

Persistence of SME Innovation Drivers Under Disruption: Longitudinal Evidence from a European Peripheral Region

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Abstract

Understanding the determinants of firm-level innovation is essential for explaining how SMEs sustain competitiveness and adapt to changing economic conditions. This study examines the drivers of innovation in SMEs located in Extremadura, a peripheral Spanish region classified as a European convergence region. Using a unique series of consecutive annual surveys covering the period 2017–2022, the analysis investigates both the determinants of innovation and their stability before and after the COVID-19 pandemic.

The empirical analysis employs logistic regression models with year fixed effects and predicted probability estimates to assess the relationship between firm characteristics, organizational practices, and innovation. The results confirm the importance of structural resources and outward orientation. Firm size and exporting activity emerge as the strongest and most consistent predictors of innovation, while process automation is positively associated with innovation outcomes. Environmental scanning exhibits a negative relationship with innovation, suggesting that intensive external monitoring does not necessarily translate into innovative activity. Organizational variables show limited direct effects once structural and operational factors are taken into account.

To assess temporal stability, interaction effects between key firm practices and the post-COVID period are estimated. The results indicate that these interaction effects are not statistically significant, suggesting that the principal determinants of innovation remained broadly stable despite the disruption generated by the pandemic.

The study contributes to the innovation literature by providing rare longitudinal evidence from a peripheral European region and by demonstrating the persistence of established innovation drivers under conditions of major economic uncertainty. The findings also highlight the importance of place-based policies that support exporting activity, process upgrading, and capability development as mechanisms for sustaining innovation in less-developed regional contexts.

Keywords: Innovation; SME; Firm capabilities; Peripheral regions; COVID-19; Longitudinal analysis

Submitted: June 5, 2026 / Approved: June 24, 2026

1. Introduction

Innovation is widely recognized as a key driver of firm competitiveness and regional development. Yet, the determinants of innovation remain highly heterogeneous across firms and territorial contexts, particularly in peripheral and less-developed regions where structural constraints, weaker knowledge infrastructures, and a predominance of small firms shape innovation opportunities. Although a substantial body of research has examined innovation dynamics in advanced economies and core regions, considerably less is known about how innovation drivers operate and persist over time in convergence regions exposed to major economic disruptions.

A growing body of research in economic geography and innovation studies emphasizes that innovation cannot be understood solely as a firm-level phenomenon, but rather as the outcome of interactions between firms and their regional environments (Cooke, 2001; Lundvall, 2007). Regional innovation systems differ substantially in terms of technological capabilities, institutional quality, knowledge infras-

tructures, and network density, generating distinct opportunities and constraints for firms (Boschma, 2005; Parrilli et al., 2020). As a consequence, innovation drivers are not universally stable across territories but are embedded within region-specific economic and institutional conditions (Rodríguez-Pose, 2013; Isaksen and Trippl, 2017).

These contextual differences are particularly relevant in peripheral and convergence regions. Firms operating in such environments often face thinner innovation systems, characterized by weaker knowledge spillovers, more limited institutional support, and reduced access to innovation networks (Tödtling and Trippl, 2005; Isaksen and Trippl, 2017). As a result, they frequently rely more heavily on internal resources and external market connections to sustain innovation activity. Understanding which factors drive innovation in these contexts, and whether their influence remains stable over time, is therefore of considerable theoretical and policy relevance.

Previous research has identified a broad set of firm-level determinants of innovation, including structural resources, organizational

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practices, and operational capabilities Miranda et al. (2012). In a recent large-scale analysis of European SMEs, Hervás-Oliver et al. (2021) demonstrate that innovation outcomes are shaped by a combination of firm characteristics and capability-related factors whose relevance varies across regional contexts. Their findings reinforce the importance of considering both firm-level and territorial dimensions when explaining innovation performance. However, despite the growing evidence on the determinants of SME innovation, little is known about whether these relationships remain stable when firms face major exogenous disruptions.

The COVID-19 pandemic provides a unique opportunity to examine this issue. The pandemic represented one of the most significant economic shocks in recent decades, disrupting markets, supply chains, organizational routines, and investment decisions. A growing literature has examined its effects on innovation activities, suggesting that crises may simultaneously constrain innovation efforts and stimulate adaptive responses depending on firms' capabilities and resource endowments (Krammer, 2022; Trunschke et al., 2024). Recent contributions further emphasize that shocks can reshape firms' strategic priorities, redirect managerial attention, and affect the returns associated with different organizational and operational practices (Balland et al., 2019; Sargento and Lopes, 2024).

Despite these advances, important gaps remain. First, longitudinal evidence on SME innovation in peripheral European regions remains limited. Second, most studies examine innovation drivers using cross-sectional data, providing little insight into their temporal stability. Third, while the post-pandemic literature has generated important knowledge on firms' responses to disruption, there is still limited evidence on whether the determinants of innovation themselves changed or remained stable following the COVID-19 shock.

Guided by these gaps, this study addresses the following research questions: (RQ1) Which firm-level characteristics and capabilities are most strongly associated with innovation in a peripheral regional context? (RQ2) Do operational and information-related practices, specifically process automation and environmental scanning, maintain their relationship with innovation before and after the COVID-19 shock? and (RQ3) To what extent do established innovation drivers remain stable under conditions of heightened economic uncertainty?

To answer these questions, we exploit a unique series of consecutive annual firm-level surveys conducted in Extremadura, a peripheral region of Spain classified as a European convergence region. The resulting dataset spans the period 2017–2022 and provides a rare opportunity to examine innovation dynamics using repeated cross-sectional evidence collected consistently over multiple years. This temporal perspective allows us not only to identify the principal drivers of innovation but also to assess their stability before and after a major exogenous shock.

The paper makes three contributions. First, it provides longitudinal evidence on the determinants of SME innovation in a peripheral European region, extending a literature that remains dominated by

cross-sectional analyses. Second, it contributes to the growing debate on innovation resilience by examining whether established innovation drivers remained stable following the COVID-19 disruption. Third, it complements previous evidence on European SME innovation, particularly the work of Hervás-Oliver et al. (2021), by showing that the principal determinants of innovation remained broadly stable despite a period of exceptional economic uncertainty. Taken together, the findings highlight the persistence of structural and operational drivers of innovation and underscore the resilience of innovation processes in peripheral regional contexts.

2. Literature Review

Research on SME innovation has increasingly converged on the idea that innovative performance is shaped by the interaction of multiple, interrelated drivers. A common approach in the literature distinguishes between three broad categories: structural resources, firm-level capabilities, and contextual conditions. This classification reflects the multidimensional nature of innovation processes in small firms, where outcomes depend not only on internal characteristics but also on how these interact with external environments and constraints.

Within the set of structural resources, firm size and access to external markets have consistently been identified as key drivers of innovation. Firm size is commonly associated with advantages in financing, risk diversification, and the organization of innovation activities (Cohen and Klepper, 1996). At the same time, exporting activity connects firms to external sources of knowledge, enabling learning, benchmarking, and technological upgrading through exposure to international competition (Salomon and Shaver, 2005; Golovko and Valentini, 2011; Love and Ganotakis, 2013).

Beyond these classical effects, recent research highlights that structural resources influence not only the capacity to innovate but also the direction and intensity of innovation efforts. Cross-country comparative studies show that the drivers of innovation performance vary systematically with income levels and structural conditions, indicating that the effectiveness of firm-level drivers is shaped by broader economic environments (Bate et al., 2023). This reinforces the idea that structural resources must be understood in interaction with contextual conditions rather than as isolated factors.

This perspective is further supported by Hervás-Oliver et al. (2021), who show that SME innovation across European regions depends on a combination of structural resources, firm capabilities, and regional conditions. Their findings highlight the importance of considering both firm-level and territorial determinants when explaining innovation outcomes and provide an important benchmark for understanding innovation in peripheral contexts.

Beyond structural characteristics, a growing stream of literature emphasizes firm-level capabilities as central drivers of innovation. In SMEs, innovation frequently emerges from the accumulation and interaction of internal capabilities, such as managerial practices, operational processes, and market-oriented activities, rather than from

formal R&D investments alone. Evidence from sector-specific studies shows that leadership, strategy, and process management jointly shape firms' innovation capacity, highlighting the importance of organizational and managerial dimensions alongside technological ones (Anzules-Falcones et al., 2020).

At a more general level, recent contributions underline that innovation capabilities are multidimensional and context-dependent, with different types of capabilities generating heterogeneous outcomes depending on firms' resource endowments and external conditions (Del Carpio-Gallegos and Miralles, 2019). In particular, operational capabilities, such as process improvements, automation, and embodied technological change, support incremental innovation through learning-by-doing and continuous adaptation, especially in resource-constrained environments.

The importance of process-related capabilities has been highlighted by Hervás-Oliver et al. (2016), who argue that process innovation capabilities constitute a distinct source of competitive advantage in SMEs. Their findings indicate that firms capable of systematically improving and upgrading operational processes are better positioned to generate innovation outcomes, particularly in resource-constrained environments.

Within this capability-based perspective, information-related practices such as environmental scanning play a more nuanced role. While scanning activities are often associated with improved opportunity recognition, research on knowledge search suggests that their effects depend on firms' absorptive capacity and resource constraints. Extensive search may generate coordination costs, cognitive overload, or reactive behaviour, particularly in SMEs with limited managerial bandwidth (Katila and Ahuja, 2002; Laursen and Salter, 2006). As a result, information practices do not necessarily translate into innovation, and may in some cases reflect defensive or uncertainty-driven responses.

Organizational practices add an additional layer of complexity to the analysis of innovation drivers. Rather than exerting strong direct effects, factors such as coordination mechanisms, adaptability, and customer orientation typically operate through complementarities with other firm-level capabilities. This perspective is consistent with the distinction between STI (science–technology–innovation) and DUI (doing–using–interacting) modes of innovation, which emphasizes the importance of interactions between technological capabilities, organizational routines, and market relationships (Jensen et al., 2007; Fitjar and Rodríguez-Pose, 2013).

This argument is consistent with the findings of Hervás-Oliver et al. (2014), who show that organizational innovation and process innovation are closely interconnected in SMEs and that innovation outcomes often depend on the complementarity between organizational arrangements and operational improvements rather than on isolated practices. Their results suggest that organizational factors may act as enabling conditions that enhance the effectiveness of other innovation-related capabilities.

Recent research further supports this view by showing that innovation outcomes in SMEs are shaped by configurations of interdependent practices rather than isolated factors. Organizational capabilities facilitate the integration of knowledge and resources, enabling firms to leverage operational investments and external linkages more effectively, particularly under conditions of resource scarcity and environmental uncertainty (Díaz-Duarte et al., 2025).

In this context, specific organizational dimensions such as adaptability, customer orientation, coordination mechanisms, and perceived competitive pressure have been identified as relevant factors shaping firms' ability to respond to changing environments and to integrate internal and external knowledge. While their effects are often indirect and contingent on complementarities with other capabilities, these dimensions capture important aspects of how firms organize and deploy resources in support of innovation activities, particularly within DUI-oriented processes and organizational configurations that enhance workforce flexibility and knowledge integration (Jensen et al., 2007; Parrilli et al., 2020; Franco and Landini, 2022).

Importantly, the relative importance of these drivers is not uniform across contexts. A well-established stream of research in economic geography highlights that firms located in peripheral or convergence regions face structural constraints that differ significantly from those in core regions, including weaker knowledge infrastructures, limited institutional support, and reduced access to innovation networks (Tödtling and Trippel, 2005; Isaksen and Trippel, 2017).

These contextual differences shape not only the level of innovation but also the mechanisms through which it is generated. Firms in peripheral regions tend to rely more heavily on internal capabilities and external market connections to compensate for weaker local spillovers, while the effectiveness of innovation drivers depends on region-specific conditions such as institutional quality and network density (Parrilli et al., 2020; Rodríguez-Pose, 2013). This reinforces the view that innovation is inherently context-dependent and that firm-level drivers cannot be fully understood without considering the territorial environments in which firms operate. Although previous studies have identified the principal determinants of SME innovation across European regions (Hervás-Oliver et al., 2021), considerably less attention has been devoted to examining whether these relationships remain stable over time, particularly in peripheral and convergence regions exposed to major economic shocks.

Finally, recent research has examined how major exogenous shocks affect innovation dynamics. Evidence from economic crises suggests that adverse shocks can simultaneously constrain innovation investment and trigger adaptive responses, depending on firms' resource endowments and strategic flexibility (Archibugi et al., 2013; Amore, 2015).

More recent studies highlight that firm resilience and innovation capabilities play a central role in enabling firms to survive and adapt under conditions of environmental turbulence (Kyrdoda et al., 2023). While existing evidence suggests that major disruptions may affect

innovation trajectories and firms' strategic responses, it remains unclear whether such shocks fundamentally alter the determinants of innovation themselves. Consequently, an important unresolved question is whether established innovation drivers persist under conditions of heightened uncertainty or whether their effects change following major exogenous disruptions such as the COVID-19 pandemic.

3. Methodology

Building on the conceptual framework, the empirical analysis examines how structural resources, operational and information-related capabilities, and organizational practices jointly shape firm-level innovation in a peripheral regional context, and whether these relationships remained stable following the COVID-19 pandemic.

3.1. Data and sample

The empirical analysis is based on a unique longitudinal dataset constructed from the annual innovation surveys developed by the Chair of Innovation at the University of Extremadura. These annual reports collect data on firm-level innovation activities, organizational practices, and market conditions in the Autonomous Community of Extremadura, a peripheral region of Spain, with a lower GDP per capita and a higher unemployment rate than national average.

From an innovation point of view, Extremadura is currently defined by a strategic shift toward digitalization and green energy, as part of its regional innovation context anchored by the RIS3 Extremadura 2027 strategy (Junta de Extremadura, 2021). Within the analysis period (2017–2022), a structured questionnaire was administered to a sample of (SMEs) headquartered in Extremadura, covering a wide range of sectors and firm sizes. The survey collected detailed primary data on innovation-related behaviours and managerial practices at the firm level, including dimensions that are not typically captured in standard innovation statistics, such as internal coordination mechanisms, environmental scanning, and organizational adaptability.

A notable strength of this data source is its annual continuity and consistency in survey design, which allows for the construction of a repeated cross-sectional time series covering multiple consecutive years, rather than isolated snapshots. This enables a more nuanced assessment of temporal patterns in the drivers of innovation, including the stability of innovation drivers around major economic shocks such as the COVID-19 pandemic. The availability of these consecutive annual data distinguishes this study from most innovation surveys, which are typically conducted at long intervals or limited to a single cross-section.

Beyond its regional focus, the dataset offers a rare opportunity to examine the temporal stability of innovation drivers using consistently collected firm-level information over multiple consecutive years. This feature is particularly valuable given the limited availability of longitudinal evidence on SME innovation in European convergence regions.

While response rates vary across years and are subject to standard limitations of survey data (e.g., self-selection), the dataset provides, to the best of our knowledge, one of the few multi-year, firm-level, primary data sources on innovation behaviour in a regional context within the EU.

Table 1 reports the number of firms surveyed each year, the corresponding sampling frame, and response rates, together with innovation rates. While response rates are in line with those typically observed in firm-level surveys, especially in SME contexts, the consistency of the data collection process across years supports the comparability of results over time. Although response rates declined over time, no substantial changes were introduced in the questionnaire design, sampling frame, or data collection procedures, supporting comparability across survey waves.

The 2,582 survey responses reported in Table 1 represent the total number of completed questionnaires across all survey waves. The effective sample used in the regression analysis ($N = 1,787$) is lower because observations with missing values in one or more variables included in the multivariate models were excluded through listwise deletion.

Table 1. Sample composition and innovation rates by year

Year	Firms (responses)	Sampling frame	Response rate (%)	Innovation rate (%)
2017	454	5,026	9.0	48.9
2018	788	5,047	15.6	49.7
2019	383	5,047	7.6	49.6
2020	368	4,633	7.9	52.7
2021	295	4,578	6.4	54.6
2022	294	5,196	5.7	54.8

3.2. Measures and variable construction

The dependent variable is firm-level innovation (FLI), operationalized as a binary indicator equal to one if the firm reports having introduced any innovation activity during the reference period, and zero otherwise. The reference period covers the three years preceding each survey wave, in line with standard practice in innovation surveys. This measure captures whether firms engage in innovation activities, regardless of the specific type or intensity of innovation.

The independent variables are constructed from structured questionnaire items included in the annual survey. The empirical specification includes variables capturing structural firm characteristics (firm size and exporting activity), operational and information-related practices (process automation and environmental scanning), and organizational practices (organizational adaptability, customer orientation, competitive pressure, and coordination mechanisms).

Firm size is measured as an ordinal categorical variable based on the average number of employees during the last year, while exporting activity is captured through an ordinal indicator reflecting the share

of foreign sales in total firm turnover. Process automation is measured using a single-item indicator that reflects the extent to which firms rely on automated production and internal processes. Similarly, environmental scanning is captured through a single-item indicator that reflects the intensity with which firms monitor external markets, competitors, and technological trends.

Organizational practices are captured through four variables: organizational adaptability, customer orientation, competitive pressure, and coordination mechanisms. Organizational adaptability reflects the firm's ability to reorganize internal structures and processes in response to changing conditions. Customer orientation captures the extent to which firms systematically incorporate customer feedback into decision-making. Competitive pressure measures the perceived intensity of competition in the firm's main markets. Coordination mechanisms capture the degree of internal coordination across departments and functional areas. Each of these variables is operationalized as an index based on multiple Likert-scale items.

Prior to model estimation, the internal consistency of all multi-item constructs was assessed. Table 2 reports the reliability statistics for the composite indices corresponding to organizational adaptability, customer orientation, competitive pressure, and coordination mechanisms. Cronbach's alpha values exceed the conventional threshold of 0.70 for all constructs, ranging from 0.88 to 0.90, indicating satisfactory internal consistency.

Firm size, exporting activity, process automation, and environmental scanning are measured using single-item indicators derived directly from the survey questionnaire. Consequently, internal consistency measures such as Cronbach's alpha are not applicable to these variables. Overall, the reliability results support the use of the composite indices and single-item measures in the subsequent regression analysis.

The use of single-item indicators for process automation and environmental scanning is appropriate because both variables refer to specific, observable organizational practices that can be directly assessed by respondents. Such measures are commonly employed in firm-level surveys when constructs are concrete, narrowly defined, and easily identifiable.

Table 2. Reliability statistics of multi-item constructs

Construct	Number of items	Cronbach's alpha
Organizational adaptability	5	0.88
Customer orientation	7	0.90
Competitive pressure	4	0.89
Coordination mechanisms	5	0.90

3.3. Empirical analysis

Given the binary nature of the dependent variable, the probability that firm i innovates in year t is estimated using a logistic regression model. To account for unobserved time-specific factors affecting all firms, all specifications include year fixed effects, which control for macroeconomic trends, policy changes, and common shocks.

Formally, the baseline model is specified as:

$$\Pr(\text{FLI}_{it} = 1) = F(X_{it}\beta + \delta_t),$$

where $F(\cdot)$ denotes the logistic cumulative distribution function, X_{it} is a vector of firm-level explanatory variables, and δ_t represents year fixed effects.

To ensure numerical stability and robust inference in the presence of repeated cross-sections and potential heteroskedasticity, models are estimated using a generalized linear model (GLM) with a binomial family and logit link, and robust standard errors are reported throughout.

To assess the temporal stability of the main innovation drivers, the analysis explicitly examines temporal heterogeneity associated with the COVID-19 shock. A binary indicator identifying the post-COVID period (2021 onwards) is introduced, while observations up to 2020 are treated as the pre-COVID period. This classification is consistent with the survey design, as each wave refers to innovation activities over the three years preceding the survey. In particular, the 2020 survey captures the period 2017–2019 and therefore does not include the effects of the COVID-19 shock.

To assess the temporal stability of innovation drivers after the COVID-19 shock, interaction terms with the post-COVID indicator are introduced. These interactions are estimated only for variables that show a statistically significant association with innovation in the baseline model and whose effects are likely to be sensitive to changes in the economic environment. Specifically, interaction terms are included for process automation and environmental scanning. This approach allows us to assess whether the role of key operational and information-related capabilities differs between the pre- and post-COVID periods, while avoiding an excessive number of parameters that could reduce estimation precision.

Several robustness checks are conducted to assess the stability of the results. Alternative model specifications yield qualitatively similar patterns. In addition, year fixed effects are included to control for common macroeconomic shocks affecting all firms. Predicted probabilities are computed to facilitate the interpretation of the estimated effects and to compare results across periods.

Given the repeated cross-sectional nature of the data, the results are interpreted as associational rather than causal. The analysis is therefore intended to identify consistent patterns in firm-level innovation behaviour and to assess their stability across different economic contexts.

4. Results

The results of the logistic regression model estimating the probability that a firm engages in innovation activities are reported in Table 3. All statistical analyses were conducted using R statistical software. The model includes year fixed effects to control for time-specific shocks common to all firms, given the repeated cross-sectional nature of the data.

Table 3. Logistic regression results for firms' innovation probability

	Odds Ratio (OR)	95% CI (Lower)	95% CI (Upper)	p-value
Firm size	1.654***	1.541	1.776	0.000
Exporting activity	1.347***	1.213	1.495	0.000
Process automation	1.182***	1.107	1.261	0.000
Environmental scanning	0.874***	0.802	0.951	0.002
Organizational adaptability	1.054*	0.991	1.121	0.097
Customer orientation	1.053	0.946	1.173	0.346
Competitive pressure	1.04	0.944	1.145	0.428
Coordination mechanisms	1.015	0.951	1.083	0.657

Notes: Odds ratios reported. Effective sample size: N = 1,787 firms. Robust standard errors were used throughout. *** significant at the 99% level, ** at the 95% level, and * at the 90% level.

The results show that firm size exhibits the strongest and most robust positive association with the likelihood of innovation. Larger firms are significantly more likely to innovate, suggesting the presence of scale-related advantages in mobilizing resources, absorbing risks, and sustaining innovation-related investments.

Exporting activity is also positively and statistically significantly associated with innovation propensity. This finding is consistent with learning-by-exporting mechanisms and with the idea that exposure to international markets fosters knowledge acquisition and innovation-related capabilities.

Process automation displays a positive and statistically significant relationship with innovation, indicating that firms with more automated processes are more likely to engage in innovative activities. This result suggests that operational capabilities and investments in process technologies play a direct role in enabling innovation.

Environmental scanning is negatively associated with innovation, as indicated by an odds ratio below one. This suggests that higher levels of external monitoring are linked to a lower likelihood of innovation. One possible interpretation is that intensive scanning, in the absence of complementary internal capabilities, may reflect reactive or defensive strategic behaviour rather than proactive innovation efforts.

By contrast, organizational adaptability is statistically significant only at the 10% level, while customer orientation, competitive pressure, and coordination mechanisms do not display statistically significant associations with innovation once other firm-level characteristics and year fixed effects are considered. Importantly, the estimated coefficients remain stable across alternative specifications, indicating that the main results are not driven by model choice or omitted temporal effects.

To further assess the temporal stability of the principal innovation drivers, interaction terms between the post-COVID indicator and the four variables that exhibited statistically significant associations in the baseline model (firm size, exporting activity, process automation, and environmental scanning) were estimated. Table 4 reports the estimated interaction effects. None of the interaction terms reached statistical significance, indicating that the relationships between these key determinants and innovation remained stable across the pre- and post-COVID periods. These findings provide additional evidence supporting the persistence of the principal innovation drivers despite the disruption generated by the COVID-19 pandemic.

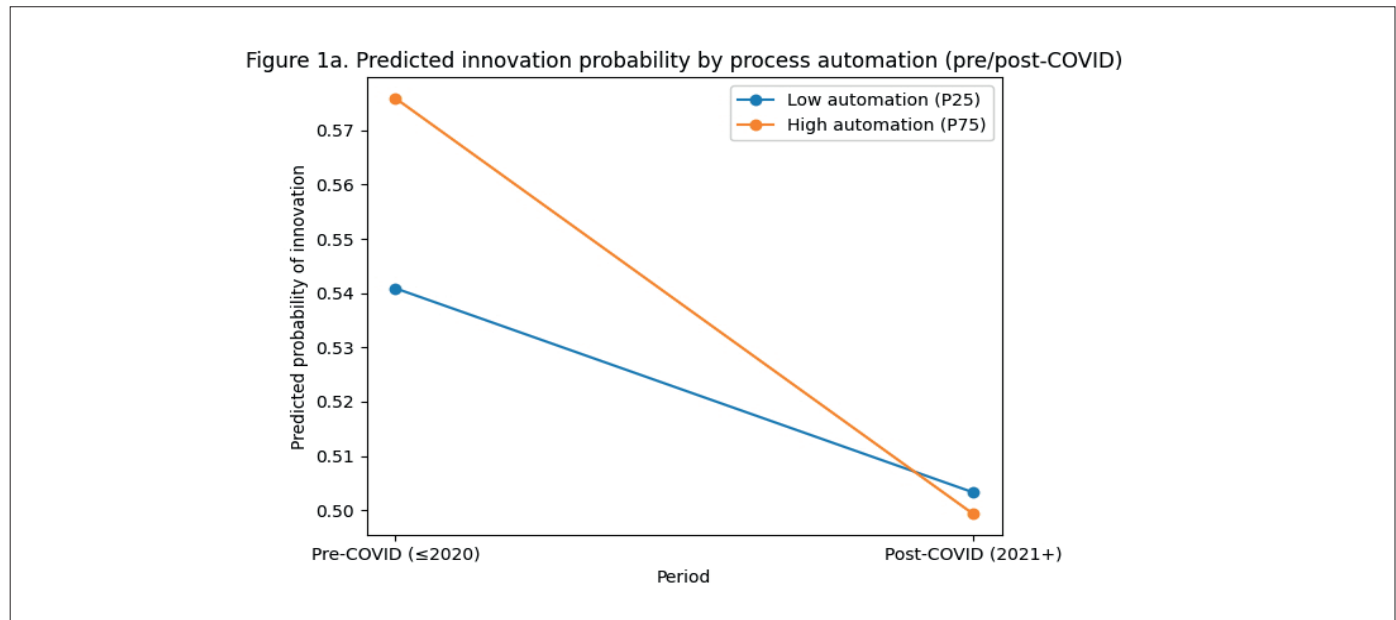
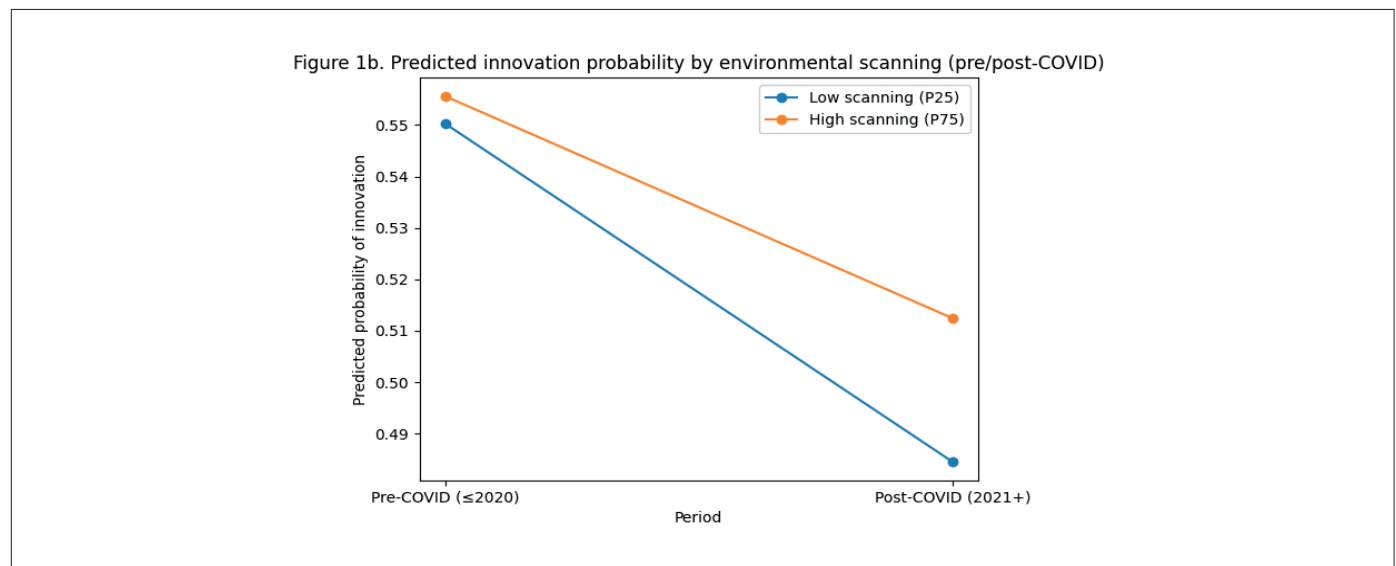
Table 4. Post-COVID interaction effects

Interaction term	Odds Ratio	95% CI Lower	95% CI Upper	p-value
Firm size × Post-COVID	1.021	0.862	1.209	0.813
Exporting activity × Post-COVID	0.927	0.813	1.058	0.259
Process automation × Post-COVID	0.992	0.879	1.120	0.899
Environmental scanning × Post-COVID	1.038	0.909	1.186	0.581

Notes: Odds ratios reported. Effective sample size: N = 1,787 firms. None of the interaction effects is statistically significant.

Figures 1 and 2 present predicted probabilities of innovation before and after the COVID-19 pandemic. Although some visual differences can be observed across periods, the corresponding interaction effects are not statistically significant. Table 4 further confirms that none of the interaction terms involving firm size, exporting activity, process automation, or environmental scanning reached statistical

significance. Therefore, the figures should be interpreted as descriptive illustrations of the estimated models rather than as evidence of structural changes in the determinants of innovation. Overall, these results indicate that the effects of the principal innovation drivers remained stable across the pre- and post-COVID periods.

Figure 1. Predicted probability of innovation by process automation (pre and post COVID)**Figure 2.** Predicted probability of innovation by environmental scanning (pre and post COVID)

Several robustness checks support the validity of the results. Estimations excluding year fixed effects yield coefficients of similar magnitude and statistical significance for the main variables. Likewise, reduced specifications including only statistically significant variables produce consistent results, with process automation remaining positively associated with innovation and environmental scanning retaining a negative association. These findings indicate that the main results are not driven by model specification or the inclusion of temporal controls.

Moreover, the estimated effects remain stable in terms of direction and magnitude across specifications, reinforcing the substantive interpretation of the main coefficients.

Overall, the results provide strong empirical support for the role of firm size, export activity, and process automation as key drivers of innovation. These findings highlight the importance of firm size, exporting activity, and process automation in sustaining innovative activity. At the same time, the evidence suggests that information-intensive practices such as environmental scanning may be associated with more reactive strategies that do not necessarily translate into higher innovation outcomes.

5. Discussion

This study exploits a longitudinal sequence of consecutive firm-level surveys to examine innovation dynamics in a peripheral European

region before and after the COVID-19 shock. The results highlight the persistent role of structural firm characteristics, particularly firm size and exporting activity, while also providing evidence on the stability of operational and information-related practices as determinants of innovation. More broadly, the findings suggest that the principal drivers of SME innovation remained remarkably resilient despite the substantial economic disruption generated by the pandemic.

Regarding RQ1, the findings show that structural firm characteristics remain central drivers of innovation in peripheral regional contexts. Firm size emerges as the strongest predictor of innovation, indicating that larger firms benefit from greater resource availability, risk absorption capacity, and organizational capabilities that support innovation activities. Exporting activity is also positively associated with innovation, suggesting that firms exposed to international markets benefit from learning opportunities, competitive pressures, and access to external knowledge sources. These results are consistent with previous evidence on SME innovation in European regions, particularly the work of Hervás-Oliver et al. (2021), which highlights the importance of structural resources and external market linkages as key determinants of innovation performance. In peripheral regions, where local knowledge infrastructures and innovation networks tend to be less developed, these factors appear especially relevant.

Regarding RQ2, the results confirm that process automation and environmental scanning display distinct relationships with innovation. Process automation is positively associated with innovation, supporting the view that operational investments contribute to upgrading, efficiency improvements, and learning-by-doing processes that facilitate innovation. By contrast, environmental scanning exhibits a negative association with innovation, suggesting that intensive monitoring of external developments does not necessarily translate into innovative outcomes. One possible interpretation is that firms facing resource constraints may devote substantial attention to environmental monitoring without possessing the complementary capabilities required to transform external information into innovation activities.

Importantly, however, the interaction effects associated with the post-COVID period are not statistically significant. This finding indicates that the relationships between process automation, environmental scanning, and innovation remained broadly stable before and after the COVID-19 shock. Although predicted probabilities display some visual variation across periods, there is no statistical evidence that the pandemic fundamentally altered the role of these practices as drivers of innovation. This result is noteworthy because it suggests that, despite the unprecedented disruption generated by COVID-19, the mechanisms linking firm-level capabilities and innovation outcomes remained largely unchanged.

Regarding RQ3, the findings provide evidence of substantial temporal stability in the determinants of innovation. Organizational practices such as adaptability, customer orientation, competitive pressure, and coordination mechanisms do not display strong direct associations with innovation once structural characteristics and operational practices are taken into account. Rather than acting as standalone drivers, these factors appear to function as enabling conditions that support

the effective deployment of other resources and capabilities. More importantly, the absence of significant interaction effects suggests that the principal determinants of innovation remained stable throughout the observation period.

Taken together, these findings contribute to current debates on innovation resilience and regional innovation systems. While recent studies have suggested that major disruptions may alter innovation trajectories and reshape the value of firm capabilities, the present results point to a different interpretation. In the context of a peripheral European region, innovation appears to be driven by a relatively stable set of structural and operational factors whose importance persists even under conditions of heightened uncertainty. Consequently, the contribution of this study lies not in demonstrating a reconfiguration of innovation drivers following COVID-19, but rather in showing the resilience and persistence of established innovation determinants during a period of exceptional economic disruption.

6. Conclusions

This study examines firm-level innovation dynamics in a peripheral European region using a longitudinal sequence of consecutive primary surveys spanning the pre- and post-COVID period. By exploiting repeated cross-sectional data with year fixed effects, the paper provides evidence on the determinants of SME innovation and their stability under conditions of major economic disruption.

Three main conclusions emerge from the analysis. First, structural resources and outward orientation remain central drivers of innovation. Firm size and exporting activity consistently exhibit strong positive associations with innovation, underscoring the importance of resource availability, scale-related advantages, and access to external markets. In peripheral regional contexts, where local innovation systems are often characterized by weaker knowledge infrastructures and more limited spillovers, these factors appear particularly important in supporting innovative activity.

Second, operational and information-related practices display contrasting relationships with innovation. Process automation is positively associated with innovation, confirming its role as an operational capability that supports upgrading, learning, and efficiency improvements. Environmental scanning, by contrast, exhibits a negative association with innovation, suggesting that intensive monitoring of external developments does not necessarily translate into innovative outcomes and may reflect more reactive strategic behaviour. While predicted probabilities display some variation across periods, the absence of significant interaction effects indicates that these relationships remained broadly stable before and after the COVID-19 shock.

Third, organizational practices such as adaptability, customer orientation, competitive pressure, and coordination mechanisms do not display strong direct effects once structural characteristics and operational practices are taken into account. These factors appear to function primarily as enabling conditions that support the effective deployment of other innovation-related resources and capabilities rather than as independent drivers of innovation.

Taken together, the findings suggest that the principal determinants of SME innovation remained remarkably stable despite the disruption generated by the COVID-19 pandemic. Rather than revealing a reconfiguration of innovation drivers, the results point to the persistence of established relationships between firm characteristics, capabilities, and innovation outcomes. This contribution is particularly relevant because it is based on a multi-year firm-level dataset from a European convergence region, a context that remains underrepresented in the innovation literature.

From a policy perspective, the results highlight the importance of supporting structural capacity and international market engagement in peripheral regions. Policies focused exclusively on R&D incentives may overlook key mechanisms through which SMEs sustain innovative activity. Measures that encourage exporting activity, process upgrading, and capability development may therefore be especially effective in strengthening innovation performance and resilience in less-developed regional contexts.

Several limitations should be acknowledged. First, the repeated cross-sectional nature of the data precludes tracking individual firms over time, limiting the possibility of identifying causal mechanisms and within-firm adjustment processes. Second, response rates declined over the observation period, from 9.0% in 2017 to 5.7% in 2022. Although these values are comparable to those commonly reported in SME surveys, a potential self-selection bias cannot be completely ruled out. Third, key constructs rely on self-reported survey measures and two variables—process automation and environmental scanning—are measured using single-item indicators, which may not fully capture the complexity of these practices. Finally, the analysis focuses on a single peripheral region, which may limit the generalizability of the findings to more central or technologically advanced environments.

Future research could build on these findings by combining survey data with administrative records, developing longitudinal firm panels, and undertaking comparative analyses across regions with different innovation-system characteristics. Such approaches would help clarify how contextual conditions influence the effectiveness and persistence of innovation drivers under conditions of economic uncertainty.

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