124*** | -0.030*** | 0.034*** | 0.116*** |
| | (0.007) | (0.006) | (0.002) | (0.006) | (0.011) |
| Constant | -0.744*** | -0.401*** | -0.103*** | 0.493*** | 1.002*** |
| | (0.044) | (0.027) | (0.011) | (0.019) | (0.020) |
| Pseudo R2 | 0.26 | 0.32 | 0.37 | 0.38 | 0.30 |
| N | 107,306 | 107,306 | 107,306 | 107,306 | 107,306 |
| **Panel B: Medium-size firms** | | | | | |
| Science-based | -0.279*** | -0.367*** | -0.298*** | 0.002 | 0.223*** |
| | (0.007) | (0.004) | (0.012) | (0.008) | (0.011) |
| Applied-science | -0.371*** | -0.120*** | 0.025*** | 0.088*** | 0.084*** |
| | (0.011) | (0.008) | (0.004) | (0.005) | (0.009) |
| Applied-smart-tech | -0.229*** | -0.382*** | -0.398*** | 0.052*** | 0.224*** |
| | (0.007) | (0.005) | (0.010) | (0.011) | (0.013) |
| Applied-smart-creative | -0.215*** | -0.113*** | -0.011*** | 0.060*** | 0.269*** |
| | (0.007) | (0.005) | (0.002) | (0.002) | (0.004) |
| Constant | -0.849*** | -0.560*** | -0.238*** | 0.074*** | 0.474*** |
| | (0.016) | (0.015) | (0.011) | (0.013) | (0.022) |
| Pseudo R2 | 0.35 | 0.40 | 0.43 | 0.44 | 0.39 |
| N | 155,018 | 155,018 | 155,018 | 155,018 | 155,018 |
| **Panel C: Large-size firms** | | | | | |
| Science-based | -0.079*** | -0.179*** | -0.200*** | -0.137*** | 0.007 |
| | (0.029) | (0.010) | (0.022) | (0.010) | (0.018) |
| Applied-science | -0.271*** | -0.049** | 0.155*** | 0.226*** | 0.409*** |
| | (0.053) | (0.024) | (0.026) | (0.023) | (0.041) |
| Applied-smart-tech | -0.004 | -0.172*** | -0.279*** | -0.147*** | -0.074*** |
| | (0.026) | (0.010) | (0.019) | (0.017) | (0.019) |
| Applied-smart-creative | -0.124*** | -0.118*** | 0.013 | 0.131*** | 0.322*** |
| | (0.023) | (0.010) | (0.021) | (0.019) | (0.033) |
| Constant | -0.879*** | -0.566*** | -0.372*** | -0.188*** | -0.071* |
| | (0.049) | (0.025) | (0.028) | (0.033) | (0.037) |
| Pseudo R2 | 0.33 | 0.38 | 0.33 | 0.35 | 0.38 |
| N | 12,115 | 12,115 | 12,115 | 12,115 | 12,115 |

* $p$ < 0.1; ** $p$ < 0.05; *** $p$ <0.01. Standard errors are computed by bootstrap based on 100 replications. Significance levels: *, 10%; **, 5%; ***, 1%. *Imitative* is the innovation type omitted. Time and sectoral dummies are included. Manufacturing firms.

Table 6: Estimates for productivity growth in European firms by firm age

| | Quantiles | | | | |
|---|---|---|---|---|---|
| **Panel A: Young Firms** | 10 | 25 | 50 | 75 | 90 |
| Science-based | -0.312*** | -0.340*** | -0.194*** | 0.053 | 0.366*** |
| | (0.026) | (0.017) | (0.021) | (0.034) | (0.040) |
| Applied-science | -0.461*** | -0.192*** | -0.006 | 0.069*** | 0.071*** |
| | (0.021) | (0.016) | (0.010) | (0.013) | (0.019) |
| Applied-smart-tech | -0.215*** | -0.403*** | -0.365*** | 0.045 | 0.395*** |
| | (0.027) | (0.013) | (0.056) | (0.047) | (0.050) |
| Applied-smart-creative | -0.262*** | -0.113*** | -0.016*** | 0.043*** | 0.120*** |
| | (0.012) | (0.008) | (0.003) | (0.006) | (0.011) |
| Constant | -0.698*** | -0.271*** | -0.064*** | 0.311*** | 0.868*** |
| | (0.034) | (0.014) | (0.011) | (0.020) | (0.037) |
| Pseudo R2 | 0.28 | 0.34 | 0.39 | 0.40 | 0.31 |
| N | 55,298 | 55,298 | 55,298 | 55,298 | 55,298 |
| **Panel B: Old Firms** | | | | | |
| Science-based | -0.245*** | -0.346*** | -0.269*** | 0.011 | 0.265*** |
| | (0.009) | (0.007) | (0.010) | (0.009) | (0.013) |
| Applied-science | -0.424*** | -0.155*** | -0.004 | 0.045*** | 0.049*** |
| | (0.016) | (0.005) | (0.004) | (0.005) | (0.006) |
| Applied-smart-tech | -0.203*** | -0.375*** | -0.403*** | 0.032*** | 0.251*** |
| | (0.007) | (0.006) | (0.011) | (0.009) | (0.013) |
| Applied-smart-creative | -0.233*** | -0.118*** | -0.017*** | 0.060*** | 0.242*** |
| | (0.007) | (0.004) | (0.002) | (0.002) | (0.005) |
| Constant | -0.870*** | -0.588*** | -0.271*** | 0.157*** | 0.673*** |
| | (0.015) | (0.009) | (0.005) | (0.011) | (0.019) |
| Pseudo R2 | 0.32 | 0.37 | 0.40 | 0.42 | 0.35 |
| N | 219,141 | 219,141 | 219,141 | 219,141 | 219,141 |

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Notes: Standard errors are computed by bootstrap based on 100 replications. Significance levels: *, 10%; **, 5%; ***, 1%. *Imitative* is the innovation type omitted. Time and sectoral dummies are included. Manufacturing firms.

Overall, Table 5 and Table 6 provide very similar findings to those obtained for all firms, showing the robustness of our results. In particular, the evidence shown in both tables tell us that the major beneficiaries from local knowledge spillovers are the fast-growing productivity firms. A result that is consistent across firms of different size-cohorts and vintages, which suggests that accumulating market experience does not offer additional capabilities to reap productivity gains from regional innovation modes. In turn, this evidence highlights the importance of firms' internal capabilities to absorb external knowledge as suggested by Cohen & Levinthal (1990) in order to reap productivity gains from the regional innovation mode.

## 5. Portuguese regional innovation modes: the role of science

As a peripheral country in the context of EU, Portugal has been improving its innovation capabilities over the last two decades and its position in the EU Innovation Index, from a low to moderate innovator during the 2000s to a strong innovator by 2018, and went back to a moderate innovator in the last evaluation in 2022. A better understanding of this evolution requires a more detailed look at innovation modes' diversity across space and the role played by science in changing innovation capabilities and performance at regional level.

Although scientific progress has become a more direct driver of innovation, the interaction between science and economic performance takes various forms in different countries and regions, owing to differences in institutions, research financing, networking and cooperation as a way to search for alternative sources of knowledge, and innovation capabilities.

In order to uncover the specific characteristics of Portuguese regional innovation modes, their evolution, and the potential role of science in shaping economic performance, we collected data for the components of territorial innovation mode as specified by Capello & Lenzi (2013a), namely: (i) conditions for knowledge creation measured by R&D expenditure in the public sector and R&D expenditure in the business sector and conditions for innovation creation, measured by non-R&D innovation expenditures and by SMEs introducing innovations; (ii) pre-conditions for knowledge creation, measured by the population with tertiary education, and pre-conditions for innovation creation, measured by employment in innovative enterprises; and (iii) pre-conditions to benefit from external knowledge measured by innovative SMEs collaborating with others. The regional and local data and indicators use the Nomenclature of Territorial Units for Statistics (NUTS) and come from the Regional Innovation Scoreboard (RIS) and ESPON databases, both run under the auspices of EUROSTAT. The change in the indicators was calculated as a variation rate between 2015 and 2019. Table 7 presents these indicators and their recent evolution for the Portuguese NUTS2 regions.

Table 7: Some indicators of regional innovation modes, NUTS2 regions, Portugal, 20152019

| | Mean 2015-2017 | | | | | Mean 2018-2019 | | | | | Change rate 2015-2019 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Norte | Centro | Lisboa | Alent | Algar | Norte | Centro | Lisboa | Alent | Algar | Norte | Centro | Lisboa | Alent | Algar |
| **Knowledge creation** | | | | | | | | | | | | | | | |
| R&D expenditure in the public sector | 4.415 | 4.494 | 4.713 | 3.492 | 3.818 | 4.525 | 4.428 | 4.686 | 3.541 | 3.675 | 0.057 | 0.000 | 0.018 | 0.037 | -0.050 |
| R&D expenditure in the business sector | 4.046 | 3.876 | 4.125 | 2.835 | 1.296 | 2.649 | 2.591 | 2.691 | 2.025 | 1.087 | -0.027 | 0.000 | -0.037 | 0.055 | 0.133 |
| **Innovation creation** | | | | | | | | | | | | | | | |
| Non-R&D innovation expenditures | 5.080 | 5.186 | 4.588 | 4.926 | 4.872 | 5.182 | 5.230 | 4.594 | 5.038 | 4.970 | 0.040 | 0.014 | 0.018 | 0.047 | 0.034 |
| SMEs introducing product innovations | 4.644 | 4.891 | 4.823 | 4.747 | 4.701 | 4.948 | 5.097 | 5.069 | 5.005 | 4.856 | 0.121 | 0.079 | 0.096 | 0.102 | 0.091 |
| **Pre-conditions knowledge creation** | | | | | | | | | | | | | | | |
| Population with tertiary education | 4.331 | 4.392 | 4.754 | 3.833 | 3.511 | 4.454 | 4.592 | 4.791 | 4.063 | 4.149 | 0.042 | 0.014 | 0.018 | 0.084 | 0.146 |
| **Pre-conditions innovation creation** | | | | | | | | | | | | | | | |
| Employment in innovative enterprises | 4.827 | 5.078 | 4.959 | 4.897 | 4.606 | 4.962 | 5.203 | 5.089 | 5.029 | 4.753 | 0.056 | 0.049 | 0.052 | 0.054 | 0.063 |
| **Pre-conditions to benefit from external knowledge** | | | | | | | | | | | | | | | |
| Innovative SMEs collaborating with others | 4.137 | 4.644 | 4.656 | 4.392 | 3.338 | 4.406 | 4.832 | 4.750 | 4.608 | 3.725 | 0.113 | 0.071 | 0.048 | 0.089 | 0.279 |

Notes: Values are in natural logarithm.

Overall, there is a positive evolution in almost all components and across regions for the period under scrutiny, but there are clear differences in this evolution across regions and components, suggesting heterogeneity on the ways of doing innovation and leveraging science to achieve economic performance.

In particular, the indicators suggest that public investment in science and R&D is essential for knowledge creation. Some regions (Norte, Lisboa and Alentejo) manage to show a stronger focus on knowledge creation based on scientific knowledge. Given that the public R&D investment has a large role in these regions, this would suggest that knowledge tends to be of a more fundamental nature, than the knowledge that is produced more intensively by R&D in the business sector, as it is the case of the Algarve region. Nonetheless, the remarkable decrease in private R&D expenditures over the more recent years indicates that the conditions for knowledge creation are mainly driven from public investment in science and R&D. More importantly, there seems to be a crowding-out effect as increases in public investments in science are absorbed by reductions on private investments or, when the public investment falls the business sector seems to react by increasing investments in science and R&D. These apparent contradictory movements cast some doubts on the ability to leverage the role of public investment in science.

On the other hand, other regions than Lisboa, are experiencing higher changes on pre-conditions to knowledge and innovation creation and pre-conditions to benefit from external knowledge, suggesting a catching-up process regarding the regions' endowments. This seems to be the case of Algarve that appears to improve remarkably on pre-conditions related to tertiary education, employment and firms' collaboration in innovation activities, suggesting that firms in that region leverage the increase in intra-mural R&D expenditures by searching for alternative sources of knowledge based on collaboration and the access to external and more multidisciplinary knowledge.

The Norte region is other case of a significant improvement on firms' collaboration in innovation activities over the period 2015-2019, reinforcing the contention that external and alternative sources of knowledge could leverage and strengthen the role of science in driving economic performance. This region also comprises an increasing local pool of factors leading to innovation creation, namely those based on SMEs introducing product innovations, suggesting that in that region innovation mode has become more market-driven, making science more responsive to business needs and hence fostering the impact of science on economic performance.

The diverse nature, complexity and evolution of innovation modes across Portuguese regions is the main finding, suggesting that there are several channels to link science, innovation and economic performance. Although public R&D appears to have a more prominent role in some regions, the other conditions to innovation creation and to benefit from external knowledge seems to offer a valid and fruitful way to challenge the link between science, innovation and economic performance.

## 6. Conclusions

In this paper we investigated the role of science and regional innovation modes on driving firms' productivity. By building on two different approaches in the literature to the study of productivity, namely the regional approach to innovation patterns and the firm-level approach to firm productivity, we were able to conciliate some contradictory results found in previous studies.

Our findings prove that territorial innovation patterns, specifically the Capello & Lenzi (2013a) taxonomy, are a fruitful concept to describe innovation activities at the regional level and to point out the role of science in driving economic performance. As such, the taxonomy is a helpful tool to characterize regions and formulate public policy. Thereby, we corroborate the notion that productivity gains can also be achieved by local actors exploiting non-scientific knowledge and innovative capacity as advanced by (Capello & Lenzi 2013a,b, 2015).

More importantly, we found that regional innovation patterns are key drivers of firms' productivity and their impact varies across innovation modes. Therefore, our results help to understand the territorial dispersion of productivity and are in line with recent research on regional economic growth (Cartone et al. 2021) in that there are groups of regions with diverse innovation mode but similar growth paths.

In particular, the impact of regional innovation modes on local firms' productivity growth differs not only across innovation modes, but also across the productivity distribution and the main economic area where the regions belong to. Science-Based, Applied-Science, Applied-Smart-Tech and Applied-Smart-Creative regional modes are those with the highest impact on local firms' productivity growth. An important conclusion from our evidence is that it reiterates the importance of scientific knowledge as an input to production activities and economic growth (Cortinovis & Van Oort 2019, Mewes & Broekel 2020, Audretsch & Belitski 2020, Caloghirou et al. 2021, Pfister et al. 2021, Chen et al. 2016).

Another important finding of our study is that the impact of local innovation conditions on productivity growth is not equally distributed across firms. By analysing the firm position in the productivity growth distribution, we found that only the fast-growing, technologically advanced, firms benefit from local knowledge spillovers (Cohen & Levinthal 1990, Audretsch & Belitski 2020, Barbosa & Faria 2022).

However, this result appears to be specific to the EU main economic area. Firms located in the Mediterranean and Eastern Europe regions, which are the peripheral and transition economies regions (Evangelista et al. 2018, Crowley & McCann 2018, Hashi & Stojčić 2013), are those that are benefiting from spillovers specific to the region's innovation mode. For firms located in the Northern and Central Europe, the benefits from local knowledge spillovers are restricted to the slow-growing productivity firms, i.e, located on the left end of the productivity growth distribution, suggesting that a kind of a catching-up process is possible for these firms. An important exception are the firms located in Southern Europe and in regions whose innovation mode is based on scientific knowledge. Here, productivity gains can be observed over the entire productivity growth distribution showing the importance of science to economic growth.

Another key finding is that the most important firm-level characteristic determining the capability of absorbing external knowledge is knowledge itself, as we did not find any differences across firms of different sizes and vintages.

These results have considerable implications for the current design of European Union innovation policies. At the regional level it is clear that regions may follow different growth paths. In particular, given that growth by imitation is also a credible strategy, public policy should not be based on scientific knowledge criterions exclusively. Yet, in order to enjoy productivity gains from local knowledge spillovers, firms need to have internal capabilities that make them get closer to the technological frontier. Therefore, public policy needs also to focus on strengthening firms' internal capabilities, namely related with R&D and with its application, as well as to strength regional innovation conditions.

**Funding**: This paper is financed by National Funds of the FCT – Portuguese Foundation for Science and Technology within the project UIDB/03182/2020.

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