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Process innovation strategy in SMEs, organizational innovation and performance: a misleading debate?

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Abstract This article contributes to the study of process innovation as a growth strategy for SMEs, enriching and complementing the well-researched debate about product innovation. Thus, under-researched process innovation strategies are analyzed, and their antecedents and innovative performance implications explored. The results show that process innovation strategy is mainly shaped by the acquisition of embodied knowledge, which acts as a key mechanism for countering firms' weak internal capabilities. As process innovation is mainly production oriented, performance consequences are measured using the production process indicators of cost reduction, flexibility and capacity improvement, avoiding traditional misguided measures based on sales, which are more product oriented. Drawing on information for 2,412 firms taken from Spanish CIS data, our results suggest that R&D efforts are not positively related to production process performance, but that the latter is improved by the synchronous co-adoption of organizational and technological innovation. SMEs conducting a process innovation strategy rely heavily on the acquisition of external sources of knowledge in order to complement their weak internal innovative capabilities, and their pattern of innovation shows clear-cut differences from traditional R&D-based product innovation strategies. The article uses a resource-based view framework to generate hypotheses.

Keywords Process innovation strategy · Organizational innovation · Production performance · Embodied knowledge · Resource-based view · Organizational innovation · CIS data

JEL Classifications L20 · L26 · M20 · O32

1 Introduction

Despite recognizing that firms have specific types of innovation objectives or strategies within their "technical goals" (Cohen and Malerba 2001: 590), the innovation literature for SMEs has traditionally linked growth with product development (e.g., Stam and Wennberg 2009), over-researching the determinants (drivers or barriers) of the introduction of new products (Acs and Audretsch 1988, 1990; De Jong and Vermeulen 2006). However, Keupp et al. (2012) point out that among 342 articles analyzed only 11 clearly encompassed process innovations. The innovation management literature has scarcely analyzed process innovation, and it has mainly been limited to merely the exercise of merely predicting process

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innovators (e.g., Reichstein and Salter 2006), usually in tandem with product innovation adoption (e.g., Santamaría et al. 2009). Neither the innovative performance consequences of adopting process innovations nor the effects of synchronous co-adoption of process technological and organizational innovations have been widely explored in the literature. To the best of our knowledge, there are no previous studies using CIS data analyzing process innovation strategy for SMEs and its innovative performance consequences beyond using measures based on sales (for productivity measures) or the percentage of sales from new products.

With regard to the literature on the economics of innovation, significant debate abounds on understanding innovation performance by measuring productivity using different indicators (e.g., Parisi et al. 2006).[1] Hence, we focus our article only on innovative performance deriving from process innovation strategies for two main reasons. First, studies concerned with productivity and the measurement of TFP mainly base their conclusions on sales indicators but, in our view, process is more production oriented than sales oriented. Thus, sales figures and their productivity measures are better suited for measuring product innovation, although we recognize that product and process changes can be blurred and difficult to separate. As Wheelwright and Clark (1992) suggest, process innovation performance cannot be measured by a specific share of turnover. Process innovation is predominantly based on cost reduction or the improvement of flexibility in production. In fact, improvements in performance as a result of process innovations may include increases in capacity, flexibility and quality, the rationalization of production processes (Edquist 2001; Simonetti et al. 1995) and the lowering of labor and other costs (Vivarelli 1995; Vivarelli and Pianta 2000). This article attempts to capture all these aspects. Second, most research on process innovation uses an integrative approach and assumes that process is a complementary activity that supports product innovation (e.g., Benner and Tushman 2002, 2003; Lynn and Reilly 2003). Nevertheless, process innovation also has a production-oriented aim (e.g., Hollander 1965; Salter 1960), and this aspect has received less attention in the literature. Not much is known about process innovation strategy considered as a production-oriented activity aimed at improving efficiency. According to the OECD (2010: 19), "survey questions on the effects of process innovation (e.g., cost reductions, greater productivity and flexibility) are needed in order to gain a more complete view of the effect of innovation on the economy. At present, only the share of new products in turnover is covered." Despite the intense debate on innovation in small firms (Hall et al. 2009; Rammer et al. 2009; Simonen and McCann 2008), their process innovation strategies, determinants and performance consequences are still under-researched, despite recognition that SMEs do in fact intensively develop process innovations (European Commission 2008).[2] Summarizing, the first objective of this article is to analyze the introduction of process innovation (strategy) and its production-oriented innovative performance.

Innovation is not just about developing new technologies, but also about adopting and re-organizing business routines, and internal organization or external relations, i.e., non-technological innovation (e.g., Barañano 2003). In general, the empirical evidence is that firms have an incentive to undertake non-technological innovation when they introduce technological innovations (Schmidt and Rammer 2007). In this light, a second objective of this article derives from the fact that, as highlighted in the technology strategy literature, the depiction of process development requires a consideration of the complementary relationship between technological process and non-technological organizational innovations (Womack et al. 1990). By organizational innovation, we refer to "the implementation of a new organizational method in the firm's business practices, workplace organization or external relations" (OECD 2005: 177). Certain authors suggest that process innovation may be conceptually blurred within the organizational space, while others classify organizational innovation as simply a component of technological process innovation strategy (see Edquist et al. 2001). To the best of our knowledge, most studies addressing innovation in SMEs are solely technology oriented (e.g., Rammer et al. 2009), and they do not address the potential for a

[1] Parisi et al. (2006) use the Cobb-Douglas production function and a Tornquist index of TFP growth and regressing Solow residual on the innovation dummies.

[2] For instance, Hall et al. (2009) report that for the period 1995–2003, 50.75 % of the firms introduced process innovation and only 34.85 % did the same for product innovation.

synchronous co-adoption of technological and organizational innovation. Therefore, this article brings new perspectives to the innovation debate for SMEs by connecting the technological process and the organizational innovation modes, which constitutes the second objective.

The main contributions of this article are the following. First, this research sheds light on the still under-researched subject of process innovation strategy. Second, this article also enhances the understanding of technological process and organizational innovation concurrence in SMEs. Third, the study uses the resource-based view, together with the relational perspective in order to provide a theoretical framework to generate our hypotheses. To the best of our knowledge, this is the first article addressing process and organizational innovation in tandem with CIS data for SME firms.

The structure of the article is as follows. The second section reviews the literature, expounds the theoretical focus and develops our three hypotheses. The third section contains the empirical design, while section four presents the results and a discussion. Finally, the conclusions and implications are presented.

2 Review of the literature and theoretical focus

The resource-based view (RBV) perspective (Barney 1991; Peteraf 1993) stresses that a firm's unique internal resources at least partially determine a firm's performance. RBV establishes a correspondence between a firm's unique set of resources and capabilities and its level of performance. Through this internal perspective, innovation stems from better organizational routines and other core functions. Within the RBV, Barney (1991) identifies a broad range of resources, including all types of assets, organizational processes, knowledge capabilities and other potential sources of advantage. Complementarily, the relational perspective (Dyer and Singh 1998) argues that a firm's critical resources go beyond a firm's boundaries and that inter-firm collaborative linkages generate further relational returns (Dyer and Singh 1998). It is claimed that these strategic assets (Gulati et al. 2000) generate an impact on innovation by facilitating knowledge-sharing and an interactive learning process (Powell et al. 1996; Rowley et al. 2000). We base our study on the RBV approach and the relational perspective to develop our hypotheses.

2.1 A RBV approach to process innovation strategy

Firms are heterogeneous in their routines and strategies (Nelson and Winter 1982). This perspective of evolutionary economics perfectly fits the resource-based view of the firm (Penrose 1995). This approach claims that firms present a heterogenous performance (Peteraf 1993) because they have different repositories of resources due to restricted mobility, scarcity, difficulties to imitate and a lack of perfect substitutes (Barney 1991). A deeper look at the RBV concept reveals that its definition of resources or organizational capabilities—i.e., "…all assets, capabilities, organizational processes, firm attributes, information, knowledge etc., controlled by a firm that enable the firm to conceive of and implement strategies that improve its efficiency and effectiveness" (Barney 1991: 101)—is not directly related solely to R&D investments. Moreover, neither is the relational-based view (Dyer and Singh 1998), which refers to external sources of knowledge that also contribute to a firm's repository of resources and capabilities. These perspectives can be complemented with the knowledge-based view of the firm (Grant 1996; Kogut and Zander 1992), which considers that accumulated experiences or established routines—without focusing particularly on R&D investments—form the base of a firm's knowledge. Such knowledge, which is mainly of a tacit nature (Nonaka and Takeuchi 1995), is directly related to a firm's competitive advantage and performance. Therefore, we argue that the level of organizational capabilities in companies, together with a firm's capability to reconfigure and dynamically sustain (Teece 2007) its resources and competencies, will determine the decision to innovate.

When addressing innovation strategy, this article refers to the specific resources and competences, and their mix, as determinants of innovation performance. A firm's innovation strategy depends on its existing capabilities or knowledge stock. Therefore, a firm's innovation capability is highly correlated with its innovation strategy, and both depend on its repository of internally and externally generated resources and competences.

2.2 Process innovation strategy: hypotheses

There has been extensive research on innovation in SMEs (e.g., Rammer et al. 2009,; Simonen and McCann 2008) and on process innovation (Freel and Harrison 2006; Reichstein and Salter 2006; Rouvinen 2002). However, such papers are basically restricted to exploring the decision (and its antecedents) to introduce, or not, process innovation, rather than analyzing its performance. Research encompassing process innovation performance is scarce (some exceptions are Pisano 1994 for large science-based firms), and existing studies do not focus on small firms.

With regard to the drivers of process innovation, Reichstein and Salter (2006) refer to process innovation as the use of new capital equipment (Salter 1960) and the practices of learning by doing and learning by using (Cabral and Leiblein 2001; Hollander 1965). Similarly, OECD (2005: 49) defines process development as: "the implementation of new or significantly improved production or delivery methods. This includes significant changes in techniques, equipment and/or software." In particular, technological process innovation is related to the incorporation of new capital equipment (Salter 1960), processing machines, industrial robots or IT equipment (Edquist 2001; Heidenreich 2009; OECD 2005) or capital embodied technology (Rouvinen 2002), usually obtained from the purchase of advanced machinery or computer hardware and software (OECD 2005).

General consensus exists in the literature on the fact that process innovation strategy in small firms is much more closely related to "embodied technological change, "incorporated into physical capital formation, rather than to intangible investment in R&D (Conte and Vivarelli 2005; Santarelli and Sterlacchini 1990; Vaona and Pianta 2008). In this vein, Rouvinen (2002) indicates that process innovation is mainly led by embodied technology, while disembodied technology affects product innovation. Acs and Audretsch (1988) provide evidence that R&D efforts are directly related to the number of innovations, to skills and size; and agreed with Winter's (1984) prediction that such determinants affect large and small firms differently, due to the fact that large and small firms have varying technological environments and regimes. Similarly, Piergiovanni et al. (1997) suggest that large firms depend on R&D inputs for their innovative output, whereas small firms extensively exploit spillovers. Similarly, Cohen and Klepper (1996) provide evidence that the propensity to engage in R&D is directly related to the firm size and that large firms can achieve advantages from spreading R&D costs. Parisi et al. (2006) show that R&D spending is strongly and positively associated with the introduction of new products, whereas fixed capital spending (embodied knowledge) increases the likelihood of process innovations. Summarizing, previous literature suggests that innovation in small firms is more dependent on access to an external (to the firm) system of industrial knowledge, and less on R&D, reflecting an intensive use of embodied knowledge. Consequently, our first hypothesis states that:

Hypothesis 1 In the process innovation strategies of SMEs, there is a positive relationship between investment in embodied technical knowledge and production-oriented innovative performance.

In line with the reviewed literature, as above mentioned, we expect that the acquisition of embodied knowledge and its organizational integration both positively influence the innovation performance of process innovators. David and Foray (1995) posit that the recombination as well as re-use of known practices is an innovation pattern employed by SMEs that do not conduct R&D (following Arundel et al. 2008); this recombination works by combining existing knowledge in new ways (e.g., Evangelista et al. 2002), through imitation and reverse engineering (Kim and Nelson 2000) or by employing engineering knowledge to conduct incremental changes (Kline and Rosenberg 1986).

As recent studies have pointed out, there is no relationship between firm-level R&D and process innovation (Hervas-Oliver et al. 2011; Rouvinen 2002) because R&D is more associated with product innovation (e.g., European Commission 2008). In fact, the marketing literature has traditionally linked product innovation with effective R&D and marketing integration. Mansfield et al. (1971) and Mansfield and Wagner (1975) indicate that the effective integration of R&D product development and marketing is a prerequisite for innovation success. In particular, Cooper and Kleinschmidt (1987) argue that both marketing and technical R&D are crucial for new product introduction success. In other words, R&D is clearly related to marketing and product innovation, and not to process and production innovative performance. Consequently, a second hypothesis can be stated as follows:

Hypothesis 2 In the process innovation strategies of SMEs, there is no relationship between R&D investments and production-oriented innovative performance.

Innovation activities introduced by process innovators simultaneously involve organizational (non-technological) and technological changes (Gopalakrishnan and Damanpour 1997; Reichstein and Salter 2006) that are somewhat blurred and difficult to separate (Edquist et al. 2001; Ettlie and Reza 1992; Womack et al. 1990). The literature has often presented evidence that the application of process technology depends on changes in structure and administrative practices (Ettlie 1988; Nabseth and Ray 1974; Thompson 1967), i.e., organizational innovation activities. The systematic overlap of organizational and technology process innovation is also commonly stressed in the operations management literature (e.g., Duguay et al. 1997; White and Ruch 1990), although most of this literature is based on case studies or specific industries (Ettlie 1988; Womack et al. 1990).

The successful adoption of process technologies depends on the simultaneous introduction of appropriate administrative practices (Nabseth and Ray 1974: 310). Thus, in "organizational integration" thought (Ettlie and Reza 1992), the successful adoption of process innovations—mostly by acquiring new technologies for operations—must be complemented by integration and coordination mechanisms if the value from process innovations is to be fully captured and protection from imitation ensured.

The close relationship between technological process and organizational innovation concurrence, highlighted in the definitions provided by Edquist et al. (2001), includes two different but related activities within the concept of "process innovation": "technological process innovation" and "organizational process innovation." *Technological process innovations* are new elements that are used in the process of production and include investment goods and intermediate goods, such as processing machines, industrial robots and IT equipment. In contrast, *organizational process innovations* complement technological process innovations, but they are defined as new ways to organize business activities. They are not made up of technological dimensions but the co-ordination of human resouces and work practices, such as just-in-time production, total quality management or lean manufacturing.

The literature focused on the skill bias effect has confirmed the fact that technology and organization jointly affect the demand for skills needed for new innovations (e.g., Piva et al. 2005), and it provides evidence of the (superadditive) synergies of concurrence.[3] Lastly, Schmidt and Rammer (2007) draw on the German CIS to point out that organizational innovations are also often accompanied by new technological processes.

The complementary assets or innovation modes are discussed in the RBV (e.g., Barney 1991). In the *strategic management* literature, the *complementary assets* are recognized as having a key influence on a firm's innovation (e.g., Stieglitz and Heine 2007). Teece (1986) defines *complementary assets* as those that increase the value of a firm's technological innovations because of the fact that the combination of diverse complementary assets prevents imitation and facilitates appropriation. Dierickx and Cool (1989), using the RBV, also point out that complementary assets sustain competitive advantage by making imitation difficult.

Therefore, a third hypothesis can be stated as follows:

Hypothesis 3 In the process innovation strategies of SMEs, there is a positive relationship between the synchronous adoption of technological and organizational innovation and production-oriented innovative performance.

3 Research design

3.1 CIS data and sample

Our data belongs to the Spanish (Eurostat) CIS for 2006. The CIS questionnaire draws on a long tradition of innovation research (Cohen and Levinthal 1990) and is extensively used in most European countries.

[3] This literature does not focus on innovative performance but on the demand for new skills [see Piva et al. (2005) for an integration of the literature].

Table 1 Descriptive variables

Variable	All manufacturing SMEs ($N = 13{,}638$)				SMEs technological innovators ($N = 6{,}404$)				SMEs pure Process innovators ($N = 2{,}412$)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Size	1.518	0.369	0	2.396	1.572	0.3858	0.000	2.396	1.545	0.365	0.301	2.396
Group	0.155	0.362	0	1	0.197	0.398	0	1	0.172	0.377	0	1
Export	0.519	0.500	0	1	0.679	0.467	0	1	0.552	0.497	0	1
Internal R&D expenses	0.472	1.064	0	5	0.853	1.293	0	5	0.353	0.932	0	5
External R&D expenses	0.195	0.578	0	5	0.352	0.729	0	5	0.196	0.560	0	5
Tech_expend	0.392	0.849	0	5	0.779	1.068	0	5	1.052	1.246	0	5
Internal_sources	2.142	1.006	0	3	2.178	0.997	0.000	3.000	1.933	1.095	0	3
Industrial_sources	–	–	–	–	0.0	1.0	−2.817	3.022	0.0	1.0	−2.789	3.331
Science_sources	–	–	–	–	0.0	1.0	−1.501	4.080	0.0	1.0	−1.329	4.420
Inno_org	0.318	0.466	0.000	1.000	0.522	0.500	0	1	0.462	0.499	0	1

This article focuses on manufacturing SMEs (13,638 firms) (Table 1).

The dependent variable is defined as the production-oriented innovative performance from the introduction of process innovations *(Production Performance* variable) obtained from the Spanish CIS 2006 question: "Please indicate the impact or effect that your innovation activities have had on your enterprise in the period 2004–2006."[4] It is measured on a scale from 0 to 3, where 0 is equal to *none* and 3 equals the highest impact (1 means *low* and 2 means *medium*). We select the specific production-oriented innovative performance, depicted by four items that are reduced to one single component applying principal component analysis (PCA): labor cost reduction, production flexibility, improved capacity or a reduction of materials. This reflects the production-oriented innovative performance from process innovation adoption. Following this procedure, one single component from the analysis, through its scores, represents the dependent variable that explains 60.56 % of the variance (KMO = 0.702, $p < 0.01$) (Table 2).

Regarding the sample, our empirical analysis is limited to examining 2,412 Spanish manufacturing SMEs, which were those technology innovators that only engaged in process innovation. Therefore, the production effects measured are consequences from the adoption of only engaging in process innovation strategies (i.e., not product innovation strategies). Therefore, we focus exclusively on process innovators in order to better understand the pattern of their innovation drivers and production-oriented performance consequences. The sample presents a clear advantage due to the fact that production-oriented innovation performance and process performance (related to costs, flexibility and capacity) are directly caused by the introduction of new processes; that is to say, there is not product innovation performance.

Table 4 in the Appendix shows the variables. In short, from Table 4, key variables are (1) embodied technology expenditures per sales (*Tech_expend*), which reflect the acquisition of advanced machinery, equipment and computer hardware or software, and is divided by sales, and (2) adoption of organizational innovation (*Inno_org*), defined as the binary decision to co-adopt (with technological innovation) at least one organizational innovation in the firm (formed by the combination of the following dummies: introduction of new business practices in the organization; new knowledge management systems; new organization methods for the workplace). See Appendix.

[4] The same applies for the UK questionnaire (CIS3 and CIS4). Nevertheless, since 2008, the Spanish questionnaire modified and changed the variable in order to capture the idea of *objectives* (similar to "innovation goals," related to technological trajectories in the sense of Dosi 1982) or *factors* for the decision to innovate. The same approach is observed in the CIS for the UK questionnaire: CIS5 and CIS6 versions mentioned factors or objectives, while the previous third and fourth version mentioned effects. Therefore, we used 2006 data and observed that innovation performance of innovation activities are treated coherently as output from the innovation strategy. Finally, it is important to notice that, although the CIS is standardized for Europe, each country has some peculiarities.

Table 2 Correlation matrix (Pearson's index)

		1	2	3	4	5	6	7	8	9	10
1	Production performance	1									
2	Size	−0.023	1								
3	Group	−0.162	0.347[a]	1							
4	Export	−0.001	0.282[a]	0.111[a]	1						
5	Internal R&D expenses	0.056	−0.140[a]	0.018	0.069[a]	1					
6	External R&D expenses	0.031	0.011	0.131[a]	0.091[a]	0.347[a]	1				
7	Tech_expend	0.115*	−0.187[a]	−0.083[a]	−0.132[a]	−0.106[a]	−0.097[a]	1			
8	Internal_sources	0.239[a]	0.022	0.118[a]	0.054[a]	0.187[a]	0.101[a]	−0.001	1		
9	Industrial_sources	0.421*	−0.016	−0.008	0.037	0.061*	0.003	0.037	0.141[a]	1	
10	Science_sources	0.074[a]	0.117[a]	0.097[a]	0.111[a]	0.252[a]	0.295[a]	−0.107[a]	0.130[a]	−0.008	1
11	Inno_org	0.159[a]	0.027	0.006	0.028	0.120[a]	0.066[a]	−0.018	0.117[a]	0.189[a]	0.048

[a] Level of significance: 1 %

3.2 Model and methodological issues

The model specification, in line with the stated hypotheses, is based on the resource-based and relational views, as previously mentioned, since internal knowledge (to the firm) and external knowledge accessed through search strategies both give a firm the capability to innovate (e.g., Hervas-Oliver et al. 2011). The model in a simplified version is as follows:

$$\begin{aligned}&\text{Production oriented innovative performance}_i\\&= \text{intercept}\\&\quad+\beta 1\text{Embodied knowledge acquisition}_i\\&\quad+\beta 2\ \text{Non-technological innovation co-adoption [organizational]}_i\\&\quad+\beta 3\ \text{Internal and external R\&D capabilities}_i+\beta 4\ \text{External and internal information sources of knowledge}_i+\beta 5\ \text{Size}_i+\beta 6\ \text{industry}_i+\varepsilon_i\end{aligned}$$

where β is the parameter to be estimated, and ε is the error term.

As stated above, the sample used is based on two thresholds (i.e., whether or not firms are actively innovative, and whether they implement solely process innovations). Thus, results could suffer from additional selection bias. Heckman's two-stage analysis (Heckman 1979) has been run in order to tackle with these selection problems. Both steps were divided into a first stage in which, after a *Logit* analysis, an inverse Mills ratio was obtained for use in a second step, as an additional independent variable, in order to explain the variation in innovation performance of the selected sample.

For the first step, two *Logit* regressions were carried out, one for each threshold. The first Logit, predicting whether or not a firm is actively innovative (Logit*: inno_tech* variable), was run using all available observations (13,638 firms). The second Logit, predicting whether or not an actively innovative firm (or technological innovator) innovated in terms of process (Logit: *inno_process* variable), used only the 6,404 technologically innovative firms. Two inverse Mills ratios were obtained, one from each logit: *inv_mill_inno_tech* and *inv_mill_inno_process*, respectively. Note that the first inverse mills ratio (*inv_mill_inno_tech*) was included as an additional independent variable in order to run the second logit (see Catozzella and Vivarelli 2011).

For the second step of the Heckman analysis, both inverse Mills ratios were included as additional variables when running the OLS in order to explain the variation in the innovation performance of the selected sample (2,412). The dependent variable measures the production-process performance by process innovators. Both of the inverse Mill ratios were fruitless in the OLS, as they turned out to be non-significant ($p > 5$ %), suggesting that the samples obtained did not suffer from selection bias. It is important to note that the first two logit models were run to conduct Heckman procedures, not to predict the adoption of technological or solely process innovations. In line with Heckman′s technique (Heckman 1979), one explanatory variable (*inno_problems* and *process_industry* for each logit model respectively) was used in the selection equation, and not in the outcome equation.

4 Results and discussion

4.1 Results

According to Table 3, the specification offers a good fit (adjusted R^2 0.23, 0.22 and 0.22 for the first, second and third estimations, respectively). Our results indicate that neither investments in internal R&D activities (*Internal_R&D_expenses)* nor in external R&D influence production-oriented innovative performance. The coefficients are negative and are statistically non-significant. Conversely, the acquisition of embodied knowledge (*Tech_expend*) contributes to increasing production innovation performance (coefficient 0.096, 0.10 and 0.106, respectively, all of them significant at 1 %). Also, the *Inno_org* variable, which addresses whether a firm has synchronously co-adopted organizational innovation with process innovation, contributes positively to improving production-oriented innovative performance, as there is a positive and significant coefficient in the specification (0.069, 0.065 and 0.073, respectively, all $p < 0.01$). This last result suggests that the implementation of

Table 3 Results of OLS techniques

	OLS: dep variable Production performance		
	Specif. 1	Specif. 2	Specif. 3
	Coef. Beta (SE)	Coef. Beta (SE)	Coef. Beta (SE)
Size	0.004 (0.025)	0.002 (0.025)	0.013 (0.025)
Group	−0.027 (0.052)	−0.033 (0.052)	−0.038 (0.053)
Export	−0.016 (0.039)	−0.015 (0.038)	−0.020 (0.040)
Internal R&D expenses	−0.004 (0.022)	−0.003 (0.022)	−0.011 (0.022)
External R&D expenses	0.007 (0.035)	0.006 (0.035)	0.010 (0.036)
Tech_expend	0.096* (0.015)	0.100* (0.015)	0.106* (0.016)
Internal_sources	0.177* (0.017)	0.178* (0.017)	0.187* (0.018)
Industrial_sources	0.383* (0.019)	0.381* (0.019)	0.374* (0.019)
Science_sources	0.069* (0.020)	0.062* (0.019)	0.054* (0.020)
Inno_org	0.069* (0.037)	0.065* (0.037)	0.073* (0.038)
Industry_NACE_code	yes		
Low_tech		0.088 (0.095)	
Med_tech		0.077 (0.094)	
Supplier_dominant			0.010 (0.072)
Scale_intensive			-0.006 (0.065)
Supplier_specialized			-0.021 (0.085)
N	2,412	2,412	2,412
R^2	0.241	0.2314	0.232
Adjusted R^2	0.231	0.2275	0.2275
Error	0.000	0,00	0,00
F	23.56	59.23	50.94

Source: own; level of significance: 1 % ($p < 0.01$) (*). VIFS were controlled showing no problems of multicollinearity organizational innovation activities contributes to improving production process performance.

Further, the results indicate in all three specifications that internal sources of knowledge improve production innovation performance (*Internal_sources*, 0.177, 0.178 and 0.187, respectively, all $p < 0.01$), suggesting that there is important knowledge dispersed within a firm that can be deployed to improve production-oriented innovative performance. In addition, the external sources of knowledge variables indicate that external sources of knowledge from industrial agents (i.e., in the value chain; *Industrial_sources*) and from science sources (i.e., from universities and R&D centres; *Science_sources*), are both positive and significant (in all specifications, $p < 0.01$). This means that there are gains to be made in production innovation performance from the sourcing of external knowledge, especially from industry sources, as shown by the coefficients presented in Table 3 (0.383 in Industry, compared to 0.069 in Science, specification 1, both significant at $p < 0.01$).

Sectoral dummies are significant, showing there is inter-industry heterogeneity. Similarly, after applying the Pavitt and OECD classifications, there is no empirical evidence that those taxonomies influence the innovation pattern. In both cases, the results show no industry heterogeneity. The variable *log Size* is non-significant in all three specifications, indicating that the size does not influence process performance; that is to say, process performance does not depend on the size of the firm.

The results indicate that R&D (internal or external) activities do not explain any gains to production-oriented innovative performance (i.e., with regard to increased production flexibility, greater production capacity, lower labor costs, less materials or energy usage reductions). Therefore, production-oriented innovative performance is highly influenced by access to external sources of knowledge, mainly thanks to the acquisition of embodied knowledge and the sourcing of external knowledge (mainly from the industry). This production-oriented innovative performance is amplified by introducing organizational innovation, with a significant and positive relationship.

4.2 Discussion

When discussing and placing our results within the context of the literature, the following three key issues come to the fore. First, we provide evidence that the acquisition of embodied knowledge is a major determinant of process innovation, confirming what has previously appeared in the literature (Edquist 2001; Heidenreich 2009; OECD 2005). However, our evidence is more focused on the positive effect that the acquisition of embodied knowledge has on production-oriented process innovation performance rather than simply addressing whether process innovations are adopted. In addition, it is interesting to point out that there is no relationship between R&D and production-oriented innovative performance, confirming previous findings (Hervas-Oliver et al. 2011; Rouvinen 2002), although these works only tested the relationship between R&D and process innovation adoption, and their results are not fully comparable to ours.

Second, the synchronous co-adoption of organizational and technological innovations by process innovators is positively related to production-oriented innovative performance: the organizational integration of new process technologies increases returns made from the process innovation strategy, in the sense that production process performance is improved when that technology is integrated into the organization. Thus, results are in line with the literature on the organizational integration of technology strategy (Ettlie 1988; Nabseth and Ray 1974; Thompson 1967), suggesting that technology is an opportunity for restructuring and that actual outcomes depend on the way new processes associated with new technology are coupled with the organization (Barley 1986; Cohen and Zysman 1987; Damanpour 1991; Ettlie and Reza 1992).

Third, the pattern of process innovation suggests the existence of weak internal capabilities, which are substituted by an intensive process of accessing external sources of knowledge, mainly through the acquisition of embodied knowledge, in line with "the embodiment perspective" in the literature (e.g., Jorgenson 1966).

Our results present new findings that are not truly comparable to those found in the literature so far, especially to the extent that our work does not relate R&D to the adoption of process innovation, but rather to production-oriented innovative performance from the introduction of process innovation. The subtleties are quite different, and thus our findings suggest that R&D activities do not yield superior production or process effects. Our study has produced similar findings to those using productivity measures, such as Parisi et al. (2006), which show that fixed capital spending increases the likelihood of process innovations.

Process innovation strategy is mainly formed by capabilities obtained from access to and recombination of external sources of knowledge (embodied knowledge, industrial sources and so forth), together with organizational innovations complementing and reinforcing those innovation capabilities. This structure confirms the RBV and relational views (Barney 1991; Dyer and Singh 1998, respectively), which predict a link between a firm's repository of (innovation) capabilities and performance.

Our findings must be interpreted with caution. In line with Kleinknecht (1987), there is evidence that most firms do, in fact, conduct tacit or informal R&D, which is not accounted for properly in official surveys, and so when we assume that there is not R&D, we only refer to R&D that is officially identified as such. In other words, there is probably informal "R&D" in most of the firms, which recorded "no" to carrying out R&D activities. To some extent, it can be said that process innovators mainly occur in technological regimes which are characterized by low degrees of cumulativeness and appropriation, a low importance of basic sciences (higher or applied sciences), and a heightened role for external sources of knowledge (see a synthesis of technological regimes in Breschi et al. 2000), which are features of the low and medium–low technology industries where process innovation is more important. In addition, we should also take into consideration the fact that R&D investments take long periods to obtain returns.

5 Conclusions

This article explores the less-researched subject of process innovation strategy and its effects on production-oriented innovative performance in small manufacturing firms, including the effects of the synchronous co-integration of organizational innovation and process technologies. This article provides insights into process innovation strategy, its drivers and production performance, establishing differences from what is found for the well-studied subject of product innovation strategy and avoiding the use of indicators based on sales. This article has focused on 2,412 Spanish manufacturing SMEs that were solely process innovators. To the best of our knowledge, this is the first article addressing process and organizational innovation in tandem with CIS data.

Our results suggest that our three hypotheses are confirmed, establishing that: SME process innovators investing in embodied technical knowledge do improve their production-oriented innovative performance (hypothesis 1); R&D investments by SME process innovators do not influence production-oriented innovative performance (hypothesis 2); and SME process innovators synchronously co-adopting organizational innovations do improve their production-oriented innovative performance (hypothesis 3), leading to the following conclusions.

First, the acquisition of new equipment in the form of embodied knowledge is the main antecedent of improved production-oriented innovative performance due to technological process innovation, and it is complemented by access to other external sources of knowledge, mainly from within the industry. Moreover, R&D investments do not improve or influence production-oriented innovative performance, contradicting the traditional assumption based on the study of product innovation.

Second, the synchronous co-adoption of technological and organizational process innovation is positively related to production-oriented innovative performance, confirming the organizational integration idea (Ettlie and Reza 1992).

Third, process innovators rely on access to external sources of knowledge, reflecting their weak in-house capabilities, demonstrating a completely different pattern from that of product innovators (who usually innovate on a basis of R&D activities). These results enrich the repository of knowledge addressing SMEs and complement other similar, but product-related, debates (Rammer et al. 2009; Simonen and McCann 2008) on innovation.

Finally, the article has implications for scholars studying innovation in small firms. First, it is clear that process innovation strategies deserve to be given more attention by academia. Second, antecedents of production-oriented innovative performance, especially with regard to small firms engaging in process innovation, should not be considered limited to R&D investments. Third, technical process innovation strategies should also be analyzed in tandem with organizational ones; by doing so, the additional effects of synchronicity on production performance in small firms should be studied and extended by integrating technological and non-technological modes. In addition, scholars should also refine and exploit analysis of the still under-researched subject of process innovation strategy in other countries and data sets. In future studies, a more in-depth analysis of the role of process innovators should be carried out for other European Union countries.

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Appendix

See Table 4.

Table 4 Variables in the analysis

Dependent variable	Meaning	Codification
Production Performance (Production-oriented innovative performance)	Production Performance, from PCA application to the pure process innovators sample B production variables: KMO: 0.702; variance explained: 59.9 %). Resulting from the following variables measuring the effects of process innovation activities on:	Continuous, scores from PCA
	Higher production flexibility (product or service)	
	Higher production capacity	
	Lower labor cost per unit	
	Fewer materials and energy per produced unit	
	Each effect has been measured on a four-point scale: no effect = 0; low effect = 1; medium effect = 2; high effect = 3	
Independent variable		
Tech_expend	*Embodied technology expenditures per sales* it comprises expenditure on the acquisition of machinery and equipment with improved technological performance, including major software, per sales, measured in a *5 points scale*	0–5 scale
	(0: 0; 1: 0 % < x ≤ 1 %; 2: 1 % < x ≤ 5 %; 3: 5 % < x ≤ 10 %; 4: 10 % < x ≤ 50 %; 5: > 50 %)	
Inno_org	Indicates whether the enterprise has introduced at least one new or improved *organizational change* or management innovations during the research period, in order to be considered as management innovator	Dummy 0-1
Control variables		
Internal_sources	The importance of the internal sources of information to innovate (by internal it is considered the firm's own departments, staff, firms from the same group, etc.)	0–3 interval
	The importance of information of each source has to be in a four point scale: Not used = 0; Poor, value = 1; Medium, value = 2; High, value = 3	
Industrial_sources Science_sources	External sources factors Industry and Science are the result of a PCA applied to different variables corresponding to different sources of information for innovation	Continuous, from scores from the second factor analysis
	Industrial_sources: corresponds to clients, suppliers, competitors, consultants, commercial events, scientific journals and magazines, and professional associations	
	Science_sources: corresponds to consultants, commercial laboratories, private R&D firms, universities, technological centers, and public research centers	
	The importance of information of each source has to be in a four point scale: not used = 0; poor, value = 1; medium, value = 2; high, value = 3	
	These variables have been calculated for the two following samples:	
	Technological innovators sample (6,404 firms): KMO: 0.8485; variance explained: 56 %	
	Pure Process innovators sample (2,412 firms): KMO: 0.8339; variance explained: 56.29 %	

Table 4 continued

Dependent variable	Meaning	Codification
Inno_tech	Indicates whether the enterprise has undertaken innovative projects (subsequently abandoned or still to be completed) or introduced a new or improved product/services and/or process during the research period: innovative active firm	Dummy 0–1
Inno_pure_process	Indicates whether the technological innovator has carried on only process innovations, without undertake product innovations	Dummy 0–1
Internal R&D expenses	Intramural R&D expenditures per sales measured in a 5 points scale:	0–5 scale
	(0: 0; 1: 0 % $< x \leq$ 1 %; 2: 1 % $< x \leq$ 5 %; 3: 5 % $< x \leq$ 10 %; 4: 10 % $< x \leq$ 50 %; 5: > 50 %)	
External R&D expenses	*Extramural R&D expenditures per sales:* comprises the acquisition of R&D services per sales measured on a *5-point scale*	0–5 scale
	(0: 0; 1: 0 % $< x \leq$ 1 %; 2: 1 % $< x \leq$ 5 %; 3: 5 % $< x \leq$ 10 %; 4: 10 % $< x \leq$ 50 %; 5: > 50 %)	
Size	Logarithm of the annual average of full-time employees in 2006	Continuous
Industry_NACE_code	Industry classification by NACE-93 (2-digits, 23 sectors), from 15 to 37	Dummy: 0–1
Group	Indicates if the enterprise belong to a group of enterprises	Dummy: 0–1
Process_industry	Indicates whether the industry sector of the firm belongs to the process industries group	Dummy 0–1
	Process Industries CNAE: 17;19;20;21;22;23;24.1;24.2;24.3;5;36;37 (See Lager, 2011)	
(Industry)	OECD classification of manufacturing industries based on R&D intensity. Equal to one if the firm belong to any of the groups	Dummies: 0–1
Low_tech	(High_tech used as baseline in the OLS)	
Med_tech		
High_tech		
(Industry)	Four dummies corresponding to the Pavitt's taxonomy (Pavitt,1984):	Dummies: 0–1
Supplier dominated	Supplier dominated: NACE (17;18;19;20;21;25;361; 36(exc.361,365);37)	
Scale intensive	Scale intensive: NACE (15;22;23;26(exc. 263);271;272;273;2,751;2,752;274;2,753;2,754;28;34;351;35(exc.351;353)	
Specialized suppliers	Specialized Suppliers: NACE (29;30;31;33)	
Science based	Science based : NACE (24(exc. 244);244;321;32(exc. 321);353)	
	(Science based used as baseline in the OLS)	

Source: own

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