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A panel fsQCA investigation on European regional innovation

Malcolm Beynon [a], David Pickernell [b], Martina Battisti [c], Paul Jones [b,*]

[a] Cardiff University Business School, Colum Road, Cathays, Cardiff CF103EU, UK
[b] School of Management, Swansea University, Bay Campus, Swansea SA1 8EN, Wales, UK
[c] Grenoble Ecole De Management, 12 Rue Pierre Semard, 38000 Grenoble, France

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ABSTRACT

Taking an evolutionary economic geography perspective, we build on literature on innovation modes, the aim of this study being to explain variations in SME innovation performance across European regions over time. Drawing on five waves of data from the EU Regional Innovation Scoreboard between 2011 and 2019, our sample includes 221 regions across 27 EU Member States, as well as Norway, UK, Serbia, and Switzerland. We apply nascent panel fuzzy-set Qualitative Comparative Analysis to explore how different combinations of SME innovation modes explain innovation performance across different EU regions (i.e. geographical scope) as well as within different EU regions over time (i.e. temporal stability). Findings show that whether DUI or STI modes are more effective in the context of SMEs crucially depends on the timeframe considered, but also the geographical location of SMEs. The study offers novel insights into the diverse and complex nature through which regional innovation evolves over time, advancing understanding on regionalization as well as temporality of SME innovation modes in Europe. It also provides an important basis for discussing innovation policy across Europe.

1. Introduction

Since Jensen et al. (2007) identified two different innovation modes - Doing, Using and Interacting (DUI) and Science, Technology and Innovation (STI) – researchers have explored how these two innovation modes, alone or in combination with each other, explain innovation performance (for a recent overview see Doloreux and Shearmur, 2023). However, findings on the effectiveness of innovation modes have been highly inconsistent, particularly for small and medium-sized enterprises (SMEs), resulting in the recent call to "*better explain the existing inconsistencies*" (Hu et al., 2020:1015). Geography has also recently been identified as a potential explanation for why findings on relationships between SME innovation modes and performance differ so much (Alhusen and Bennat, 2021; Beynon et al., 2021; Hervás-Oliver et al., 2021; Parrilli and Radicic, 2021).

As a result, comparative research across different regional contexts is relevant, to account for spatial specificities, and to provide more nuanced analysis of relationships between innovation modes and performance. Another potential explanation of inconsistent findings in previous research is research to date is predominantly cross-sectional, there being a lack of studies exploring temporality of innovation modes (Parrilli et al., 2023). It is likely that innovation modes evolve over time, specifically with regards to geographical scope and temporal stability, but comprehensive longitudinal analyses within as well as across regions to explore innovation dynamics over time are still rare (Hervás-Oliver et al., 2021).

This study is situated within the broader regional innovation and evolutionary economic geography literature (Cooke, 2021) and aims to explore not only the relevance of geographic specificities for innovation, but also their evolution over time. We therefore address the following research question: *How do different combinations of SME innovation modes explain innovation performance across different EU regions (*i.e. *geographical scope) as well as within different EU regions over time (*i.e. *temporal stability)?* Providing in-depth evidence on the temporal dynamics of regional innovation across Europe allows us to shed light on the aforementioned inconsistencies (Hu et al., 2020) and advance understanding of SME innovation. It also provides an important foundation to develop more effective place-based innovation policies (Sunley et al., 2023; Trippl et al., 2020).

Drawing on five waves of data from the EU Regional Innovation Scoreboard (RIS), *covering a nine-year period between 2011 and 2019* and including 221 regions across 27 EU Member States plus four non-EU

* Corresponding author.
E-mail addresses: Beynonmj@cardiff.ac.uk (M. Beynon), d.g.pickernell@swansea.ac.uk (D. Pickernell), martina.battisti@grenoble-em.com (M. Battisti), w.p.jones@swansea.ac.uk (P. Jones).

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States (Norway, UK, Serbia and Switzerland), we apply *nascent panel* fuzzy-set Qualitative Comparative Analysis (fsQCA) in combination with map-based analysis. This approach (see Ragin, 2008) allows us to identify and visualize changes in geographical scope and temporal stability of SME innovation to more effectively understand relationships between innovation modes and performance.

Findings make several contributions to knowledge: First, this study contributes to the literature on the role of geography and temporality on SME innovation modes by responding to recent calls to better understand regional specificity (Alhusen and Bennat, 2021; Beynon et al., 2021; Hervás-Oliver et al., 2021; Parrilli and Radicic, 2021), as well as temporal dynamics of innovation modes (Parrilli et al., 2023). Findings show that whether DUI or STI modes are more effective in the context of SMEs crucially depends on the timeframe considered, but also the geographical location of SMEs. Our comparative and longitudinal approach covering 221 EU regions over a nine-year timeframe helps explain some of the inconsistencies found in previous research. Second, we advance conceptualization of innovation performance, from a firm-level measure focused on innovative sales performance of SMEs in a region, to a multi-level measure that considers quality of regional innovation represented by the proportion of employment in knowledge-intensive activities. Third, findings illustrate the methodological benefits of panel fsQCA combined with map-based analysis, allowing evaluation of geographical scope as well as temporal stability of recipes. This is important, making it possible to evaluate and contrast regional innovation performance and evolution within, and between, EU regions over a substantial period, indicating the practical relevance of the findings as an important basis for discussing innovation policy.

The remainder of the manuscript is structured as follows: Section 2 reviews the literature on innovation modes and their drivers from an SME perspective. Section 3 discusses the relevance of geography and temporality of innovation modes, followed by Section 4 that discusses innovation performance at firm and regional level. In Section 5 we present our configurational approach, followed by the methodology in Section 6. Findings are presented in Section 7 and we discuss their implications for theory and practice in Section 8. We conclude with Section 9 where we discuss limitations and offer suggestions for future research.

2. Innovation modes and their drivers: an SME perspective

Doing, Using and Interacting (DUI) is a less R&D intensive mode exploiting mostly synthetic (engineering-based) or symbolic (culture-based) knowledge through informal processes of problem-oriented learning with, for example, clients and suppliers (Shearmur and Doloreux, 2021). The resulting innovation is typically incremental, for example, cost reductions or quality improvements (Jensen et al., 2007). This mode is strongly driven by SMEs *internal capacity to innovate, t*he "doing" part of this innovation mode in particular happening among different actors within a firm who share experiences and knowledge to identify problems, discover opportunities for innovation and develop new, but mostly improved products and processes, which eventually enhance firm knowledge bases (Alhusen and Bennat, 2021).

In contrast, the "using" and "interacting" part of this innovation mode is more *externally* driven. Innovating through "using" results for example from using customer feedback to improve a product or service. Innovating through "interacting" results from interactions with other firms including suppliers, distributors and competitors, but also public institutions such as universities. Through informal interaction with these actors, SMEs access new and complementary external sources of information and knowledge that mostly drive incremental improvement of existing innovation (Alhusen and Bennat, 2021; Thomä and Zimmermann, 2020). Importantly, this type of *external interaction,* mostly along supply-chain, can *compensate* for lack of internal innovation capacity (Hervás-Oliver et al., 2021). This distinction between internal and external drivers is relevant in the context of SME innovation given their heterogeneous nature and need to be inclusive of the full range of innovation activities (Parrilli and Radicic, 2021).

The Science, Technology and Innovation (STI) mode, in contrast, exploits mostly analytic knowledge (science-based) (Shearmur and Doloreux, 2021). This mode aims at producing radical innovation through deliberately searching for new products and processes. It is characterized by high R&D intensity, achieved through engaging in external *science and technology cooperation* (Alcalde-Heras et al., 2023). In particular, it is formal collaborations between private sector firms and public sector research institutions, such as universities, which drive the STI mode. To be able to undertake STI, SMEs also rely on highly *qualified human capital* (Thomä and Zimmermann, 2020; Isaksen and Trippl, 2017). The supply of qualified and advanced skills varies significantly across regions (Hollanders, 2021). It is important to note, however, that supply of human resources is not limited to highly specialized science and technical fields, as these are not easily accessible for SMEs. As such, availability of qualified human capital is a relevant *complement* to the external science and technology cooperation of SMEs.

In the SME context, findings on effectiveness of innovation modes have been highly inconsistent. Parrilli and Elola (2012) showed the STI mode was more effective for SMEs in the Basque region of Spain compared to the DUI mode or even a combined DUI-STI mode. This finding is contrary to other studies that found, for SMEs, the DUI mode or a combined DUI-STI mode most effective. For German SMEs, Thomä and Zimmermann (2020) found SMEs more likely to demonstrate higher growth rates when engaged in the more R&D intensive STI innovation mode. However, for the majority of SMEs, STI did not result in performance gains over and above the performance achieved through DUI alone. This is supported by Apa et al. (2021) for a sample of SMEs from the Italian region of Veneto. They found that for SMEs, formal collaborations with universities proved mostly unproductive, pointing towards limited effectiveness of this mode in terms of innovation performance. This lack of economic benefit of engaging in STI might explain why SMEs frequently only rely on more informal innovation modes based on DUI, as evidenced for example by Amara et al. (2008) for a sample of SMEs in Montreal, Thomä (2017) for German SMEs and Trott and Simms (2017) for SMEs in the UK. A growing number of studies, however, argue that a combined DUI-STI mode is most effective for SMEs (Jensen et al., 2007; Apanasovich et al., 2016; González-Pernía et al., 2015; Parrilli et al., 2023). Lastly, Beynon et al. (2021) identified four SME innovation patterns across EU regions. Three pattern representing DUI modes were mostly found in regions in the Western periphery and one pattern representing a combined DUI-STI mode was mostly found in core or metropolitan regions of Europe.

3. Geography and temporality of innovation modes

Overall, the relationship between geography and entrepreneurship is still not well understood (Sternberg, 2022), but recent research points towards the importance of distinguishing between metropolitan (or core) and peripheral geographies when explaining variations in innovation performance (Doloreux and Shearmur, 2023; Eder, 2019).

In core geographies, comprising large metropolitan areas, resources are generally more abundant, but the costs of living are often higher and the quality of living lower. Smaller cities might compensate lower resource availability through relative proximity to large metropolitan areas, but also improved digital infrastructure. The more peripheral regions are, the more likely it is that their access to resource-rich environments and critical infrastructure is reduced. Finally, rural areas often suffer from unfavorable regional conditions and general resource scarcity (Eriksson and Rataj, 2019; Sternberg, 2022). These different spatial characteristics are thus likely to influence which combinations of innovation modes are more effective in explaining innovation performance. This means certain innovation modes might be more relevant in some spatial setting than others, the resulting combinations of innovation modes likely to represent different geographies and thus different types of SME innovation.

While an emergent stream of research highlights the relevance of spatial specificities to provide more nuanced analysis of relationships between geography and SME innovation (Alhusen and Bennat, 2021; Beynon et al., 2021; Hervás-Oliver et al., 2021; Parrilli and Radicic, 2021), research to date is predominantly cross-sectional in nature, lacking exploration of temporality in innovation modes (Parrilli et al., 2023). It is however likely that innovation modes evolve over time, specifically with regards to geographical coverage and temporal stability. SMEs who might have been successful using a DUI mode only, might find that - to remain competitive - they need to integrate the STI mode to allow them to exploit more globally distributed knowledge. In contrast, SMEs pursuing combined DUI-STI might find that STI does not provide sufficient economic gains and they resort to DUI only. Changes to such innovation modes at firm-level are then likely to be consequential for the regional innovation system. Conversely, specific policy interventions at regional level might, over time, trigger changes to innovation modes at firm level. However, Capello and Lenzi (2019) argue that changes in regional innovation systems are likely to be slow and incremental, because of the path-dependent nature of innovation. This points not only to the importance of longitudinal research, but also the relevance of considering innovation performance at firm as well as regional level.

4. Innovation performance at firm and regional level

The inconsistent results discussed earlier, have led to calls for more systematic assessment of the economic effects of DUI and STI modes at firm as well as regional level (Hu et al., 2020; Thomä and Zimmermann, 2020). In response, we conceptualize innovation performance as a multi-level phenomenon, consisting of the proportion of innovative sales in SMEs, as well as the proportion of employment in knowledge-intensive activities per region. These two measures represent firm and regional-level outcomes respectively, both important to understand structural changes to innovation across regions as well as within regions over time.

Innovative sales performance represents economic success of SME innovation (Radicic et al., 2019). It illustrates the success of the innovation in the market, frequently used as a measure of innovation outcome (Love et al., 2014). This outcome is particularly relevant in the context of SMEs, capturing effects of innovation more broadly including non-R&D innovation (Negassi, 2004; Radicic and Pugh, 2017). Conversely, employment in knowledge-intensive activities represents the degree to which knowledge is used in economic activities in the region. It is a measure of the quality of the regional innovation system and its spillover potential across regions through knowledge-intensive services (Leydesdorff and Fritsch, 2006), shown to be a particularly relevant measure in SME innovation contexts (Parrilli and Radicic, 2021).

Innovative sales also represents non-technological innovation performance, employment in knowledge-intensive activities representing technological innovation performance. This distinction is important, offering "technological nuance" (Parrilli and Alcalde-Heras, 2016: 755), capturing innovation breadth, including SME innovation, which tends to be less technology intensive (Thomä and Zimmermann, 2020). This inclusivity is particularly relevant for analyzing regional variation, capturing regions on both sides of the innovation paradox – those who have comparably stronger innovation performance based on relatively small investments in science and technology and vice versa (Parrilli and Alcalde-Heras, 2016). Acknowledging regional idiosyncrasies is even more relevant when analyzing longitudinal innovation performance. Over the last nine years, only 40 % of regions improved their innovation performance, the remaining regions experiencing a decrease in their performance relative to the EU average. In regions where innovation performance improved, DUI and STI drivers have played a significant role, highlighting the importance of SME innovation plays in improving regional innovation performance (Hollanders, 2021).

5. A configurational approach

Building on more recent notions of regional innovation as a dynamic system reflective of complex processes evolving over time (Capello and Lenzi, 2018, 2019; Cooke, 2021), a configurational approach directly addresses the need for assessing regional variations of SME innovation modes over time (Hervás-Oliver et al., 2021). It complements evolutionary economic geography perspectives that focus on the emergence of concentrations of innovation activity, via complex processes that places great importance on development and change (Coenen et al., 2017; Boschma and Frenken, 2006; Isaksen and Trippl, 2017).

Summarizing, we expect the two DUI and the two STI drivers to interact in complex ways to form distinct configurations explaining innovation performance. We further expect that different configurations explain innovative sales performance compared to employment in knowledge-intensive activities, and that these configurations change in geographical scope and temporal stability. However, given the inconsistencies in previous research and the overall lack of comparative and longitudinal research in this area, previous work is not sufficient for us to develop and test specific propositions. Instead, we follow an inductive configurational approach to explore "*how or why multiple attributes combine into distinct configurations to explain a phenomenon, while also recognizing that complex causal explanations may involve more than one configuration of attributes leading to the outcome of interest*" (Furnari et al., 2021: 779).

A configurational approach thus allows us to provide more nuanced analysis that considers complex interaction effects of different innovation mode drivers and different innovation performance outcomes and how they vary across different regions as well as time. These complex interaction effects have long been overlooked given the inability of traditional regression analysis to identify often complex interactions between different innovation drivers and spatial specificities and their combined effects on innovation performance at firm as well as regional level.

6. Methodology

Fuzzy-set Qualitative Comparative Analysis (fsQCA) is now an increasingly popular technique (Kumar et al., 2022; Nikou et al., 2022) due to its advantage of exploring causal complexity by identifying multiple configurations, i.e. specific combinations of interconnected conditions that explain the desired outcome (Rihoux and Ragin, 2009). It is an asymmetrical approach that builds on complexity theory (Misangyi et al., 2017) and on set-theoretical principles and Boolean algebra (Ragin and Fiss, 2008). Compared to symmetrical approaches, such as for example regression-type analysis, that predominantly identify which variable has the greatest effect, fsQCA identifies how different conditions interact to explain an outcome of interest. FsQCA is thus particularly useful when analyzing complexity, i.e. situations "in which an outcome may follow from several different combinations of conditions" (Ragin, 2008: 23). FsQCA achieves this by combining "the reasoning and methodological rigor of case-oriented qualitative methods for capturing rich contextual information with variable-oriented quantitative methods that deal with a larger number of cases, resulting in much more generalizable analytical inferences (Kumar et al., 2022: 2).

Findings from fsQCA reflect complexity theory through three key characteristics: The first is conjunctional causation, where some conditions might have an effect in conjunction with other conditions, but not on their own (Schneider and Wagemann, 2010; Woodside, 2013). The second is equifinality, where more than one combination may lead to the same outcome (Fiss, 2011). Lastly, fsQCA reveals asymmetrical relationships between conditions and outcomes, where configurations for presence of an outcome, such as high innovative sales performance, differ from configurations for absence of that outcome (Meyer et al., 1993).

To better understand temporal effects, we apply panel fsQCA, a novel

approach to analyze the distribution of consistency and coverage across cases and over time (Guedes et al., 2016). We follow the approach developed by Garcia-Castro and Ariño (2016) to apply qualitative comparative analysis to panel data sets to explore how innovation modes evolve over time, specifically with regards to geographical coverage and temporal stability.

Previous research on SME innovation modes has either used qualitative approaches (e.g. Alhusen and Bennat, 2021; Trott and Simms, 2017) or regression-type analysis using cross-sectional data (e.g. Hervás-Oliver et al., 2021; Parrilli and Radicic, 2021; Thomä and Zimmermann, 2020). The added value of our approach lies in providing a more differentiated understanding of SME innovation modes that goes beyond identifying net effects of explanatory variables (Woodside, 2013) to accounting for geographical complexity as well as temporality.

6.1. Data and measures

This study builds on data from the EU Regional Innovation Scoreboard (RIS) for 2011, 2013, 2015, 2017 and 2019. RIS allows analysis of regional innovation based on 21 indicators mirroring the indicators used in the European Innovation Scoreboard. It includes comparable innovation relevant data for 221 regions across 22 EU Member States, country level data for (EU countries) Cyprus, Estonia, Latvia, Luxembourg, and Malta (in these countries NUTS 1 and NUTS 2 level are identical to country) as well as data for the (non-EU) regions of Norway, UK, Serbia, and Switzerland. The research makes use of the data as made available in the dataset, the data simply indexed against the EU average, such that the EU average = 100. The data has not been processed beyond and these indices have been used in prior research, as highlighted in Beynon et al. (2021).[1]

6.1.1. Outcomes

Innovative sales performance (ISP) is an index created by comparing sales of new-to-market and new-to-firm innovations as a percentage of total turnover for SMEs in each region against the EU average for this indicator. Radicic et al.'s (2019) empirical study identified technological (product and process) innovations, and non-technological (organizational and marketing) innovations as potentially complementary with commercial success of product and process innovations (i.e., innovative sales). This outcome was also previously used by Květoň and Kadlec (2018) and Żelazny and Pietrucha (2017). Employment in knowledge-intensive activities (EMK) is an index created by comparing proportions of employed persons in medium- and high-tech manufacturing sectors and knowledge-intensive services sectors in each region against the EU average for this indicator. Leydesdorff and Fritsch (2006) suggested regional innovation system quality in Germany was largely determined by medium- and high-tech manufacturing, the high-tech component of knowledge-intensive services also linked specifically, while knowledge-intensive service firms operating at an inter-regional level may also be important conduits for knowledge spillovers across regions. Krätke (2007) used a variation of this outcome in analyzing concentration of the European knowledge economy. Graphical (scatterplot and boxplot) elucidation of these ISP and EMK index values are shown in Fig. A1 in the appendix, over the considered separate years, indicating variation across the specific years for these outcomes, which supports the need for this longitudinal approach.

6.1.2. Conditions

For DUI-based conditions, SMEs in-house innovation capacity (IIC) is an index of SMEs innovating in-house as a percentage of SMEs in each region against the EU average for this indicator. SMEs external interactions along the supply chain (EI) is an index created by measuring innovative SMEs collaborating with others as a percentage of SMEs in each region against the EU average for this indicator. STI-based conditions are then Scientific, R&D intensive cooperation (R&D), an index created by comparing public-private (excludes the private medical and health sector) co-publications (academic publications) per million population in each region (publications assigned to the country/countries in which the businesses or other private sector organizations are located) against the EU average for this indicator. This type of cooperation is relatively low risk for SMEs (Radicic et al., 2019), but indicates regional interactivity and linkages as enablers of innovation (Autant-Bernard et al., 2006; Żelazny and Pietrucha, 2017). Qualified human capital (HC) is an index of percentage of population aged 25–34 in each region who completed tertiary education, against the EU average for this indicator. De Noni et al. (2018), identify regional innovation as partly depending on local human capital, and use tertiary educational attainment as a proxy for this human capital.

6.2. Analysis

Analysis was performed in five steps that we outline here. The detailed descriptions and justifications including tables and visualizations are reported in the appendix. The analysis was performed using the statistical programming language R, using the QCA package which provides the most comprehensive range of functionalities for conducting various types of QCA data analysis (Nikou et al., 2022). In addition, MAPLE (www.maplesoft.com) was used to aid with data calibration and visualization. The five steps are next briefly described;

i) The first step was to perform *data calibration*, meaning transforming the raw data into set membership scores. Conditions and outcomes are considered in terms of fuzzy sets, where values relate to degree of membership of a case to the condition or outcome. The transformation process to fuzzy sets employed here is the direct method described in Ragin (2008), which includes identification of qualitative anchors (cut-off thresholds), see Fig. A2 in appendix and surrounding discussion.
ii) Following best practice expressed by Schneider and Wagemann (2010), the second step was to perform *necessity analysis* to assess whether any of the conditions are necessary for the outcome (Vis and Dul, 2018). It was found no conditions were viewed as necessary (see Table A1 and Fig. A3).
iii) Next, we performed *sufficiency analysis* to assess the conditions that are sufficient to produce the outcome based on a truth table (see Table A2 in appendix – including impact of established frequency and consistency thresholds – see Fig. A4). This allows construction of solutions of recipes describing the relationship between conditions and outcomes. Three different solutions can be considered, parsimonious, intermediate and complex. This approach follows Ragin's (2008) illustration of the complexity-parsimony continuum, where easy counterfactuals cannot be identified, complex and intermediate solutions are identical. In this study, no easy counterfactuals are considered appropriate (the longitudinal nature of the study mitigates ability to consider easy counterfactuals on the European region level or year level separately – as both would need to be considered). Hence two solutions are considered, complex (equating to intermediate – Beynon et al., 2020), and parsimonious. Consequent sufficiency analyses associated with both outcomes (ISP and EMK) are shown in Table 1.
iv) To understand the temporal stability of recipes, the next analytical step included the analysis of fsQCA results across different years and regions, using *panel data and techniques* developed by Garcia-Castro and Ariño (2016) and Guedes et al. (2016). The impact of time is considered in two ways, i) between cross-sectional measures of consistency (BECONS) representing specific year observations, and ii) across time measures of

[1] https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en

Table 1
Sufficiency analysis results for presence and absence of innovative sales performance (ISP) and employment in knowledge-intensive activities (EMK) outcomes.

Conditions	Innovative Sales Performance (ISP)					Employment in knowledge-intensive activities (EMK)			
	ISP		~ISP[b]			EMK		~EMK[b]	
Complex Solution	COISP1	COISP2	CNISP1	CNISP2	CNISP3	COEMK1	COEMK2	CNEMK1	CNEMK2
DUI driver (IIC): In-house innovation capacity		●	●	⊖	⊖		●	⊖	
DUI driver (EI): External interaction along the supply chain	●	●	⊖	⊖	⊖				●
STI driver (R&D): Scientific, R&D intensive cooperation	⊖	●	●	●	⊖	●	●	⊖	⊖
STI driver (HC): Qualified human capital	●	⊖	⊖	●	⊖	●			
Configurations (in strong membership terms)	6, 14	15	11	4	1	4, 8, 12, 16	11, 12, 15, 16	1, 2, 5, 6	5, 6, 13, 14
Consistency[a]	0.868	0.904	0.910	0.900	0.891	0.854	0.875	0.821	0.836
PRIscore[a]	0.571	0.563	0.547	0.614	0.774	0.698	0.734	0.703	0.564
Raw Coverage[a]	0.414	0.410	0.277	0.243	0.446	0.563	0.603	0.687	0.432
Unique Coverage[a]	0.121	0.117	0.076	0.057	0.247	0.085	0.126	0.357	0.103
Solution Consistency, PRI score, Coverage	0.857, 0.545, 0.531		0.883, 0.750, 0.593			0.848, 0.709, 0.689		0.803, 0.672, 0.790	
Parsimonious Solution	POISP1	POISP2	PNISP1	PNISP2	PNISP3	POEMK1		PNEMK1	PNEMK2
Configurations (in strong membership terms)	6, 14	15	11	4	1	4, 8, 11, 12, 15, 16		1, 2, 5, 6	5, 6, 13, 14
Consistency[a]	0.868	0.895	0.911	0.904	0.890	0.828		0.821	0.836
PRIscore[a]	0.571	0.554	0.619	0.643	0.772	0.681		0.703	0.564
Raw Coverage[a]	0.414	0.421	0.300	0.281	0.469	0.705		0.687	0.432
Unique Coverage[a]	0.111	0.119	0.075	0.057	0.245	–		0.357	0.103
Solution Consistency, PRI score, Coverage	0.854, 0.540, 0.533		0.881, 0.750, 0.601			0.828, 0.681, 0.705		0.803, 0.672, 0.790	

Note: ● (○) represents the presence (absence) of the condition; blank spaces indicate the condition is irrelevant in the specific recipe. Large and small sized circles denote whether the condition is deemed core or peripheral.
[a] The consistency and coverage values are over the whole data set of cases (not just from those configurations shown associated in strong membership terms).
[b] ~ sign refers to absence of the outcome.

consistency (WICONS) representing specific European-region observations. Both measures (BECONS and WICONS) are considered for recipes from the complex solutions associated with each outcome. As previously, these are also explained in detail in the appendix.

v) As a last step, *map-based analysis* was conducted to depict the geographical scope of each identified recipe as well as its evolution over time[2] (see Figs. 1 and 2).

7. Findings

7.1. Innovation mode recipes based on fsQCA

First, we consider results for innovative sales performance (ISP). Table 1 shows presence of high innovative sales performance is described by two recipes, (COISP1 and COISP2), both representing a combined DUI-STI mode. Both recipes feature SMEs' external interactions along the supply chain as a core condition. In recipe COISP1, this DUI driver is only complemented by access to qualified human capital, but not by scientific, R&D intensive cooperation. Thus, this recipe represents a *non-R&D intensive DUI-STI mode*. In recipe COISP2, both DUI drivers are present with scientific, R&D intensive cooperation substituting for absence of qualified human capital. Compared to the previous recipe, this recipe represents a more *balanced DUI-STI mode*.

Three recipes (CNISP1, CNISP2, CNISP3) then describe absence of high innovative sales performance. It is noteworthy that SMEs' external interactions along the supply chain is absent from all three recipes. Due to the lack of the external DUI driver, CNISP1 represents an *ineffective innovation mode*, engaging in R&D cooperation and relying on in-house innovation capacity alone not creating sufficient economic benefit in terms of innovative sales performance. Similarly, CNISP2 is an *ineffective STI mode* as STI drivers on their own are not supporting innovative sales performance. Lastly, CNISP3 represents an *ineffective non-innovation mode* with all DUI as well as STI drivers being absent.

For employment in knowledge-intensive activities, results in Table 1 show two recipes (COEMK1 and COEMK2) explaining presence of high regional knowledge-intensity. COEMK1 represents an *effective STI mode* with presence of scientific, R&D intensive cooperation as well as qualified human capital. While these two STI drivers were not sufficient to explain presence of high innovative sales performance, they are sufficient to explain presence of high regional knowledge-intensity. This highlights the specific role STI drivers play in sustaining innovation performance at the regional level, but not necessarily the firm level. The second recipe COEMK2, represents a *R&D intensive DUI-STI mode* in which presence of scientific, R&D intensive cooperation complemented by presence of in-house innovation capacity is sufficient to sustain high regional knowledge-intensity. In contrast, the same two conditions were not sufficient to explain presence of high innovative sales performance (CNISP2). This shows the importance of using multi-level conceptualization of innovation performance accounting for firm level economic outcomes as well as regional level outcomes.

Lastly, two recipes (CNEMK1 and CNEMK2) describe absence of high employment in knowledge-intensive activities. CNEMK1 represents an *ineffective non-innovation mode* with all innovation drivers being either absent or not relevant. Similarly, CNEMK2 represents an *ineffective DUI mode* where presence of a sole DUI driver is not sufficient to sustain a knowledge-intensive-economy.

In summary, the recipes identified in this study show that combinations of innovation drivers explaining innovation performance at the firm level (i.e. innovative sales performance) differ from those explaining innovation performance at the regional level (i.e. employment in knowledge-intensive activities). In particular, results show the DUI mode alone is not sufficient to explain presence of sustained innovative sales performance, a combined STI-DUI mode being required. In these combined STI-DUI mode recipes, for the external DUI mode driver, SMEs' interactions along their supply chain is a condition complemented by at least one of the two STI mode drivers. Lastly, our findings show presence of the two STI drivers is not sufficient to explain presence of sustained innovative sales performance, but is sufficient to explain presence of sustained knowledge-economies. Tables 2 and 3 provide short summaries of each recipe with their corresponding labels.

[2] While certain island European regions are not included in the maps provided, they are included in the results and where pertinent they are included in the discussion of the analysis given later.

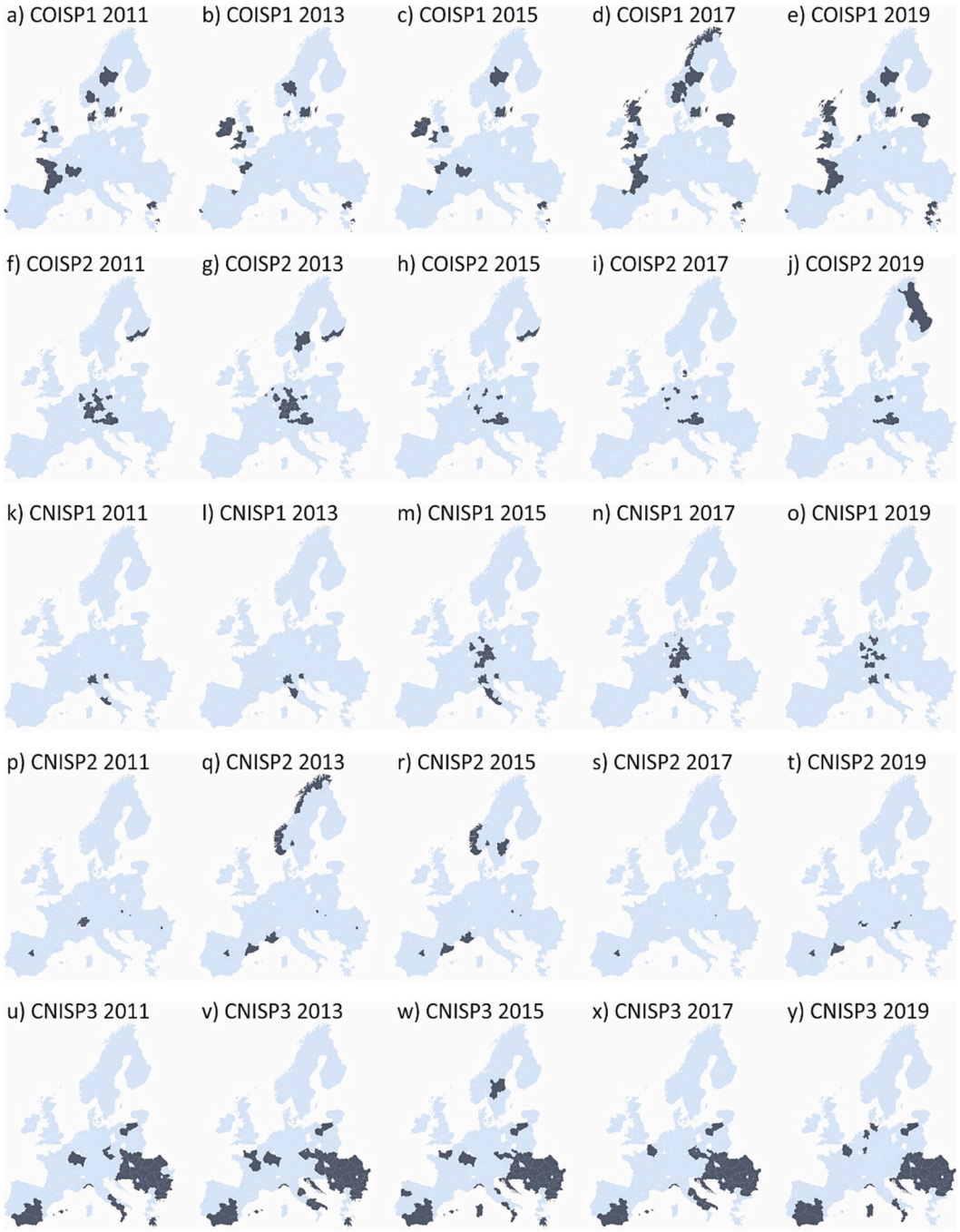

Fig. 1. Innovative sales performance recipe maps of associated European regions (in strong membership terms) shown by year.

7.2. Evolution of innovation mode recipes across regions and time based on panel and map-based analysis

Year-effect analysis based on BECONS values shows the strength of association of recipes fluctuates in consistency over time. While recipes explaining presence of high innovative sales performance decreased in consistency over time, recipes explaining presence of high employment in knowledge-intensive activities remained comparatively stable. For presence of outcomes (COISP1 and COISP2; COEMK1 and COEMK2), the relevant WICONS values suggest that, for around 50 of the included regions, there is strong consistency, while the other regions have different levels of inconsistency across the years they are included in the analysis. For absence of outcomes (CNISP1, CNISP2 and CNISP3; CNEMK1 and CNEMK2) the relevant WICONS values show that for each recipe, around 20–40 regions have strong consistency in terms of the recipes with which they are associated. The other regions have different levels of inconsistency across the years they are included in the analysis.

Geographical analysis of innovation mode recipes related to innovative sales performance show the *non-R&D intensive DUI-STI mode* (COISP1) is a Northern and Western European focused recipe, often geographically peripheral, but remaining relatively stable over time, changing from 15 regions in 2011 to 22 in 2019. The majority of regions, however, are not consistently associated with this recipe with only five regions (Attiki, Kentriki Makedonia, Pays de al Loire, Småland med öarna and Wales) associated across all years. The *balanced DUI-STI mode* (COISP2) is a central European (particularly Germany and Austria) and to a minor extent Scandinavian (particularly Finland) focused recipe that has reduced radically in geographical coverage, from 16 regions in

Fig. 2. Employment in knowledge-intensive activities recipe maps of associated European regions (in strong membership terms) shown by year.

Table 2
Recipe names: Innovative sales performance (ISP).

Recipe	Description	Recipe name
COISP1	SMEs' external interactions along the supply chain as a core condition, this DUI driver is only complemented by access to qualified human capital, but not by scientific, R&D intensive cooperation.	Non-R&D intensive DUI-STI mode
COISP2	Both DUI drivers are present with scientific, R&D intensive cooperation substituting for absence of qualified human capital.	Balanced DUI-STI mode
CNISP1	SMEs' external interactions along the supply chain is absent, and due to the lack of this external DUI driver, as well as human capital, engaging in R&D cooperation and relying on in-house innovation capacity alone does not create sufficient economic benefit in terms of innovative sales performance	Ineffective innovation mode
CNISP2	Both DUI drivers are absent, STI drivers on their own are not supporting innovative sales performance.	Ineffective STI mode
CNISP3	All DUI as well as STI drivers are absent.	Non-innovation mode

2011 to only five regions by 2019. Because the *balanced DUI-STI mode* (COISP2) requires SMEs to have presence of both in-house innovation capacity and scientific, R&D intensive cooperation, this suggests that SMEs in-house innovation capacity in relation to external R&D cooperation has become more difficult in the regions covered by this recipe, specifically after 2013 the regions best described as non-core regions of the countries they are located in. Regions in Germany make up the majority of regions associated with this recipe, however only one of the regions (Dresden) is consistently associated across all years. In contrast, there are two Austrian regions (Südösterreich and Westösterreich) which are continuously associated with this recipe.

Notably, there are no regions where the two recipes associated with the presence of innovative sales performance - the *non-R&D intensive DUI-STI mode* (COISP1) and the *balanced DUI-STI mode* (COISP2) - appear simultaneously, suggesting the two innovation recipes are *substituting* for each other, one recipe sufficient to achieve sustained innovation performance. Specifically, these recipes include *either* intense R&D cooperation (with in-house SME innovation capacity) *or* use of high levels of human capital, the fact that the regions covered tend to be economically peripheral to the countries they are located in suggesting that complete innovation systems are not in place and thus strategic choices need to be made (a view supported by the low numbers

Table 3
Recipe names: employment in knowledge-intensive activities (EMK).

Recipe	Description	Recipe name
COEMK1	Presence of scientific, R&D intensive cooperation as well as qualified human capital sufficient to sustain high regional knowledge-intensity.	Effective STI mode
COEMK2	Presence of scientific, R&D intensive cooperation complemented by presence of in-house innovation capacity is sufficient to sustain high regional knowledge-intensity.	R&D intensive DUI-STI mode
CNEMK1	All innovation drivers either absent or not relevant.	Ineffective innovation mode
CNEMK2	Presence of a sole DUI driver not sufficient to sustain a knowledge-intensive-economy.	Ineffective DUI mode

of regions having both COISP and COEMK recipes identified later).

The *ineffective DUI-STI mode* (CNISP1) is a recipe that solely covers regions in Italy and Germany. Its coverage over time increases from three regions in 2011 to 15 in 2019, with regions in Germany increasing over time, while regions in Italy are decreasing. The only region consistently associated with that recipe is Lombardia in Italy. The *ineffective STI mode* (CNISP2) is a geographically peripheral recipe inconsistently distributed over the years, with the number of regions covered ranging between two and ten. The two regions consistently associated with this recipe are Comunidad de Madrid in Spain and Budapest in Hungary. The *ineffective non-innovation mode* (CNISP3) is a Southern and South-East European focused recipe covering 63 regions in total, with coverage across years remaining relatively stable ranging from 44 to 51. However, 33 of these regions were associated with this recipe across all years. Fig. 1 illustrates the geographical coverage over time of each of the recipes.

Analysis of innovation mode recipes related to employment in knowledge-intensive activities show that the *effective STI mode* (COEMK1) seems to have a European capitals / major cities and hinterlands-focused geography, stable in coverage, ranging from 51 regions in 2011 to 59 in 2019. Interestingly, 45 regions are consistently associated with this recipe across all years. The *R&D intensive DUI-STI mode* (COEMK2) seems to have a dual Scandinavian and Central Europe geographical focus, again covering predominantly core regions and growing in coverage, from 46 regions in 2011 to 63 in 2019. A large number of regions (34) are consistently associated with this recipe across all years. The *ineffective DUI mode* (CNEMK1) is a geographically peripheral recipe, with strong concentration in Spain and Eastern Europe slightly falling in coverage, the number of regions ranging from 91 in 2011 to 81 in 2019, with 64 regions being consistently associated with this recipe across all years. The *ineffective non-innovation mode* (CNEMK2) is a Northern and Western Europe focused recipe, again geographically peripheral and slowly rising in coverage, from 38 regions in 2011 to 45 in 2019. Fourteen regions are consistently associated with this recipe across all years. Fig. 2 illustrates the geographical coverage over time of each of the recipes.

In contrast to a *substitution effect* for the two recipes (COISP1 and COISP2) explaining the presence of innovative sales performance, we find a *complementary effect* for the two recipes (COEMK1 and COEMK2) explaining presence of employment in knowledge-intensive activities. This may be because both recipes are built around intense R&D cooperation, which can beneficially be combined with, and also because the economic geography of these recipes is focused around core regions, which tend to be better resourced and more attractive than peripheral ones, making presence of both in-house SME innovation and human capital more likely.

There are 182 instances where the two recipes – *effective STI mode* (COEMK1) and *R&D intensive DUI-STI mode* (COEMK2) appear simultaneously, suggesting the two can complement each other to achieve sustained innovation performance. Overall, this phenomenon occurs in 58 of the 221 regions, geographically concentrated in Central and Northern Europe (Belgium, Denmark, Germany, Ireland, France, Netherlands, Finland, Sweden, UK, Switzerland, and Norway) and in capital city regions (of the Czech Republic and Austria, as well as covering capital regions of all the other countries previously mentioned apart from the UK). The temporal patterns are more complex. While the number of regions associated with this phenomenon rose from 26 regions in 2011 to 44 regions in 2019, few regions manage to pursue both recipes simultaneously on a continuing basis. Only 16 regions were able to pursue COEMK1 and COEMK2 recipes simultaneously across all years. Belgium, Germany, Netherlands, Finland, Sweden, and Switzerland have the highest proportions of their regions covered across most years, with Ireland and Norway having high proportions of their regions covered in the last two data points. This also suggests that small countries like Ireland and Norway are successfully improving the quality of their regional innovation, achieving beneficial outcomes in terms of employment in knowledge-intensive activities from so doing. It needs to be highlighted, however, that simultaneous presence of the two innovation recipes is both a geographically concentrated (in economically regions of the countries concerned) and relatively rare phenomenon.

There are even fewer regions (60) where presence of both innovative sales performance and employment in knowledge-intensive activities occur simultaneously. This involves exclusively combination of the *balanced DUI-STI mode* (COISP2) and the *R&D intensive DUI-STI mode* (COEMK2). These 60 regions are also unevenly distributed across the years, growing from 17 in 2011 to 24 in 2013, but then dropping to seven in 2015, eight in 2017 and only four in 2019. This illustrates that sustaining innovation performance at the firm level as well as the system level over an extended period is difficult and thus a rare phenomenon that only occurs in selected regions. Germany, while accounting for 38 of the 60 regions overall, has only one region (Dresden) consistently associated with presence of both outcomes simultaneously. This compares with two Austrian regions (Südösterreich and Westösterreich). Further, Koln and Thüringen appear in three of the years, along with Etelä-Suomi in Finland, and Flevoland in the Netherlands. These are not core economic regions in these countries, suggesting that DUI-STI modes are being used to build the economy through innovation from small firms, to a fuller innovation system, making these regions relevant for future study. This is particularly given that only Austria, Germany, Finland, the Netherlands, Sweden, and Denmark have regions achieving both outcomes simultaneously, suggesting that for most European regions these two regional performance outcomes are substitutive rather than complementary.

8. Discussion

This study advances understanding of innovation performance by identifying configurations of SME innovation drivers, their geographical scope, and stability, over time. This study provides several contributions to knowledge as well as to practice discussed in detail below.

8.1. Contributions to knowledge

Previous research has identified sole DUI mode to be effective for SMEs (Amara et al., 2008; Thomä, 2017; Trott and Simms, 2017). However, considering a nine-year time frame provides a more nuanced evidence on the relevance of DUI and STI modes. Our findings show that DUI drivers on their own are unable to explain innovation performance when measured as sustained innovative sales and even less so when measured as sustained employment in knowledge-intensive activities.

As DUI modes predominantly result in incremental innovations following existing technological paths, lack of renewal, and stagnation is likely to erode competitiveness of SMEs in the long-term.

Proposition 1. For SMEs, DUI mode on its own is unable to sustain innovation performance in the long-term.

In particular, DUI modes that rely solely on SMEs in-house innovation capacity to generate innovative sales performance (as identified by Beynon et al., 2021) are not viable in the long-term. Instead, our findings show that external DUI drivers (i.e. SMEs interaction along the supply chain) becomes a necessary condition to achieve high innovative sales performance over an extended period. In the absence of strong SME interactions along their supply chain, high innovative sales performance cannot be sustained. As a result, findings of our study highlight that - in the long-term - STI mode drivers need to complement DUI mode drivers - in particular SME external interactions along their supply chain - for regions to achieve sustained innovative sales performance. As a complement to DUI mode drivers, the two STI mode drivers act as substitutes, meaning only one STI mode driver is necessary to complement DUI mode drivers to explain sustained innovative sales performance.

Proposition 2. For SMEs to achieve sustained innovation performance, they need to pursue an innovation mode that combines an internal and/or external STI driver with at least one external DUI driver.

By contrast, sole STI mode innovation becomes more relevant, specifically to explain variations in quality of regional innovation systems. While Beynon et al. (2021) did not identify a sole STI mode recipe pointing towards the lack of economic benefit of engaging in STI for SMEs (Apa et al., 2021), the STI mode did become important when innovation performance was measured as employment in knowledge-intensive activities. STI modes require more structural investments, benefits of which are only seen when considering a longer timeframe and only in relation to the extent to which knowledge is used in economic activities across different regions (Hervás-Oliver et al., 2021; Thomä and Zimmermann, 2020). As such, this study demonstrates that recipes representing only STI mode drivers are associated with more knowledge-intensive regional economies.

Proposition 3. For SMEs, sole STI mode only explains innovation performance at the regional level, but not at the firm-level.

Overall, these findings contribute to the innovation mode literature by showing that whether DUI and/or STI modes are effective in the context of SMEs depends on the timeframe, but also the innovation performance outcome considered. While sole DUI modes might appear to be relevant when looking at a single point in time, they are unable to sustain innovation performance when an extended timeframe is considered. In this case, it is combined DUI-STI modes that are most effective, confirming recent research (Apanasovich et al., 2016; González-Pernía et al., 2015; Nunes and Lopes, 2015). However, by providing more in-depth insights into the conditions under which different innovation modes are potentially more effective, this study makes an important contribution to unraveling some of the inconsistencies identified in previous research on regional innovation in the context of SMEs.

Recent scholarly work on temporality of innovation modes (Coenen et al., 2017; Isaksen and Trippl, 2017) acknowledges some regions becoming more innovative and competitive over time, while other become less innovative and competitive. The latest regional innovation scoreboard illustrates these dynamics in innovation performance across EU regions (Hollanders, 2021). Findings from our study extend this line of research by providing in-depth evidence on the *temporal dynamics of regional innovation across Europe*. Broadly speaking, recipes explaining presence of high innovative sales performance decrease in consistency over time, while recipes explaining presence of high employment in knowledge-intensive activities remain relatively stable in consistency over time.

Innovative sales performance as an economic measure is much more prone to firm level fluctuations as it is influenced by firm level demand and supply dynamics. Conversely, employment in knowledge-intensive activities is a structural measure, less prone to firm level fluctuations. The extent to which a region represents a knowledge-intensive economy is thus comparably consistent, with change likely to be more gradual. In-depth analysis across all regions illustrates that a larger proportion of regions associated with recipes related to increased knowledge-intensity were consistently associated with these recipes across all years, compared to regions associated with recipes related to innovative sales performance.

While 66 and 42 % of regions were associated with the *effective STI mode* and the *R&D intensive DUI-STI mode*, only 15 and 5 % of regions were associated with the *non-R&D intensive DUI-STI mode* and the *balanced DUI-STI mode* were consistently associated with the respective recipes across all years. These findings highlight the temporal dynamics of innovation modes, regions unlikely to consistently be associated with one innovation mode. Rather, regions are likely to demonstrate fluctuations over time. However, these temporal dynamics are less pronounced for regions being associated with innovation modes aimed at strengthening knowledge-intensity. Interestingly, findings also point to similar temporal dynamics for absence of innovation performance. The number of regions consistently associated with a recipe related to either absence of high innovative sales performance or absence of high employment in knowledge-intensive activities range from 5 % for *the ineffective DUI-STI mode* to 13 % for the *ineffective STI mode* and 20 % for the *ineffective DUI mode*. In contrast, slightly more than half of all regions associated with one of the two *non-innovation recipes* did not show any change across all years, highlighting the relative stability of non-innovation mode recipes compared to the more dynamic change inherent in DUI/STI mode recipes.

Proposition 4. SME innovation modes that are associated with knowledge intensity are more stable over time compared to innovation modes associated with sales performance.

Lastly, findings point towards presence of substitution. Most regions were associated with only a single regional performance outcome supporting the notion of regional innovation pathways (Coenen et al., 2017). This means the large majority of regions in Europe are associated with recipes that *either* allow them to achieve sustained innovative sales performance *or* sustained employment in knowledge-intensive activities, but not both simultaneously. Only three regions in Europe - Dresden in Germany and Südösterreich and Westösterreich in Austria – were associated with a dual pathway, i.e. the *balanced DUI-STI mode* and the *R&D intensive DUI-STI mode* simultaneously across all years. This demonstrates how rare it is to achieve innovation performance at the firm as well as the regional level at the same time. The large majority of regions were associated with a substitution strategy, and their outcome focus was strongly dependent on their geographic location. Findings showed that peripheral regions are primarily associated with recipes focusing on improving firm level innovative sales performance rather than regional knowledge-intensity. In contrast, core regions are primarily associated with recipes focusing on improving the region's knowledge-intensity. Greater institutional and organizational thickness presumably provides these core regions with a critical mass of actors that are also more heterogeneous in nature (Isaksen and Trippl, 2017), allowing for more science and research support. Peripheral regions often lack this critical mass of resources and are thus more likely to pursue recipes that allow them to achieve sustained innovative sales performance, which in turn makes them more prone to fluctuations over time. Further, regional policymakers are often encouraged to focus on firm level over regional level results, leading to tensions in enterprise policy between regional competitiveness and economic and social disadvantage goals (Huggins and Williams, 2011).

Proposition 5a. SMEs in peripheral regions are more likely to pursue

innovation modes focused on improving innovative sales performance.

Proposition 5b. SMEs in core regions are more likely to pursue innovation modes focused on improving regional knowledge intensity.

8.2. Practical implications

Practical implications of this study itself are also pertinent to policy makers, as it provides a comprehensive analysis of development of regional innovation systems across Europe to inform policy. For policymakers, this suggests potential to identify and compare (particularly peripheral) regions associated with different recipes and outcomes, allowing analysis of efficacy of policies undertaken within those economic geographies. Given relative rareness of regions seeing movements between presence and absence of outcomes, these regions (Karlsruhe, Darmstadt, Stuttgart, Braunschweig, Köln, Rheinhessen-Pfalz, Thüringen, Oberfranken, Hannover, Unterfranken, Gießen, Saarland in Germany, Midtjylland, Nordjylland, and Sjælland in Denmark, Flevoland, Zeeland in the Netherlands, Northern and Western, Southern, Eastern and Midland in Ireland, Scotland and South West in UK, Mellersta Norrland, Norra Mellansverige in Sweden, Bratislavský kraj in Slovakia, Cataluña in Spain, Bucuresti - Ilfov in Romania, Nord-Norge in Norway, Bretagne in France), may be of particular relevance to policymakers, as both positive and negative examples. Overall, our findings echo earlier research that points towards the importance of place-based innovation policies (Sunley et al., 2023; Trippl et al., 2020) that strongly engage SMEs in the innovation debate.

9. Conclusions

These findings offer novel insights into the diverse and complex nature through which regional innovation evolves over time. Consequently, this study advances understanding on the regionalization as well as temporality of SME innovation modes in Europe.

9.1. Limitations and future research directions

Despite our study's strengths, including applying *panel* fsQCA to five waves of data, however, we also acknowledge a number of limitations. First, while the EU Regional Innovation Scoreboard includes specific indicators to allow for evaluation of differences in innovation across EU regions, some conditions included in this study are proxies for innovation mode drivers. In the absence of more suitable data at the EU regional level, public-private co-publications has been used in previous studies as a proxy driver for STI mode (Radicic et al., 2019; Autant-Bernard et al., 2006; Żelazny and Pietrucha, 2017), but this is only one component of scientific, R&D intensive cooperation.

Second, we were not able to consider the role of specific sectors in our study. As previous research has indicated differences in innovation modes across industries (Thomä and Zimmermann, 2020), this is a relevant avenue for future research requiring harmonized data on the representation of regional industries in the EU. Third, based on data availability, we examined development of regional innovation across a nine-year timeframe. While this constitutes a key strength of the study compared to previous, mostly cross-sectional studies, the development of regional innovation systems is ideally tracked over 15 to 20 years to better account for economic cycles.

Findings from this study could also be extended by mapping innovation support and policy interventions against recipes and associated configurations identified in this research. In particular, it would be interesting to explore relationships between policy interventions and different innovation mode recipes and their pathways, to better understand differential impacts of innovation policy in Europe. From an empirical perspective, we also echo a call by Parrilli and Radicic (2021) to make more use of Qualitative Comparative Analysis (QCA), and here in particular panel fsQCA, to explore the complex combination of innovation mode drivers at the firm, but also the regional level.

To conclude, future research could explore the substitution phenomenon in more depth. While prior research has pointed towards importance of organizational and/or institutional thickness (Isaksen and Trippl, 2017) and tensions between enterprise policy (Huggins and Williams, 2011), the mechanisms behind this substitution focus is not yet well understood. Equally important, however, is a better understanding of the innovation dynamics in peripheral regions to help them level up. For EU innovation policy to be effective, peripheral regions, particularly those in Southern and Eastern Europe, need particular attention.

CRediT authorship contribution statement

Malcolm Beynon: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **David Pickernell:** Conceptualization, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Martina Battisti:** Conceptualization, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Paul Jones:** Writing – review & editing.

Declaration of competing interest

None.

Data availability

The data are publicly available.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techfore.2023.123042.

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Malcolm Beynon is Professor of Uncertain Reasoning and Business Analytics at Cardiff. His research involves the development of novel analytic techniques, as well as the progression and application of existing techniques. He is an internationally recognized expert in the uncertain reasoning methodology, which he applies across all areas of management (as well as other disciplines).

David Pickernell is a Professor of Small Business and Enterprise Development Policy at Swansea University. His research interests cover topics related to small business, enterprise and economic development policy, entrepreneurship, economic clustering and the role of universities in innovation and enterprise.

Martina Battisti is Professor of Entrepreneurship at Grenoble Ecole de Management, France. Her current research is at the intersection of entrepreneurship and psychology with a particular focus on emotional and cognitive microfoundations of entrepreneurial behaviour. However, she is also interested in topics related to entrepreneurship and innovation more widely.

Paul Jones is Professor of Entrepreneurship and Innovation at Swansea University. He is an experienced researcher in entrepreneurial behaviour and small business management. Currently, he is Editor-in-Chief of the International Journal of Entrepreneurial Behaviour and Research and Associate Editor for the International Journal of Management Education. Paul is a Senior Fellow of the Higher Education Academy and sits on the Board of Trustees of the Institute of Small Business and Entrepreneurship (ISBE).