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The drivers of SME innovation in the regions of the EU

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ABSTRACT

European Union (EU) innovation policies have for long remained mostly research driven. The fundamental goal has been to achieve a rate of R&D investment of 3% of GDP. Small and medium-sized enterprise (SME) innovation, however, relies on a variety of internal sources —both R&D and non-R&D based— and external drivers, such as collaboration with other firms and research centres, and is profoundly influence by location and context. Given this multiplicity of innovation activities, this study argues that innovation policies fundamentally based on a place-blind increase of R&D investment may not deliver the best outcomes in regions where the capacity of SMEs is to benefit from R&D is limited. We posit that collaboration and regional specificities can play a greater role in determining SME innovation, beyond just R&D activities. Using data from the Regional Innovation Scoreboard (RIS), covering 220 regions across 22 European countries, we find that regions in Europe differ significantly in terms of SME innovation depending on their location. SMEs in more innovative regions benefit to a far greater extent from a combination of internal R&D, external collaboration of all sorts, and non-R&D inputs. SMEs in less innovative regions rely fundamentally on external sources and, particularly, on collaboration with other firms. Greater investment in public R&D does not always lead to improvements in regional SME innovation, regardless of context. Collaboration is a central innovation activity that can complement R&D, showing an even stronger effect on SME innovation than R&D. Hence, a more collaboration-based and place-sensitive policy is required to maximise SME innovation across the variety of European regional contexts.

1. Introduction

For many years and throughout several innovation plans (from the Lisbon Strategy 2000 to Europe 2020) the European Union (EU) has mostly promoted a research-led innovation policy based on a linear model of innovation (Bush, 1945; Maclaurin, 1953). Under this model investment in research and development (R&D) is a fundamental force driving innovation, productivity, and economic growth. The more you invest in R&D, the higher the economic outcomes. Following this approach, the EU has tried to ramp up investment in R&D. It had already given itself a policy target of spending 3% of GDP on R&D in the Lisbon Strategy. This target was renewed in Europe 2020, the strategy that the EU adopted for the 2010–2020 decade in order to address the structural weaknesses of its economy and improve its overall competitiveness and productivity (European Commission, 2010). Europe 2020 included five headline targets. Only one of those targets (the second target) was related to innovation: "3% of the EU's GDP should be invested in R&D" (European Commission, 2010: 3). This has not prevented EU innovation interventions from progressively moving towards a more comprehensive set of multi-dimensional innovation activities and initiatives, such as *SME Instrument, Smart Specialization*, or the recent *Digital Innovation Hubs*. These initiatives have emphasized to a greater extent the role of SMEs and the importance of collaboration for innovation (European Commission, 2015; Simonelli, 2016; Hervás-Oliver et al., 2021a). However, existing evidence still shows low SME engagement in the European innovation effort and unexpected effects from those instruments (Simonelli, 2016; De Marco et al., 2020). Until the end of 2020 the key innovation target remained the 3% R&D investment as a

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percentage of GDP (European Commission, 2010), a headline target which is likely to have benefited large firms more than smaller ones.

The emphasis on R&D of the Europe 2020 strategy, however, overlooked three important dimensions that shape the European innovation landscape. First, small and medium-sized enterprises (SMEs) dominate in Europe. Firms employing fewer than 250 persons make up over 99% of all firms in the EU, Norway, Switzerland, and the United Kingdom (UK). They account for around two-thirds of total employment and contribute to about 56% of total turnover (Papadopoulos et al., 2015). These firms have a far lower tendency and capacity than larger firms to develop in-house R&D and are, in theory, far more dependent on public R&D to compensate for their lack of internal research facilities (Czarnitzki and Hussinger, 2018). Second, despite the general effectiveness in the use of R&D across SMEs (Parrilli and Radicic, 2021, for Europe and the US), SMEs are more market-driven than research-driven and use non-R&D indicators intensively. Instead, SMEs mainly follow non-R&D based innovation processes (e.g., Ortega-Argilés et al., 2009; Hervás-Oliver et al., 2011). As Rammer et al. (2009) point out, in-house R&D activities may be particularly challenging for most SMEs due to high risk exposure, high fixed costs, high minimum investment requirements, and severe financial constraints. As a result, most SMEs prefer investing in non-R&D activities as managerial innovation (i.e., marketing and organizational innovation) and complement it with external sources of knowledge from suppliers, customers, or competitors. This non-R&D approach is especially intense in low- and medium-tech intensive industries (LMT) (Heidenreich, 2009; Trott and Simms, 2017) and in SMEs located in low-tech areas (Chen et al., 2011). Firms in these groups are typically characterized by weak internal innovation capabilities and a strong dependency on external sources of knowledge (equipment or knowledge and information from industry). Third, the linear approach to innovation does not consider the context specificities of regions and the distinct regional innovation systems where SMEs operate (Cooke and Morgan, 1994; Cooke, 2001). Innovation is, however, not evenly distributed across different territories. This aspect stresses the necessity to consider 'place' when developing innovation policies, as pointed out by the innovation system literature (Tödtling and Trippl, 2005; Asheim et al., 2011; Barca et al., 2012; Isaksen and Trippl, 2016; Hervás-Oliver et al., 2019; Parrilli et al., 2020). All in all, this study's challenge consists of assessing whether the 3% research-oriented innovation policy goal fits with the reality of SME innovation across what are heterogeneous regions in Europe.

We posit that understanding SME innovation to drive improvements in policy-making requires considering simultaneously a) R&D and non-R&D activities, especially *collaboration*, and b) the specific regional contexts where SMEs locate. The strong past emphasis on the 'linear model of innovation' may have limited the full implementation of alternative ways of promoting innovation, some of which are more likely to benefit European SMEs. SME-level innovation often depends on more intangible factors, such the quality of the local regional innovation system (Parrilli and Radicic, 2021). Collaboration and networking, both at the firm and institutional level, are fundamental for the generation and diffusion of knowledge at the root of innovation in many SMEs. Innovation in SMEs normally happens because of a myriad of collaborations that involve science and technology agents (STI) as well as those based on learning-by-doing, using and interacting (DUI) (Jensen et al., 2007). Hence, the EU has until now mostly relied on a policy that covers a fraction of the innovation opportunities available within European regions and neglects most actions —driven by non-R&D innovation drivers, internal and external collaboration, non-technological innovation, and the like— at the heart of SME-level innovation.

Consequently, it could be argued that Europe, as a whole, and the EU, in particular, have mainly developed a research-led policy framework —relying on the 'fetish' figure of spending 3% of GDP— rather than a fully-fledged and comprehensive innovation policy (Rodríguez-Pose, 2020). Some steps in that direction have been taken of recent (e.g., European Commission, 2015) through policies and actions such as the creation of the Digital Innovation Hubs (DIHs) (see Hervás-Oliver et al., 2021a). The old and dominant innovation policy paradigm has, however, overlooked much of the action —driven by within-firm developments, internal innovation activities, and different external collaborations— that form the backbone of SME innovation activities.

The question that arises at this point is the extent to which an innovation policy that is primarily reliant on R&D —and especially one reliant on public R&D— as a driver of innovation is the most adequate to deal with the innovation challenges faced by the EU and, in particular, by SMEs in the less developed and innovative regions. In this study we aim to decipher the drivers of SME innovation across European regions, assessing how the characteristics of individual regions shape and moderate how SME innovate. In doing so, we answer three related questions. First, to what extent SME innovation performance is explained by public and/or private R&D investments vis-a-vis other non-R&D type of activities? Second, what is the impact of different modes of innovation for regional innovation? Third, how much regions influence SME innovation? In this process, the study focuses on SMEs, challenging the 3% R&D-based innovation target, by arguing that innovation is a systemic and iterative learning endeavour that is, to some extent, spatially-bounded, in particular in relation to the proactive role of SMEs for innovation. In doing so, the article contributes to the understanding of 1) the critical regional collaborative patterns employed by SMEs that lead to increases in innovation; and 2) other vital internal drivers of regional innovation that raise SME innovation performance across different types of region. To fulfil this study's goal, we use the regional innovation systems, place-based, and SMEs innovation literature as the key conceptual frameworks for the analysis.

The paper addresses this question by focusing on the innovation capacity of SMEs at the regional (NUTS2) level in the years between 2014 in 2017. Specific attention is paid to how these elements combine to generate innovation at the firm-level for SMEs located in regions at different stages of development and position with respect to the technological frontier. Our results show that effective policies need to consider the specific SME innovation activities and their location. *Collaboration* is also an essential innovation activity that complements R&D. Its connection to SME innovation is stronger than that of R&D. We also evidence that SME innovation is place-based and spatially-bounded for both collaboration and R&D. Overall, we provide evidence to guide policies and point towards activities that have mostly remained 'hidden' (i.e., collaborations) but play a fundamental role in how European SMEs innovate. The aim of this article is not to evaluate EU innovation policies but to assess SME innovation performance as a means to understand better what innovation means for SMEs and how important is the specific location of SMEs in their quest to become more innovative. These represent insights that can help build up new and more effective policies.

After this introduction, the paper is organized as follows. Section Two is centred on the main theoretical framework built around the role of regional innovation systems as well as the typical innovation modes employed by their firms. Section Three presents the methodology of the study and includes the explanation of the regional innovation scoreboard (RIS), used here to contextualize our analysis. Section Four dwells on the empirical evidence with special attention to the different types of regions identified in the RIS. A final section of conclusions and policy implication completes this work.

2. A general overview of the EU strategy for innovation

As evidenced by the Europe 2020 Strategy (European Commission, 2010), until recently the EU has persevered on the central idea that innovation is to be achieved by fundamentally increasing investment in R&D to levels of 3% of GDP across the board (Rodríguez-Pose, 2020). This approach to innovation has been progressively complemented by more comprehensive efforts towards promoting innovation involving broader measures (European Commission, 2015; Simonelli, 2016;

Reillon, 2017). In fact, changes associated with the evolution of the Framework Programs (FPs) point towards a turning tide that goes beyond the conceptualisation of innovation as an R&D-led activity. Initiatives such as the Smart Specialization[1] platform are important steps in this direction, as has been the greater emphasis placed by the Horizon-2020 Framework on innovation and close-to-market activities, providing around 10% of the Horizon 2020 (H2020) budget to SMEs. But the reality has been that until the end of 2020 the 3% of GDP R&D objective remained the cornerstone of the EU innovation policy.

To what extent does this EU headline target support SME innovation? According to Simonelli (2016: 2), the empirical evidence on SME engagement in European innovation policies has been disappointing. The engagement of SMEs in Horizon-2020 was lower than in the previous framework programme (FP7). De Marco et al. (2020) also evidence unexpected effects for participating SMEs, even those in the digital sector. Mazzucato and Lazonick (2010) have also been critical of the 3% target as a source of innovation. They argue that it is a blunt indicator that does not contemplate differences in R&D spending across industries, across firms within an industry, and regions. SMEs are particularly disadvantaged by this target, which generally benefits larger firms (Demirel and Mazzucato, 2012). Renda (2015) also found the innovation approach of Europe 2020 too R&D-based. For him, this led to a strategy focused on input rather than impact, which did not take into account the fact that: i) innovation is increasingly collaborative and systemic, rather than single R&D lab-led; and ii) is embedded in regional ecosystems.

Recent evidence on regional innovation systems and SMEs points in the same direction, highlighting how regions moderate innovation (Parrilli et al., 2020) and how SMEs often innovate without necessarily resorting to R&D activities (Alhusen et al., 2021). As Thomä and Zimmermann (2020) stress, SME generally innovate through non-R&D efforts, following the DUI mode of innovation (see Jensen et al., 2007) rather than the STI mode (Hervás-Oliver et al., 2021b). In particular, this non-R&D approach to SME innovation is pervasive, especially in process-innovators and low-tech settings (Rammer et al., 2009) and in what are known as *innovation-without-R&D* regions, as Apa et al. (2020) show for Veneto in Italy. We elaborate on the role of regions for innovation and the specific features of SME innovation in the Sections below.

3. Regional heterogeneity and SME innovation

Systemic innovation is increasingly becoming viewed as a key driver for SME innovation. SMEs do not typically have the capacity to invest large sums in R&D departments oriented to produce new knowledge and innovation outputs in-house (Lundvall, 1992; Morgan and Cooke, 1998; Asheim and Gertler, 2005). Within this paper, we connect systemic innovation to regions as we argue that the innovative capacity of SMEs often derives from the characteristics of the regions where they are located. SMEs are generally locally rooted to a far greater extent than the larger and more footloose multinational companies. The former often develop a two-way relationship with their region. On the one hand, the regional economic and innovation performance depends on the performance of a critical mass of local firms. On the other, the regional context-specificity (e.g., relative development of institutions and technological infrastructure) simultaneously shapes local firms' capacity to innovate (Cooke, 2001; Doloreux and Parto, 2005; Asheim and Gertler, 2005; Rodríguez-Pose and Crescenzi, 2008; Parrilli et al., 2020). We consider that the regional institutional architecture matters in determining the specific innovation capacity of local SMEs. This idea is linked with the 'regional innovation systems' approach that dwells on the importance of these systems for locally-based enterprises, mainly clusters of small and medium-sized firms that, individually, do not have sufficient resources to develop their own independent R&D and innovation activities (Parrilli et al., 2010; Trippl, 2011; Hervás-Oliver et al., 2017; De Noni et al., 2018; Parrilli and Radicic, 2021).

Different typologies of regional innovation systems (i.e., entrepreneurial, institutionalized, or grassroots-based regional innovation systems) are identified. Within these typologies, regional dynamism, local institutions, and scientific and technological infrastructure play different roles as drivers of both the way regions go about innovation and their overall capacity to innovate (Cooke et al., 2004). They also set the bases for the specific innovation pathways and trajectories of their own regional production systems (Camagni and Capello, 2013; Alberdi et al., 2016; Capello and Lenzi, 2019).

Some scholarly contributions have taken a qualitative, systematic and policy-oriented approach to regional innovation systems (e.g., Asheim and Gertler, 2005; Asheim et al., 2011; Isaksen and Trippl, 2016, among others). Others have produced quantitative approaches and assessments (e.g., Iammarino, 2005; Leydesdorff and Fritsch, 2006; Fritsch and Slavtchev, 2011). Apart from recent contributions (Parrilli et al., 2020), most of these studies have focused on individual country analyses, rarely producing cross-country or panel data assessments and comparisons. This opens the floor for a kind of research that can shed further light on innovation dynamics involving firms and their relevant contexts, in particular in relation to the different types of regional innovation contexts/systems in which SMEs operate.

These different types of regional contexts or systems are characterized by diverse industrial settings, where the classic R&D-led linear model is far from the only innovation paradigm/approach followed by firms. One of the key principles of Lundvall's (1992) innovation systems framework is that innovation is an interactive learning process that is socially- and territorially-embedded and culturally- and institutionally-contextualized. This perspective constitutes a critique to the linear model that equates innovation capacity with R&D intensity. The interactive learning process embraces a whole gamut of actors: from traditional industries and SMEs to non-R&D activities, functioning in any type of place, including less advanced and/or peripheral regions. Therefore, the type of knowledge base that exists in each particular region, as a key component of its specificity, also indicates how innovation can differ from place to place (Asheim and Coenen, 2006). As these scholars indicate, an analytical knowledge base refers to industrial settings where scientific knowledge is highly important, firms develop R&D activities, and interact with universities. This case is typically found in advanced regions with a high endowment of IT, biotech, or other advanced industries. A more synthetic knowledge base refers to industrial settings where innovation takes place mainly through problem-solving, non-R&D activities, and knowledge embodied in machinery and equipment, with an intense interaction process along the supply chain (customers, suppliers, competitors). In this setting tacit knowledge becomes crucial and it is recombined through learning-by doing, by-using, and by-interacting. This is typically encountered in intermediate or peripheral regions with a high presence of low-tech or traditional industries (Ibid.).

Different industrial settings and knowledge bases in regions directly influence how local firms innovate. As shown by Parrilli et al. (2020), different regional specificities influence the innovation pattern developed by local firms, especially local SMEs. In general, in less advanced or peripheral regions endowed with low- and medium-low technology-intensive industries (LMT), SMEs innovate by applying non-R&D innovation activities. In this context, SMEs are likely to depend on external sources of knowledge —from public R&D to collaborating with other economic actors, both within and outside the supply-chain (Fitjar and Rodríguez-Pose, 2013)— that counteract the lack of in-house capabilities. They become strongly dependent on their regional innovation systems to achieve any type of innovation (Asheim and Coenen, 2006). Typically found in peripheral or less advanced regions, albeit not restricted to them, those SMEs in low- and medium-tech industries follow a non-R&D innovation pattern (Heidenreich, 2009;

[1] https://ec.europa.eu/regional_policy/sources/docgener/guides/smart_spec/strength_innov_regions_en.pdf

Hervás-Oliver et al., 2011; Thomä, 2017). The literature uses the terms *hidden* (Barge-Gil et al., 2011) or *neglected* innovators (Arundel et al., 2008), collectively accounting for around 50% of innovation output in European regions (European Commission, 2010). These non-R&D innovators work through problem-solving, experimentation on the shop floor, reverse engineering, and other activities that substitute for R&D. Besides, they are intensive in the use of embodied knowledge (equipment and machinery) and develop intense inter-firm interaction or networking from which they learn-by-doing and by-interacting (Hervás-Oliver et al., 2015; Apanasovich et al., 2016).

4. Regional settings and modes of innovation

Following this chain of thought, the type of region and its knowledge base is also connected to the particular modes of innovation (internal innovation activities and collaborations) developed by SMEs. Putting together the importance of R&D expenditure (Greunz, 2005), as well as that of other non-R&D activities (e.g. design and trademarks) (Parrilli and Alcalde 2016; Flikkema et al., 2019) for firm-level innovation, and echoing the recent work of Parrilli et al. (2020) on the heterogeneity of business innovation across regions, we posit in particular that SME innovation relies on a complex set of different modes of innovation that, in no small part, are contingent upon the spatial specificities of the places where they locate. We contend that differences in regional innovation systems —based on the technological and institutional capabilities managed by the economic agents within regions— determine to a large extent the capacity of individual SMEs innovate. In particular, we follow a recent relevant strand of the literature on innovation systems that identified two main forms of promoting innovation; the first is based on exhaustive investment in R&D, scientific human capital, and infrastructure (STI, for science and technology-based innovation); the second on learning-by-doing, by-using and by-interacting (DUI). This strand of literature finds that in many areas of Europe factors such as doing, using, and interacting (the DUI mode) represented the main mode of innovation for SMEs. In other places, by contrast, the STI mode is a better predictor of innovation at firm level. The latter mode, however, requires more advanced knowledge and highly skilled/scientific staff that work within R&D departments and that interact relatively little with other departments of the company (e.g., procurement, production, marketing, logistics). This model also relies on collaborations with scientific partners (universities and technology centres). In contrast, DUI depends on iterative and interactive practices and learning-by-doing within the firm as well as along the supply chain (suppliers, service providers, and clients).

We contend that SMEs in more innovative regions will be more likely to adopt a scientific/analytical and codified approach to knowledge, implying a more intense use of R&D-based activities —and particularly private R&D— driven by a higher accessibility to financial and infrastructural resources, a greater capacity to exploit private research efficiently (vis-à-vis public R&D), a more highly qualified human capital, and a greater overall absorptive capacity (Cohen and Levinthal, 1990; Zahra and George, 2002). This view is aligned with research on high-technology clusters and regions, such as Medicon Valley in Denmark/Sweden (Moodysson et al., 2008), Cambridgeshire (Garnsey and Heffernan, 2005), and Baden-Württemberg (Strambach and Klement, 2013), amongst others. In these advanced innovative regions, the interactive pattern is especially focused on promoting collaborations with science- and technology-oriented actors (universities and research labs). Supply chain collaborations are also likely to matter in these areas as a complementary driver of SME innovation. Such collaborations are mostly focused on the delivery of high-quality components that respond to technical specifications set by companies in leading regions (Fitjar and Rodríguez-Pose, 2017). In general, these regions produce the most innovative ecosystem for SMEs.

Less innovative and competitive regions (peripheral) are, according to recent evidence (Rodríguez-Pose and Wilkie, 2019; Parrilli et al., 2020; Rodríguez-Pose et al., 2021), less likely to benefit from R&D activities. In this type of region, the returns of public R&D may be affected by general inefficiency (Rodríguez-Pose, 2001) as well as by the Matthew's vicious circle of substituting private for public R&D (Antonelli and Crespi, 2013). Nevertheless, some variations are expected between different types of lagging innovators (regions). Some of them are making strong efforts to catch-up with the most innovative regions (Camagni and Capello, 2013; Parrilli et al., 2016). In these areas non-R&D-based innovation activities (e.g., design or equipment renewal) can play a crucial role in enhancing the innovation capacity and output of firms (Hervás-Oliver and Albors, 2009; Hervás-Oliver et al., 2011; Flikkema et al., 2019). SMEs in these regions will also rely on inter-firm collaboration to exchange tacit and synthetic knowledge, and to learn collectively by-doing, by-using, and by-interacting with similar agents (Lundvall, 1992; Apanasovich et al., 2016). This approach can also generate a positive impact on innovation performance (Thoma, 2017). This would imply a less intensive adoption of scientific and technological interactions and, therefore, a lower influence by universities and scientific labs on the innovation performance of SMEs than in core areas (Chen et al., 2011; Malaver, 2013). Weaker human capital and technology infrastructure endowments will also limit the capacity to innovate of SMEs in these areas (Parrilli et al., 2016; 2020). Overall, the dominant type of collaboration for SMEs in less developed areas will be based on non-R&D innovation activities and on inter-firm collaboration processes within the supply-chain. They will be less based on scientific resources (Castaldi, 2015; Hervás-Oliver et al., 2015; 2018).

In accordance with the literature presented, we develop four hypotheses aimed at explaining variations in SME innovation in different regional contexts. The aim is assessing the role of the internal and external factors as drivers of SME innovation performance:

Hypothesis 1. SME innovation output depends both on internal and external drivers, including SME collaborations and scientific contributions, R&D, and non-R&D factors.

Hypothesis 2. SME innovation output is less significantly correlated to public R&D, especially in regions far away from the technological frontier.

Hypothesis 3. In relation to regional characteristics, the most innovative regions in Europe rely mostly on private R&D, non-R&D activities and SME collaborations with both scientific and supply chain-based agents.

Hypothesis 4. Less innovative regions rely mostly on SME collaborations.

5. Methodology

5.1. The regional innovation scoreboard

We use European regions as the unit of analysis. We employ indicators extracted from the European Innovation Scoreboard. These indicators have been regionalized for the year 2017 by the Regional Innovation Scoreboard (RIS) initiative, produced by the European Commission. The RIS aims to capture the capacity of different European regional innovation systems. The RIS methodology uses primarily CIS (Community of Innovation Survey) data to build regional indicators and distinguish between advanced (leader and strong innovators) and less-advanced regions (moderate and modest innovators). The RIS focuses on SMEs indicators to capture differences in SME innovation across regions. This is crucial for this paper, as the aim is to identify the drivers of SME innovation in European regions by firms that are not individual agents in an atomized market, but whose innovation capacity depends to a large extent on the characteristics and functioning of its local technological and institutional ecosystem (Cooke, 2001; Asheim and

Gertler, 2005; Doloreux and Parto, 2005; Hervás-Oliver and Albors, 2007; Rodríguez-Pose and Crescenzi, 2008; Isaksen and Trippl, 2016; Parrilli and Alcalde, 2016; ; De Noni et al., 2018). Regions in Europe differ in their innovative capacity because of their distinct resource endowments depending on, among other factors, their levels of development. Variation in development affect the innovation capacity of SMEs located in each territory. Consequently, we raise the research question of whether different types of innovation patterns —e.g., internal and external (collaboration) for innovation— have different meaning in distinctive contexts/regions, based on their institutional environments, resources, and capabilities. Past research suggests that this is likely to be the case. Factors such as the relevance of close geographical proximity for scientific collaboration (Tödtling et al., 2012) or global collaborations along the supply chain (Fitjar and Rodríguez-Pose, 2013; Grillitsch and Trippl, 2014) have been brought to the fore as key drivers of SME innovation. With few exceptions (e.g., Parrilli and Radicic, 2021; Parrilli et al., 2020), most research focuses on specific cases (country and industry level), eluding a more exhaustive/systematic association between the most effective types of collaborations and the institutional and technological contexts in which they operate.

The RIS 2017 —including 2014–2017 data[2]— covers 220 regions across 21 EU countries, Norway, Serbia, Switzerland, and the UK. It uses indicators from the European Innovation Scoreboard (EIS), including regional data from the Community Innovation Survey (CIS). The RIS data is normalized between 0 and 1[3] at origin, with the aim of producing a composite indicator integrating variables from different scales. We include in the analysis six variables that represent the innovation drivers that better capture innovation in SMEs (innovation activities like public and private R&D expenditures, non-R&D innovation expenditures, and collaborations like inter-firm collaboration and public-private co-publications). The dependent variable is regional SME innovation. All variables are explained in Table 1.

5.2. Variables

Regional SME innovation is the dependent variable. It depicts regional SME innovation output at a regional level for the regions considered in the analysis. The dependent variable measures are the share of SMEs in a region that have introduced product or process innovations in their markets. All the variables included in the analysis are presented in Table 1. For the sake of measuring both STI and DUI modes of innovation, we comprehensively use regionally-based internal innovation activities (such as R&D or non-R&D activities), together with types of collaboration occurring in regions (for the average SME). Given our focus on the role of R&D versus non-R&D activities for SME innovation, we rely on RIS indicators representing internal and external drivers of SME innovation. Collaborative innovation is characterized by two key variables that represent supply chain-based (DUI) vs. scientific types (STI) modes of collaboration (Jensen et al., 2007; Isaksen and Karlsen, 2010; Fitjar and Rodríguez-Pose, 2013; Haus-Reve et al., 2019, among others). For the DUI mode, we resort to 'SME collaboration'. The latter measures the degree to which SMEs are involved in innovation cooperation with other firms or institutions. Complex innovations often depend on the ability of companies to draw on diverse sources of information and knowledge, or to collaborate on the development of an innovation. This variable reproduces one of the archetypical elements of the DUI mode.

Table 1
Variables and indicators.

Dependent variable	Description	Codification
Regional SME innovation	SMEs introducing product or process innovations as percentage of SMEs in a given region (relative number of SMEs that introduced a new product or a new process to one of their markets)	Scale 0–1
Independent variables	***At the regional level***	
Public_R&D	R&D expenditures in the public sector as percentage of GDP: All R&D expenditures in the government sector and the higher education sector (STI)	Scale 0–1
Private_R&D	R&D expenditures in the business sector as percentage of GDP (STI)	Scale 0–1
Non_R&D	Non-R&D innovation expenditures in SMEs as percentage of total turnover: Sum of total innovation expenditure of SMEs, excluding intramural and extramural R&D expenditures (DUI) Rationale: components of innovation expenditure, such as investment in equipment and machinery and the acquisition of patents and licenses, measure the diffusion of new production technology and ideas	Scale 0–1
SME_collaboration	Innovative SMEs collaborating with others as percentage of SMEs: Number of SMEs with innovation co-operation activities. Firms with co-operation activities are those that have had any co-operation agreements on innovation activities with other enterprises or institutions. Rationale: the indicator measures the flow of knowledge between public research institutions and firms, and between firms and other firms. The indicator is limited to SMEs, because almost all large firms are involved in innovation co-operation (DUI and STI simultaneously)	Scale 0–1
Pub-private co-publication	Public-private co-publications per million population: Number of public-private co-authored research publications. The definition of the "private sector" excludes the private medical and health sector. Rationale: This indicator captures public-private research linkages and active collaboration activities between business sector researchers and public sector researchers resulting in academic publications (STI)	Scale 0–1
Controls		
Country dummies	For each of the 22 countries: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Spain, Sweden, Switzerland, United Kingdom	Dummy 0–1

Source: RIS database and own elaboration.

For the STI mode, we rely on 'Public-Private co-publications'. This variable measures the number of public-private co-authored research publications per million people.

While the former variable portrays the interactions SMEs initiate with a multiplicity of agents along the supply chain and beyond it, into the technological realm (e.g., business incubators and technology centres), the latter is about a type of open innovation aiming to achieve scientific outputs. It is eminently science-driven, as it is the product of collaboration amongst scientists/academics based within both generally public (universities) and private organizations (companies). More

[2] The RIS methodology is explained in detail at https://ec.europa.eu/docsroom/documents/37783 (accessed September 2020).

[3] As described in the database (https://ec.europa.eu/docsroom/documents/37783), the RIS data are normalized, using the standard min-max procedure. The minimum score observed for all regions across all observations is first subtracted from the transformed score. The result is then divided by the difference between the maximum and minimum scores observed for all regions across all observations. The maximum normalized score is equal to 1 and the minimum normalized score is equal to 0. See more at RIS methodology.

information about the data can be found in the Appendix. R&D expenditure is measured as a share of GDP, as this is the basic indicator for the linear model of innovation and crucial for the innovation policies derived from it. In linear model-influenced policies, R&D expenditure is considered the main driver of future innovation, competitiveness, and wealth and essential for making the transition to a knowledge-based economy. R&D is divided into public R&D, which captures R&D expenditures in the government and higher education sectors, while private R&D captures investment in the field within private firms. R&D is particularly prominent in the science-based sector (pharmaceuticals, chemicals, and some areas of electronics), where most new knowledge is created in laboratories. Also, non-R&D activities are especially important for European regions where the economy is mainly supported by SMEs. We measure the non-R&D innovation expenditures in SMEs as percentage of turnover. This indicator encompasses the total innovation expenditure for SMEs, excluding intramural and extramural R&D expenditures.

5.3. Model

Following the hypotheses presented above, the econometric model adopts the following form:

$$Regional\ SME\ innovation_i = \beta_0 + \beta_1 STI_i + \beta_2 DUI_i + \beta_3 RIIS\_group_i + \vartheta_i + \epsilon_i \quad (1)$$

more specifically,

$$\begin{aligned} Regional\ SME\ innovation_i = {} & \beta_0 + \beta_1 Public\_R\&D_i + \beta_2 Private\_R\&D_i \\ & + \beta_3 Non\_R\&D_i + \beta_4 SME\_collaboration_i \\ & + \beta_5 Pub\_private\ copublication_i \\ & + \beta_6 RIIS\_group_i + \vartheta_i + \epsilon_i \end{aligned} \quad (2)$$

where i represents a region;

Public R&D and *Private R&D* are, respectively, the public and private R&D expenditure as a share of GDP;

Non_R&D depicts the total SME non-R&D innovation expenditure;

SME collaboration refers to the share of SMEs with innovation cooperation activities;

Pub_private copublication represents the number of public-private coauthored research publications;

RIIS groups represent the four above-mentioned innovation performance groups according to their performance in the RII, relative to that of the EU.

ϑ_i are country fixed-effects;[4] while

ϵ_i stands for the error term.

6. Empirical analysis

6.1. Descriptive statistics

The initial descriptive statistics (Table 2a, Table 2b and Fig. 1) show the average innovative behaviour of SMEs across all types of regions. Public-private co-publications are relatively uncommon for SMEs. In contrast, around 50% of SMEs in the EU rely on public R&D. Business R&D and SME collaborations are typically adopted by one third of the firms. These descriptive statistics indicate that considerable margins remain for upgrading in relation to innovation activities across European firms and regions.

6.2. General econometric results

Table 3 reproduces the results of the baseline Tobit regression as presented in Model 1 and Model 2. This analysis looks at the connection between the different drivers and rates of regional SME innovation. Model 1 includes only the five internal and external drivers that may affect the innovative capacity of SMEs in European regions. It gives a first indication of the extent to which the different innovation drivers connect to SME innovation. Model 2 introduces country level fixed-effects.

Overall, the results show that regional SME innovation is fundamentally determined by in-house private R&D conducted by the firms (STI), non-R&D innovation activities (DUI), and SME collaboration with external sources of knowledge, the latter including DUI (supply-chain actors and competitors) and STI (universities and other scientific sources). These three factors are always positively and highly significantly associated with regional SME innovation. SMEs that invest more in private R&D, pursue improvements in areas like design and trademarks, or collaborate with other firms or institutional actors, contribute to make their regions more innovative (Table 3, Model 1). Similarly, SMEs engaged in co-publication with research centres and universities also innovate more, being capable of linking business sector researchers and public sector researchers more actively, resulting in academic publications. Hence, it seems that regions that encourage SME collaboration with other firms —following the DUI and STI modes of innovation— as well as with research institutions, leading to co-publications —introducing an external form of STI innovation— end up with more innovative SMEs. By contrast, public R&D investment displays an insignificant coefficient. Public R&D is not connected to improvements in regional SME innovation, which may be explained by the substitution effect between private and public R&D (Antonelli and Crespi, 2013).

These results are reproduced when country fixed effects are included in the analysis (Table 3, Model 2). The only difference is that the coefficient for the public R&D investment becomes negative and significant. This could indicate that greater investment in R&D by the public sector is not a solution to compensate for the lack of capacity of SMEs to invest in R&D in-house. These results challenge the emphasis that, under the linear model, has been put on R&D investment for innovation. In particular, as SMEs lack the capacity to invest heavily in R&D, it is expected that public R&D would cover this gap. However, the insignificant or negative coefficients for public R&D point towards a lack of capacity by many SMEs to absorb spillovers from public R&D, especially in regions that are frequently positioned far away from the technological frontier (Rodríguez-Pose and Wilkie, 2019). This outcome reflects the lower sway of public R&D vis-à-vis private R&D for SME innovation.

Overall, Table 3 shows the array of different STI and DUI indicators that capture and explain regional SME innovation. SME-level innovation in Europe does not depend on how much is invested in public R&D in a region. It relies more on private R&D as well as on non-R&D-type investment and collaborations with actors external to the firm. SME collaborations oriented to access external information and knowledge sources (e.g., customers, suppliers, competitors) facilitates the innovation process. These activities, primarily depicting practice- and interaction-based innovation modes are often complemented with active engagements with research centres. Such private-public engagements, leading to co-publications, represent the scientific/analytic mode of innovation, which is an important driver of SME innovation processes. This general approach, however, hides the importance of more specific, place-based specificities that an in-depth type of analysis shows (see next Tables 4 and 5).

6.3. Region-specific results

Do these results hold across different levels of regional development? Looking at the different hypotheses developed in the theoretical section, we expect that the effect of the different drivers of innovation will vary

[4] A total of 22 countries —Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Spain, Sweden, Switzerland and United Kingdom— is considered in the analysis,

Table 2a
Descriptive statistics.

		Mean	Std. Dev.	Min	Max	1	2	3	4	5
1	Regional SME innovation	0.447	0.180	0	1	1				
2	Public_R&D	0.488	0.174	0	1	0.420*	1			
3	Private_R&D	0.341	0.192	0	1	0.539*	0.399*	1		
4	Non_R&D	0.306	0.123	0	1	0.197*	0.094	0.074	1	
5	SME collaboration	0.339	0.208	0	1	0.52*	0.314*	0.354*	0.024	1
6	Pub-private co-publication	0.251	0.167	0	1	0.571*	0.657*	0.652*	−0.056	0.469*

* $p<0.01$.
Source: own from RIS data;.

Table 2b
Mean variation of variables across regional SME innovation quartiles.

Variables/Quartiles	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
SME innovation	0.08	0.17	0.24	0.34	0.41	0.47	0.51	0.55	0.59	0.63	0.77
Public_R&D	0.28	0.34	0.46	0.44	0.51	0.49	0.59	0.41	0.51	0.63	0.62
Private_R&D	0.11	0.19	0.25	0.33	0.28	0.30	0.42	0.34	0.44	0.47	0.54
Non_R&D	0.16	0.35	0.22	0.29	0.31	0.37	0.29	0.32	0.27	0.24	0.37
SME Collaboration	0.06	0.10	0.20	0.40	0.37	0.34	0.35	0.44	0.49	0.51	0.42
Pub-private co-publication	0.07	0.10	0.19	0.20	0.22	0.23	0.35	0.25	0.32	0.37	0.43

Fig. 1. Mean variation of variables across regional SME innovation quartiles.

according to the level of development of each region. To test whether this is the case, we use quantile regressions as a means to assess how the factors that affect SME innovation change according to variations in regional innovative capacity. The advantage of quantile regressions is that —by allowing estimating effects at different points in a distribution— they take into account the heterogeneous capacity of SMEs to innovate in regions at different levels of development.

We argue that SMEs in less developed regions will only not just be less innovative, but will also rely much more on internal and external DUI-type relations, as indicated in H4. This is because they tend to be smaller and farther removed from the technological frontier to make use of internal R&D than SMEs in more developed areas. SMEs in more developed regions, by contrast and following H3, would, on average, benefit to a far greater extent from R&D investment as well as from external interactions. This means that SMEs in more developed areas can reap benefits from both internal and external STI and DUI drivers. In less developed areas, SMEs normally exploit non-R&D innovations, external collaborations within the supply chain, but struggle to innovate by creating scientific co-publications.

Table 4 shows the means of the different innovation drivers at different levels of innovation. It also displays the ANOVAS for the main independent variables used in the study, each of them across four quartiles of the regional SME innovation. Different regional SME innovation structures (significant at $p<0.01$) emerge along the innovation

Table 3
Drivers of regional SME innovation: robust Tobit model.

VARIABLES	MODEL 1	MODEL 2
Public_R&D	0.0406	−0.142***
	(0.0669)	(0.0448)
Private_R&D	0.184***	0.168***
	(0.0576)	(0.0398)
Non_R&D	0.268***	0.154
	(0.0904)	(0.0958)
SME Collaboration	0.296***	0.479***
	(0.0538)	(0.0734)
Pub-private co-publication	0.265***	0.287***
	(0.091)	(0.0717)
Country fixed-effects	NO	YES
Prob > Chi2	0.000	0.000
F	33.29	112.26
Log likelihood	138.38	264.27
Observations	213	213

–1 left censored observation.
–212 uncensored observations.
–0 right-censored observations.
All specifications significant at ***$p<0.01$; Robust Standard errors in parentheses.

Table 4
ANOVA tests of innovation drivers means across quartiles of regional SME innovation output.

Quartiles	0.25	0.5	0.75	1.00	F	Sig.
SME innovation	0.194	0.407	0.531	0.655	614.91	0.000
Public_R&D	0.376	0.494	0.512	0.568	26.31	0.000
Private_R&D	0.203	0.299	0.399	0.464	26.31	0.000
Non_R&D*	0.264	0.326	0.330	0.304	3.5	0.016
SME Collaboration **	0.143	0.356	0.403	0.452	34	0.000
Pub-private co-publication	0.126	0.213	0.289	0.378	32.81	0.000

(*) only significant differences between 0.25 and 0.75 ($p<0.05$); (**) only significance differences between 0.25 percentile and the rest of percentiles, all of them; and the 0.5 and the 1 (all at $p<0.01$).

Table 5
Drivers of regional SME innovation at different levels of the regional innovation distribution: logistic quantile regressions.

Quartile VARIABLE	0.2 MODEL 3	0.4 MODEL 4	0.6 MODEL 5	0.8 MODEL 6
Public_R&D	−0.601	−0.441	−0.682*	−0.198
	(0.382)	(0.44)	(0.365)	(0.411)
Private_R&D	0.659*	0.416	0.697*(+)	1.032**
	(0.335)	(0.345)	(0.36)	(0.437)
Non_R&D	0.573	0.438	0.484	0.305
	(0.622)	(0.653)	(0.826)	(0.84)
SME Collaboration	1.953*** (+)	2.766*** (+)	3.368*** (+)	3.639*** (+)
	(0.52)	(0.714)	(0.734)	(0.66)
Pub-private co-publication	1.314*** (+)	1.306**	1.235**	0.287
	(0.491)	(0.596)	(0.565)	(0.56)
Country fixed-effects	YES	YES	YES	YES
Intercept	−1.739**	−2.127***	−2.482***	−2.263***
	(0.709)	(0.815)	(0.881)	(0.661)
Observations	213	213	213	213
f (5187)	5.23	5.69	7.81	9.75
Prob > chi2	0.000	0.000	0.000	0.000

All specifications significant at ***$p<0.01$; **$p<0.05$; Standard errors in parentheses.
Tobit regression: 1 left-censored observation; 212 uncensored observations; 0 right-censored observations.
(+) significantly different quantile regression coefficients from Tobit coefficients at the 5% significance level, when the Tobit coefficient is outside of the quantile regression coefficient confidence interval;.

spectrum. Moreover, each innovation driver differs across regional SME innovation quartiles. They show statistically significant (at $p<0.01$) differences in Public R&D (0.376, 0.494, 0.512, 0.568, for quartile 1, 2, 3 and 4, respectively), Private R&D (0.2, 0.299, 0.399, 0.464), SME collaboration (0.143, 0.356, 0.403, 0.452; differences only in some pairs) and Public-private co-publication (0.126, 0.213, 0.289, 0.378). The exception is Non-R&D, only significant at $p<0.05$, with main differences between the 0.25 and 0.75 ($p<0.05$) specific pair. For the sake of brevity, more results of specific pairs are available upon request. Table 4 is graphically represented in Figs. 1 and 2. In these figures, innovation drivers differ along the regional innovation spectrum, presenting higher values as we climb up the regional innovation ladder. Advanced regions outperform less advanced ones in all indicators, except for Non-R&D activities, which show fewer differences across the different categories. This means that more innovative regions generally display higher values in both STI and DUI indicators. Less innovative regions, by contrast, rely more on Non-R&D (DUI) and SME collaboration (that include both DUI and STI collaborations) as the main sources of innovation, but with lower values, in general, relative to the most innovative regions (see Fig. 2).

In Table 5 we measure regional SME innovation patterns based on the selected set of innovation drivers through logistic quantile regressions. Table 5 presents the results of the quantile analysis, considering the link between the different drivers of innovation and regional SME innovation levels for regions located at the 20%, 40%, 60% and 80% of the regional innovative distribution. The robust Tobit coefficients are included in Model 1 (Table 3), as benchmark. Fig. 3 provides graphic representations for the coefficients of each of the drivers of SME innovation across the whole distribution of regions according to the regional innovative capacity of their SMEs. See Table 5 and Fig. 3.

Overall, the results highlight that there are a few drivers of innovation that matter to a similar extent across the whole spectrum of regions. The main exception is SME collaboration, which is strongly and positively associated with regional SME innovation both in less and more innovative regions. However, its return increases as we climb up the regional innovation ladder. SME collaborations are positively related to regional SME innovation (coefficient, 0.479 at $p<0.01$). It is, therefore, a key innovation driver across all regions. The significance of SME collaboration varies depending on where a region is located in the innovation spectrum: its effect increases in more innovative regions. There the returns are higher than in less innovative regions (expressed as "+"; 1.953, 2.766, 3.368, 3.639 at $p<0.01$). This implies that although SME collaboration is a pervasive driver of SME innovation across the board, it produces a premium for already highly innovative regions. This is in line with hypotheses H3 and H4 (Table 5 and Fig. 3). Advanced regions achieve greater returns from both DUI and STI innovation modes, reaping the benefits of combining DUI (supply-chain) and STI (universities and scientific) sources. H3 can thus be fully accepted. Moreover, less advanced regions also benefit from both DUI and STI drivers, although they are primarily led by SME collaborations, thus confirming H4.

R&D investment has an uneven association with regional SME innovation. This unevenness is particularly stark across the public/private R&D divide. Business/private R&D shows a positive relationship with regional SME innovation (R&D) (Table 5). It is an innovation driver that specially impacts non-advanced regions —(0.2 quartile), coefficient of 0.659, statistically different (expressed as "+") from the Tobit coefficient at $p<0.1$— as well as highly innovative regions —(0.8 quartile), with a coefficient of 1.032 (at $p<0.05$) that is statistically significant and also statistically different (expressed as "+") from the Tobit Business R&D coefficient (0.168 at $p<0.01$) (Table 5). This implies that Business R&D drives regional SME innovation, especially in highly innovative regions (Rodríguez-Pose and Wilkie, 2019).

Public R&D, in contrast, is negatively correlated to regional SME innovation, being less capable to drive innovation for regions located around 60% in the distribution of innovative regions (Table 5). Public

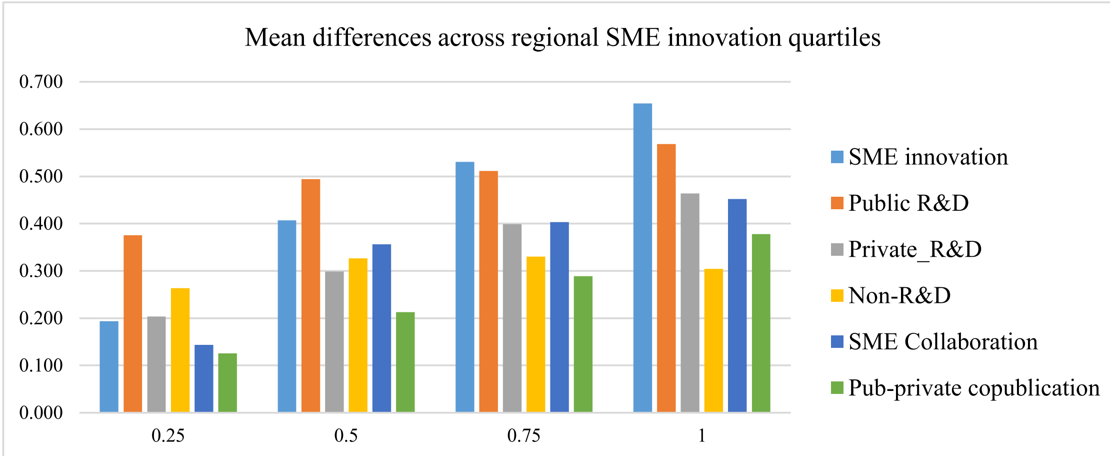

Fig. 2. Drivers of innovation across quartilesof regional SME innovation.
Source: own elaboration from RIS.

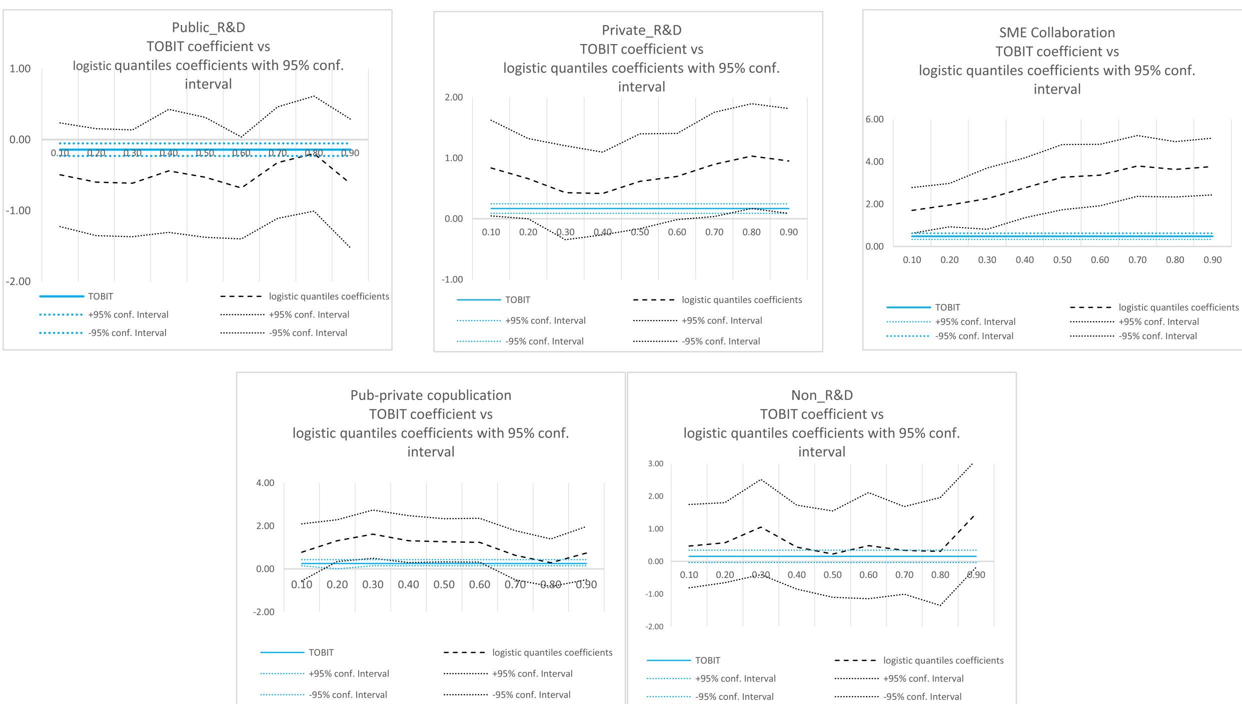

Fig. 3. Drivers of innovation and SME innovation along the regional innovative spectrum.
Source: own elaboration from analysis. Data from RIS.

R&D —which has been at the centre of the R&D innovation strategy under the linear approach to innovation and has represented the bulk of R&D in many less innovative regions— has a limited influence on SME innovation in the short-term across the whole regional distribution. We do not rule out an effect of public R&D on SME innovation, but it might be felt more in the long-term, meaning that its viability as a short term policy tool for improving regional SME innovation may be limited and more indirect that envisaged by those promoting R&D.

Public Private co-publication (PUB_PRIVATE_COPUB) is positive and significant (0.287 at $p<0.01$) and remains statistically different (expressed as "+") up to 60% of the distribution. This implies that less innovative regions (those in the first 60% of the regional SME innovation interquartile range) achieve higher returns than those in the highest 40% (Table 5). This implies that for less innovative regions co-publication is, in conjunction with collaboration and private R&D, a powerful driver of SME innovation. In contrast to expectations, however, when measuring their impact on regional innovation, the coefficients are stronger in regions with a lower innovative capacity (Table 5, Fig. 3). In the higher quartiles, regional innovation depends much more on internal R&D, non-R&D activities, and SME collaborations (that include broader collaborations with universities) as key factors for their outstanding innovation performance.

Finally, non-R&D activities present the weakest link with innovation across regions. Non-R&D efforts also impact on regional SME innovation, but their returns are pretty stable across the regional innovation distribution. Non-R&D investments (e.g., acquisition of machinery or access to extramural patents paying licenses) pay-off in a similar way across all regions, regardless of their capacity to innovate. Although the coefficient is positive across the whole distribution, it remains insignificant until approaching the top 10% most innovative regions. It is only there that activities such as design or trademarks, among other non-R&D activities, seem to be fundamental for SME-level innovation (Table 5, Fig. 3). For the sake of brevity, see Table A1 in the Appendix, showing the full logistic percentile regression.

Overall, the results present clear differences in SME innovation patterns depending on where a region is relative to the innovation frontier. In more innovative regions SMEs benefit not only from STI-type innovation drivers (such as private R&D), but also from DUI-type drivers such as non-R&D activities conducted within the firm as well as from STI and DUI type collaborations. In less innovative regions, SME innovation is mostly reliant on activities external to the firm, primarily collaborations. These can be both SME collaborations, and (STI) activities leading to joint research with public research institutions. In this latter case the number of firms capable of conducting such activities is limited. The results show the importance of stratifying the analysis and producing results that differentiate the behaviour of SMEs in different types of regions, from innovation leaders to moderate and modest innovators.

This type of analysis puts in evidence that one-size-fits-all R&D-based innovation policy interventions, as those that have dominated the Lisbon Agenda and the Horizon2020 programme, are unlikely to work efficiently and effectively across such a wide and varied range of regional contexts. Regional context-specificities need to be taken into account to promote an appropriate place-sensitive innovation policy across Europe (Iammarino et al., 2019; Parrilli et al., 2020). As a reflection, it is important to notice that in the case of less advanced regions collaboration is the primary source of regional innovation: not including it in innovation policies can lead to perpetuating these regions as laggards in the European innovation landscape.

7. Conclusions and policy implications

This study has aimed to decipher the drivers of regional SME innovation in Europe. Following previous theoretical and case-study-based contributions (Cooke et al., 2004; Asheim and Gertler, 2005, among others) and broader empirical analyses of business innovation (Parrilli et al., 2020) and innovation policy across a range of different contexts (Iammarino et al., 2019), we have sought to determine drivers of SME innovation and how they vary depending on the characteristics of the region where SMEs operate. In doing so, we have answered three related questions. First, we have assessed the extent to which regional innovation and regional innovation by SMEs is explained by R&D investments vis-à-vis other non-R&D activities. Second, we have verified the importance of different types of innovation drivers —some of which are more scientifically-oriented and other more supply chain-oriented— for SME innovation. Third, we have delved into the regional context in which SMEs operate and determined how it affects their capacity to innovate. Overall, this study sheds light on *what* innovation means for SMEs, showing *collaboration* as an even stronger driver than R&D, and the importance the specific location of SMEs has for innovation.

The results indicate that, in Europe, SME innovation in more innovative regions is driven by the effective exploitation of both STI and DUI innovation drivers. In less innovative regions SME innovation is more the result of collaborations and public/private co-publication. Put differently, we provide strong evidence that signals that collaboration is a crucial factor for SME innovation, whose role is stronger than that of R&D and is moderated by the place where an SME is located.

The results of the analysis highlight that the 3% R&D-based innovation policy, which has been a constant of EU innovation policies over the last 20 years —albeit complemented with other innovation approaches (European Commission, 2015; Reillon, 2017)— may not be the most adequate way to harness SME innovation across the whole of Europe. The emphasis on R&D as the main input in the innovation process has proven to be far from the best way of advancing innovation at SME level, at least across a significant number of regions in Europe, particularly the less innovative ones. In general, the pursuit of such a research-based innovation policy has overlooked the diversity of the European innovation landscape, having harmful consequences for SME innovation in many parts of Europe for two main reasons. First, SMEs are pervasive across Europe and, especially in less advanced regions and traditional industries; they struggle to perform R&D in-house. Instead, SME innovation in these regions generally tends not to be based on R&D investments or on the absorption of basic knowledge spilling over from research institutions (Rammer et al., 2009), but on processes of learning-by-doing, by-using. and by-interacting. Innovation in SMEs in heavily dependent on inter-firm collaboration. As evidenced by the results of the analysis, collaboration is far stronger driver than innovation than R&D. Second, the regional context and the distinctive regional innovation systems in which SMEs operate influence how firms innovate (Cooke and Morgan, 1994; Parrilli and Alcalde, 2016). The main drivers of innovation vary considerably from regions with modest innovation capacities to those at the pinnacle of innovation. This implies that implementing the same policy across the board, disregarding the place and environment in which SMEs operate, may not be the most adequate policy to promote SME innovation. This is especially the case of the least innovative regions, where SMEs often lack the capacity to implement their own R&D and to benefit from knowledge stemming from

Table A1
Drivers of regional SME innovation at different levels of the regional innovation distribution: full logistic percentile regression.

	FULL LOGISTIC PERCENTILE REGRESSION										
Variables	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95
Public_R&D	−0.298	−0.495	−0.601	−0.615	−0.441	−0.532	−0.682*	−0.326	−0.198	−0.617	−0.112
	0.472	0.370	0.382	0.381	0.440	0.428	0.365	0.398	0.411	0.459	0.553
Private_R&D	1.102**	0.835**	0.659*	0.429	0.416	0.616	0.697*	0.896**	1.032**	0.951**	0.431
	0.457	0.400	0.335	0.393	0.345	0.396	0.360	0.435	0.437	0.438	0.423
Non_R&D	0.503	0.469	0.573	1.054	0.438	0.225	0.484	0.34	0.305	1.468*	1.523
	0.810	0.648	0.622	0.742	0.653	0.671	0.826	0.682	0.840	0.835	0.964
SME Collaboration	1.606***	1.702***	1.953***	2.254***	2.766***	3.271***	3.368***	3.797***	3.639***	3.771***	4.155***
	0.475	0.547	0.520	0.732	0.714	0.780	0.734	0.729	0.660	0.679	0.757
Pub-private co-publication	0.89	0.772	1.314*** (+)	1.614***	1.306**	1.260**	1.235**	0.634	0.287	0.731	0.493
	0.690	0.672	0.491	0.569	0.596	0.545	0.565	0.581	0.560	0.630	0.579
Country fixed-effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Intercept	−1.751***	−1.521**	−1.739**	−2.045***	−2.127***	−2.403***	−2.482***	−2.429***	−2.263***	−2.706***	−3.015***
	0.58	0.69	0.709	0.769	0.815	0.847	0.881	0.766	0.661	0.712	0.816
Observations	213	213	213	213	213	213	213	213	213	213	213
f (5187)	4.79	4.27	5.23	3.42	5.69	6.83	7.81	8.46	9.75	11.13	11.89
Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

All specifications significant at ***$p<0.01$;**$p<0.05$; Bootstrap Standard errors in parentheses.

universities and research centres and must rely on external DUI-type interactions.

The one-size-fits-all linear approach of trying to increase R&D investment in SMEs across all regions in Europe to 3% of GDP is not just unrealistic, but also likely to yield limited results. This is particularly the case in regions where a large majority of SMEs may be located far away from the innovation frontier. There, innovation is primarily driven by activities which are not necessarily linked to R&D investment and, especially, collaboration. In these areas there is a need to develop policies that emphasise SME collaborations and the role of local ecosystems. Hence, we posit that innovation policies for SMEs, both at the national and European level, need to become more place-sensitive in order to become more effective at delivering innovation for SMEs (e.g., Tödtling and Trippl, 2005; Asheim et al., 2011; Rodríguez-Pose, 2013; Boschma, 2015; Alberdi et al., 2016; Isaksen and Trippl, 2016; Hervás-Oliver et al., 2019; Parrilli et al., 2020). This approach can help overcome some of the limitations observed in recent Framework Programmes (for example, FP7 or Horizon 2020) (Mazzucato and Lazonick, 2010; De Marco et al., 2020). As suggested by Renda (2015), innovation in SMEs will benefit from the more collaborative and systemic character of innovation and the embedded ecosystems where firms locate. This is in line with the innovation management literature that has consistently indicated that SMEs innovate through non-R&D efforts (Rammer et al., 2009; Santamaría et al., 2009; Thomä and Zimmermann, 2020; Alhusen et al., 2021; Hervás-Oliver et al., 2021b).

The results of the analysis go in line with some earlier literature on the importance of innovation systems for SME innovation (Lundvall, 1992; Cooke, 2001; Tödtling and Trippl, 2005; Asheim et al., 2011; Alberdi et al., 2016). They hint that innovation policies must differentiate among territories, focusing more on private R&D activities in more innovative regions, while putting perhaps more emphasis on the creation of networks, interactions, and innovation pipelines in those areas where SMEs are ill-equipped to either generate or absorb scientific knowledge. Policies that combine STI and DUI elements in different measures, depending on the conditions of the places in which SMEs operate, are more likely to deliver results that will foster SME innovation to a far greater extent than current policies do (Parrilli et al., 2020).

This is because regions in Europe vary considerably in terms of innovation assets and capabilities (Tödtling and Trippl, 2005; Boschma, 2015), meaning that more place-sensitive innovation will respond better to the specific characteristics of different types of SMEs in different innovation-prone and innovation-averse environments. Pursuing R&D in many parts of Europe is not the only or the best way for SME innovation. Many SMEs across the continent would benefit far more from enhancing collaborations and non-R&D innovation activities.

While this study has provided new insights into how regional SME innovation is a multifaceted process that varies along the regional innovation spectrum, it is not devoid of limitations. These are derived from the use of RIS data and its lack of distinction among persistent, radical or other type of innovators. The use of this source also implies that some of variables are just proxies (such as co-publications). It might not always be the case that all variables are independent from one another (e.g., public R&D may boost private R&D). The role of hysteresis in the capacity of SMEs to innovate would also deserve the attention of future research, as past regional innovation trajectories may have persistent effects on regional SMEs innovation rates. In particular, the great recession that followed the 2007–2008 financial crisis may have had a prolonged influence on SME innovation across regions of Europe, even after the recovery started. For future research, the topic of how regions moderate innovation could also be enriched by utilizing and combining different datasets to capture regional heterogeneity for explaining SME innovation, such as structural business statistics that introduce regional business demography, employment composition by sectors, or specialization patterns. In addition, different statistical methods to capture regional SME innovation can also enrich the analysis of the influence of regions on SME innovation.

Despite these caveats, the results of the analysis underline that innovation policies targeting SMEs need to be far more comprehensive and integrative of the different drivers —internal and external— that shape the complex process of innovation in SMES. There is a need to find a more adequate use and combinations of STI- and DUI-types of intervention across European regions in a way that takes into account that innovation is not just a linear and research-based process, but that, especially in the case of SMEs, it involves interactive learning and taking into account the economic and social context in which SMEs are embedded.

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CRediT authorship contribution statement

José-Luis Hervás-Oliver: Conceptualization, Writing – original draft, Writing – review & editing, Investigation, Supervision, Formal analysis, Methodology, Resources, Data curation, Visualization, Validation. **Mario Davide Parrilli:** Conceptualization, Writing – original draft, Writing – review & editing, Investigation, Supervision, Formal analysis, Methodology, Resources, Data curation, Visualization, Validation. **Andrés Rodríguez-Pose:** Conceptualization, Writing – original draft, Writing – review & editing, Investigation, Supervision, Formal analysis, Methodology, Resources, Data curation, Visualization, Validation. **Francisca Sempere-Ripoll:** Conceptualization, Writing – original draft, Writing – review & editing, Investigation, Supervision, Formal analysis, Methodology, Resources, Data curation, Visualization, Validation.

Declaration of Competing Interest

There are no conflicts of interest

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Appendix

Table A1.

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