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The returns from process innovation: patterns, antecedents and results

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Abstract

The excessive concentration of the innovation literature on product innovation, its drivers and its effects, has almost neglected an important strategy which develops and sustains a firm's competitive advantage: the process innovation activities. Specifically, the paper unfolds the black-box of the process innovation strategy using the process innovation strategy as a mediator to explain a firm?s performance and not just as a mere dependent variable for predicting process innovators. In addition, the paper connects theoretically the process innovation with the management innovation mode to understand their relationship. Using CIS data for Spain, the main contributions found are: (1) most of the process innovation performance is explained without R&D variables; (2) it is observed a strong dependence on external sources of knowledge to explain the process innovation performance, mainly through the acquisition of embodied knowledge; (3)

it is observed an important "implementation" effect or "learning by trying" effect on a firm?s performance due to the fact that the acquisition of embodied knowledge requires a synchronous adoption of the management innovation mode which reprocesses the organization in order to couple the new technology sourced; (4) the acquisition of embodied knowledge is also positively moderated, and thus the process performance is amplified, when the use of external sources of knowledge is also congruent with the introduction of the new technology sourced; (5) the product innovation strategy is not related to the process innovation performance, i.e. there is an absence of complementarities. The paper presents important implications for scholars and policymakers

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The excessive concentration of the innovation literature on product innovation, its drivers and its effects, has almost neglected an important strategy which develops and sustains a firm's competitive advantage: the process innovation activities. Specifically, the paper unfolds the black-box of the process innovation strategy using the process innovation strategy as a mediator to explain a firm's performance and not just as a mere dependent variable for predicting process innovators. In addition, the paper connects theoretically the process innovation with the management innovation mode to understand their relationship. Using CIS data for Spain, the main contributions found are: (1) most of the process innovation performance is explained without R&D variables; (2) it is observed a strong dependence on external sources of knowledge to explain the process innovation performance, mainly through the acquisition of embodied knowledge; (3) it is observed an important "implementation" effect or "learning by trying" effect on a firm's performance due to the fact that the acquisition of embodied knowledge requires a synchronous adoption of the management innovation mode which reprocesses the organization in order to couple the new technology sourced; (4) the acquisition of embodied knowledge is also positively moderated, and thus the process performance is amplified, when the use of external sources of knowledge is also congruent with the introduction of the new technology sourced; (5) the product innovation strategy is not related to the process innovation performance, i.e. there is an absence of complementarities. The paper presents important implications for scholars and policymakers.

Key words: process innovation strategy, process innovation performance, management innovation, embodied knowledge acquisition, product innovation.

1. Introduction.

The excessive concentration of the innovation literature on product development and its effects (e.g. Vega-Jurado et al., 2008) has almost neglected an important strategy which develops and sustains a firm's competitive advantage: the process innovation strategy (e.g. European Commission, 2008; Niehaves, 2010; Reichstein and Salter, 2006). The process innovation strategy is defined as the activities which relate to the "new elements introduced into an organization's production or service operations, input materials, task specifications, work and information flow mechanism, and equipment used to produce a product or render a service, with the aim of achieving lower costs and/or higher product quality" (Reichstein and Salter, 2006). This paper explores a firm's process innovation activities, exercise which is scant in the literature compared to the huge amount of literature related to product innovation. In particular, the paper uses the process innovation strategy as a mediator to explain a firm's performance and not just as a mere dependent variable for predicting process innovators. In this vein, the paper focuses on the process innovation performance, its antecedents and its effects on a firm's innovative performance. To the best of our knowledge, most of the literature on process innovation, with relatively few exceptions (e.g. Reichstein and Salter, 2006), has been focused on predicting the accomplishment of the process innovation strategy, that is, the effective implementation or introduction of a new or significantly improved production process, distribution method or support activity. Put differently, there is observed a systematic tendency in the literature to use the process innovation outcome as a dependent variable, that is, just use a dummy variable to predict process innovators (Pires et al., 2008), synchronous adoption of product and process innovation strategies (Santamaria et al., 2009) or incremental versus radical process innovators (Reichstein and Salter, 2006). This research bias means that the antecedents used to predict product and process innovators are mostly the same as the ones used for measuring product innovation. In addition, when addressing a firm's innovative performance, most of the literature has been devoted to the understanding of product innovation (e.g. Taylor, 2010; Turner et al., 2010), fact which also has emphasized the use of R&D measures. In fact, the process innovation performance or its effects are rarely used in the innovation literature, compared with the over-researched typical percentage of annual sales that comprises new or substantially improved products over a period of time. All in all, this paper covers the aforementioned gaps and offers a contribution to the literature of innovation management by unfolding the specific particularities of the process innovation strategy, its antecedents and effects on a firm's performance. Thus, focusing on the process innovation effects or outcomes is paramount to managing firm innovation (Crossan and Apaydin, 2010). The paper controls for the product innovation strategy it in order to better isolate the process innovation phenomenon and also tackles the relationship between the process and the management innovation strategies, as some works have suggested (e.g. Edquist, 2001; Womack et al., 1990) to understand better all the potentialities offered by the process innovation strategy. The paper extends the conversation about innovation by filling the theory with empirical findings from the process innovation phenomenon which presents implications for the management of innovation and the management of technology literature. Moreover, the paper's results also extend the conversation by providing new evidence on the relationship between the process and the rest of the innovative strategies, i.e. product and management.

The study is based on 8923 firms using data from the Technological Innovation Survey carried out in Spain in 2006. This survey is the one used to provide data for CIS (Community Innovation Survey) purposes. The structure of the paper is as follows. In the second section the literature is revised and the hypotheses are formulated. Then, in the third section the empirical design and results are presented, while, finally, the conclusion is discussed in the last section.

2. Theory development and hypothesis

Process innovation is defined as new elements introduced into a firm's production or service operation to produce a product or render a service (e.g. Rosenberg, 1982; Utterback and Abernathy, 1975) with the aim to improve productivity, capacity, flexibility or quality, among others. Following Reichstein and Salter (2006) process innovation is related to new capital equipment (Salter, 1960) and the existence of learning-by-doing and learning-by-using (Cabral and Leiblein, 2001; Hollander, 1965). Process innovation activities are typically introduced for reducing costs, rationalizing or increasing the flexibility and performance of production processes (Edquist, 2001; 2001; Simonetti et al., 1995) and lowering labour costs (Vivarelli and Toivanen, 1995; Vivarelli and Pianta, 2000).

Process innovation and R&D activities

As Reichstein and Salter (2006) states, a central difficulty in the context of disentangling the process innovation phenomenon is to differentiate between product and process related R&D expenditures, due to the fact that conventional R&D statistics do not make this distinction. Despite the little effort that scholars have devoted to this particular task, however, the evidence is quite controversial. On the one hand, Reichstein and Salter (2006), Mairesse and Mohnen (2005) and Baldwin et al. (2002) found a positive relationship between process innovation and R&D intensity. On the other hand, Hervas-Oliver et al. (2011), Huang, Arundel and Hollanders (2010), Barge-Gil et al. (2011) or Rouvinen (2002) found no relationship between firm-level R&D and process innovation adoption. The reason for this possible non-existing relationship between R&D intensity and process innovation is found on the fact that firms innovate through activities which do not require R&D (Arundel et al., 2008), such as combining existing knowledge in new ways (e.g. Evangelista et al., 2002), through imitation and reverse engineering (Kim and Nelson, 2000) or conducting incremental changes relying on engineering knowledge (Kline and Rosenberg, 1986). Specifically, product innovation is more related to the carry out R&D compared with process innovators (Hervas-Oliver et al., 2011; Huang et al., 2010; Rouvinen, 2002) which is more in line with the non-R&D performers (Arundel et al., 2008). Therefore, process innovation is more related to performing non-R&D activities (European Commission, 2008; Hervas-Oliver et al., 2011; Huang et al., 2010). As Arundel et al. (Arundel et al., 2008) points out describing the Innobarometer 2007: "*non-R&D innovators, compared to R&D performers, are more likely to focus on process innovation and to source ideas from within the firm from production engineers and design staff. The higher prevalence of process innovation among non-R&D performers suggests that there are more options for developing process innovations without performing R&D.*

Non-R&D innovators spend less on innovation than R&D performers." All in all, the first hypothesis is stated as follows:

H1: Process innovation activities performance is not expected to be driven by R&D intensity

Process and organizational innovation

In general, innovation is claimed not to be an exclusive technological effort, but a strategic, market-driven perspective (e.g. Bessant & Tidd, 2007; Terziovski, 2010) in which technological and management or organizational (administrative) activities complementary support each other (Damanpour & Evan, 1984; Damanpour, 1987). Management innovation is defined as policies of recruitment, allocation of resources, and the structuring of tasks, authority and reward (Evan, 1966), among others. Ettlie (1988) dubs the simultaneous use of management innovation and technological innovation "synchronous innovation" and argues that the use of appropriate forms of management innovation made technological innovation more effective in manufacturing firms in the United States in the 1980s. That positive gain of complementing technical and non-technical innovation in tandem is supported in the literature (e.g., Battisti & Stoneman, 2010; Damanpour et al., 2009; Damanpour and Evan, 1984). In particular, addressing specifically the role of process innovation activities and their relationship with organization activities the evidence is even more stressed, although it seems that the innovation management literature has not yet successfully adopted the evidence from other strands of literature about the manifested close relationship between the process and the organization or administrative innovation, as it is described below. Usually the process innovation activities involve both organizational and technological changes (Gopalakrishnan and Damanpour, 1997; Reichstein and Salter, 2006) blurred and difficult to separate (Edquist et al., 2001; Ettlie and Reza, 1992; Womack et al., 1990). Edquist et al., (2001) includes within the process innovation phenomenon two distinct but related activities: technological process and organizational process innovation. Following the latter work, *technological process innovations* are new goods that are used in the process of production and include investment goods and intermediate goods such as processing machines, industrial robots and IT equipment. Complementary, *organizational process innovations* are new ways to organize business activities such as production and have no technological elements but with the co-ordination of human resources and work practices, such as just-in-time production, total quality management or lean production. All in all, the management literature has evidenced that the application of process technology in industries depends on changes in structure and administrative practices (Ettlie, 1988; Nabseth and Ray, 1974; Thompson, 1967). Besides of the management literature, the systematic overlap of the organizational and process innovation is also systematically stressed in the operations management literature. For instance, group technology, uniform workload, multifunction employees, Kanban, and just-in-time purchasing practices within the *lean* manufacturing systems are made up of technological and organizational processes simultaneously (e.g. White and Ruch, 1990). Similarly, flexible manufacturing technique use advanced manufacturing technologies, have an organizational structure with less levels and uses innovative human resources policies (Duguay et al., 1997). In this vein, the second hypothesis is related with the fact that process and organization innovation are usually observed in tandem. And the effects on the process performance are amplified when the process is accompanied with management innovation, as Luria (1987) evidenced that the changes in organizational structure or process technology alone did not yield any significant cost reductions in automobile component plants. Therefore, the second hypothesis is stated as follows:

Hypothesis 2. A firm's complementary adoption of process and organization innovation simultaneously will positively affect the process innovation performance.

Specifically, the technological process innovation is related to the incorporation new capital equipment (Salter, 1960), processing machines, industrial robots or IT equipment (Edquist, 2001) or just capital embodied technology (Rouvinen, 2002) usually obtained from the purchase of advanced machinery, computer hardware and software (Huang et al., 2010), among other non-R&D activities. This idea addresses the fact that the returns on process innovation from embodied technology acquisition are positive and constitute one of the main drivers of incorporating technology in a firm to renew its processes and its process innovation performance. In general, it is recognized that process innovation in small firms is much more related to the ''embodied technological change'' incorporated in the physical capital formation rather than in intangible investment in R&D (Conte and Vivarelli, 2005; Santarelli and Sterlacchini, 1990; Vaona and Pianta, 2008). Flowers (2007) refers to the acquisition, implementation and exploitation from the demand-side or the buyer perspective, which is less explored in the literature, rather than the extensively researched supplier-centricity. That is, when selling/purchasing equipment or infrastructure, both physical (machinery) or intangible (a software like an ERP, Enterprise Resource Planning, MRP, Manufacturing Resource Planning, or other IT systems for production or organizational purposes) most of the work on technological change is focus, by large, on the supply-side dynamics (Adner and Levinthal, 2001; Dosi, 1992; Flowers, 2007) rather than on the demand (buyer) side. In this vein, the buyer/producer firm (which buys technology capital goods or services from others suppliers in order to integrate them into their own products) is distinct from the buyer/user firm which buys technology capital goods and services in order to use them within their own operational infrastructure (Flowers, 2007). In this paper we refer to the buyer/user typology and the explanation of the implementation of the acquired embodied technology, to the best of our knowledge, is solely addressed at the *technology strategy* literature which presents some evidence about the implementation of technology to work as commercially successful operating systems, starting mainly in the 80's (Bessant, 1985; Leonard-Barton and Deschamps, 1988; Rhodes and Wield, 1985). Implementation of new equipment or embodied knowledge is an organizational learning process (Voss, 1988) which constitutes a key component of the innovation process (Leonard-Barton and Deschamps, 1988) which has been systematically under-researched (Fleck, 1994; Flowers, 2007; Voss, 1988). Fleck (1994) has described the implementation as a process of "learning by trying" or "learning by struggling to get it to work", that is, improvements and modifications done to the constituent components before the configuration can work as an integrated entity. Specifically, Fleck (1994) point out that the *learning by trying* is different from the *learning by doing* (progressing up the learning curve, Arrow, 1962) and the *learning by using* (improvements made after functioning, Rosenberg, 1982).

The point is to understand that the acquisition of new technology requires a mutual adaptation of technology and organization (Ettlie, 1988; Ettlie and Reza, 1992; Fleck, 1994; Leonard-Barton and Deschamps, 1988; Voss, 1988), that is, the adaptation of the technology transfer through the implementation process requires that managers recognize and assume responsibility for both technical and organizational change (Leonard-Barton and Deschamps, 1988). For instance, Ettlie (1988) found that better performing organizations synchronize the adaptation of administrative policies with the introduction of technology. Fleck (1994) also recognized the necessity to adapt the management procedures to the new technology implemented and Voss (1988) explicitly addressed the complementary effects of integrating new technology with the organizational perspective in order to successfully adopt new technology for process innovation. All in all, technology is an occasion for structuring and the actual outcomes depend on how the new processes brought from the new technology are coupled with the organization (Barley, 1986; Cohen and Zysman, 1987; Damanpour, 1991; Ettlie and Reza, 1992; Markus and Robey, 1988; McCann and Galbraith, 1981). As Ettlie and Reza (1992) states that the technology suppliers provide new technologies embodied in software or hardware which are difficult to protect because those transactions are governed by a weak appropriability regime. In this sense, capturing value from process innovation activities needs to make process innovation an unique occasion for restructuring and creating coupling arrangements (Cohen and Zysman, 1987) with internal and external change processes. In addition, from the operations management literature, it is also evidenced that the technology adoption process by acquiring embodied technology is amplified when the workplace and structure changes follows simultaneously (Boer and During, 2001). These complementarities between process innovation and organization innovation is confirmed in recent papers which have accessed to the CIS data addressing all different type of innovation modes (Polder et al., 2010). Therefore, we expect that the returns on process innovation from embodied technology acquisition, which is a prominent driver of the process innovation, will be amplified when organizational changes follow, complements and couple that introduction of technology in a firm. Thus, the third hypothesis is stated as follows:

Hypothesis 3. The effects that the technology acquisition exerts on the process innovation performance are positively moderated by the simultaneous adoption of management innovations

Sourcing knowledge external to the firm is also a way to complement the acquisition of capital goods. In fact, it is well documented the role of suppliers assisting the buyer/user firm in the process of sourcing knowledge related to the implementation of machinery and equipment for process innovation (e.g. Ettlie et al., 1984; Ettlie and Reza, 1992; Voss, 1985). This social learning process of sourcing external knowledge is form by the interaction among different people who posses the dispersed knowledge when acquiring embodied knowledge is acknowledge in Baetjer (2000). As Boer and During (2001) pointed out, the implementation of a successful flexible manufacturing system, in terms of both technical and business success, requires an integrated techno-organizational innovation rather than just the mere implementation of a new piece of equipment. The resource-based approach enhances the process of resource accumulation and learning in the decision to acquire external knowledge (Robins and Wiersema, 1995). In this vein, Ettlie and Reza (1992) have studied the successful adoption of process innovation and found that organizational integration of suppliers and customers alongside with internal capabilities such as design and manufacturing affect positively the productivity of new manufacturing systems implementation in firms. In this vein, the fourth hypothesis is stated referring to the fact that the effect on a firm's process innovation performance of the acquisition of embodied knowledge, as aforementioned, is expected to be reinforced when the necessary knowledge to effectively adopt the new technology is sourced with a close interaction with the industrial (referred to the value chain, that of suppliers, customers or competitors through imitation) external knowledge. As a result, the fourth hypothesis is stated:

Hypothesis 4: The effect that the technology acquisition exerts on the process innovation performance is moderated positively by complementing it with the use of external sources of knowledge from the industry or the value chain.

Following Damanpour et al. (2009) both internal and external sources of knowledge positively affect the innovation process. External communication means environmental scanning and extra-organizational communication professional activities of members can hiring innovative ideas (Jervis, 1975; Miller and Friesen, 1982), Innovative organizations exchange information with their environments effectively (Tushman, 1977). Internal communications facilitates dispersion of ideas within a communication organization and increases their amount and diversity, which results in cross-fertilization of ideas (Aiken and Hage, 1971), which also creates an internal environment favourable to the survival of new ideas (Ross, 1974). The resource-based approach enhances the process of resource accumulation and learning in the decision to acquire external knowledge (Robins and Wiersema, 1995). In this vein, Ettlie and Reza (1992) have studied the successful adoption of process innovation and found that organizational integration of suppliers and customers alongside with internal capabilities such as design and manufacturing affect positively the productivity of new manufacturing systems. Specifically for process innovation there is literature which confirms some important points about the influence of these external sources of knowledge. Von Hippel (1988) suggests that process innovators work closely with external suppliers. Similarly, Freel and Harrison (2006), Rouvinen (2002) and Cabagnols and Le Bas (2002) found a correlation between the tendency of a firm to engage in process innovation and its cooperation with suppliers and universities. In the same vein, Vonortas and Xue (1997), following the approach of Bhoovaraghavan et al. (1996), studied the influence of customers in the case of process innovation. All in all, the role of consultants (e.g. Flowers, 2007) and especially the role of suppliers providing knowledge for process innovation (e.g. Cabagnols and Le Bas, 2002; Ettlie et al., 1984; Ettlie and Reza, 1992; Rouvinen, 2002; Voss, 1985). Therefore, the fifth and sixth hypotheses are related to internal and external (industry and non-industry agents) are as follows:

Hypothesis 5: External sources of knowledge from the industry and non-industry agents will be positively associated with a firm's process innovation performance

Hypothesis 6: Internal sources of knowledge will be positively associated with a firm's process innovation performance.

Complementary, there is a research stream which have discussed the product versus process innovation dilemma, i.e. and independent from each other or rather complementary, at firm's level (see Damanpour, 2010 for a full revision). On the one hand, Soudes and Padmanabhan (1989) evidenced that this joint accomplishment is rather difficult. In fact, following Damanpour (1991) the rates of adoption of product and process innovations are different during the stages of the development of a business (Utterback and Abernathy, 1975) and firms also differ in their emphases on product or process innovation for providing competitive advantages (Ettlie, 1983;

Hull et al., 1985). On the other hand, the stream of literature advocates for considering the product and process innovation process interdependent, getting complementarities from each other and permitting firms to gain more competitiveness and advantage (Baba, 1989; Collins et al., 1988; Gerwin, 1988). Thus, Reichstein and Salter (2006) analysed a large sample of UK manufacturing firms and found that that product and process innovation were interdependent. Similarly, Cabagnols (1999) studied the dynamics of product versus process innovation and vice versa taking into account its continuity and consistency finding that continuity was highest in the former and consistency similar in both. Martinez-Ros (2000) analysed a large sample of Spanish firms and found product and process innovation to be complementary and dependent basically on the market and firm's characteristics. Therefore, the seventh hypothesis is as follows:

Hypothesis 7: Process innovation performance is positively influenced by the synchronous adoption of product innovation activities

3. Empirical design

The data is sourced from the Spanish Innovation Survey (Technology Innovation Survey is the official name) administered by the Spanish National Statistics Institute (INE) and conducted in 2006. This survey is based on the core of Eurostat Community of Innovation Survey (CIS). In the Spanish Innovation Survey firms are asked about the type of innovation introduced over the two years period covered by the survey (in our case 2004-2006). The questionnaire clearly distinguishes between technical (product and process) and non-technical (organizational and marketing) innovations [1]. The selection of the sample was based on firms which are innovative active (innovation expenditures >0). The sample of 8923 firms was selected covering NACE-92 2-digit industries from 14 to 74. NACE 55 was selected as baseline for dummies specification.

4. Model and variables

The dependent variable, which measures a firm's process innovation performance, used in this research is based on a factor analysis. It is formed by the resulting punctuations from a factor analysis apply on four different measures (variables) from the CIS questionnaire. Three process oriented effects include "improved production flexibility," "reduced unit labour costs," "increased capacity," and "reduced materials and/or energy per produced unit." The four original variables are ordered responses, represented on a scale from zero (absence, no effect) to 3 (maximum). Following this procedure, one single factor, through its punctuations, represents the dependent variable which explains 61 % of the variance (KMO = 0.71, p<0.01). The final resulting variable is different from a firm's overall performance or productivity, and permits to isolate better the outcomes from the process innovation adoption. Then, ordinary least squares (OLS) are used in the analysis.

In Table 1 show the list of variables representing the stated hypothesis and Table 2 shows the descriptive statistics and correlation matrix of these variables. The internal sources of information to innovate (*Int_sources*) represents those which arise from the firm's own departments, staff, firms from the same group, etc. The importance of that information has been measured in a four-point scale (not used = 0; poor, value = 1; medium, value = 2; high, value=3). Addressing the external sources of knowledge in which a firm taps to, those are captured across a wide range of external information sources: suppliers, customers, competitors, consultants, commercial laboratories, private R&D firms, universities, technological centres, public research centres, commercial events, scientific journals and papers and professional associations. All these variables have been reduced to two factors through a factor analysis with a KMO of 0.86 and a 61% of explained variance, see Table 1. The first factor obtained from a factor analysis (*Ext_sources_fact_industrial*), corresponds to the sources related with the industrial agents from the value chain as customers, suppliers or competitors and other sources also related with the industry as commercial events, scientific journals and magazines and professional associations. The second factor (*Ext_sources_fact_science*) corresponds to more scientific and specific pecuniary knowledge (commercial laboratories, private R&D firms, universities, technological centres and public research centres), see Table 1 for details.

Table 1. Table of variables for the analysis

	Meaning	Codification
Dependent variable: INNO_effects	Process innovation factor effects on firms from a PCA applied to the sample. Resulting from the following variables measuring the effect on firms of process innovation on: - Reduced unit labour costs - Increased capacity - Improved production flexibility - Materials and energy saving Each effect has been measured in a four range scale: no effect = 0; Low effect = 1; Medium effect =2; High effect = 3	Continuous, from punctuations from factor analysis
Int_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.). 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	0-3 interval.
Ext_sources_fact_Industrial Ext_sources_ fact_Science	External sources factors Industry and Science are the result from a PCA applied to different variables corresponding with different sources of information to innovate (KMO: 0.86; Variance explained: 61%) - External_sources_Industrial: corresponds to clients, suppliers, competitors, consultants, commercial events, scientific journals and magazines, and professional associations - External sources_Science: corresponds to consultants, commercial laboratories, private R&D firms, universities, technological centres, and public research centres.	Continuous, from punctuations from the second factor analysis carried out

Information sources	External_sources_fact Industry	External_sources_fact Science
Suppliers (Info _SUPL)	**0,550**	-0,081
Clients (Info _CLI)	**0,662**	0,205
Competitors (Info _COMP)	**0,707**	0,195

Consultants, commercial laboratories, private R&D firms (Info _CONS)	0,314	**0,585**
Universities (Info _UNI)	0,138	**0,815**
Public research centres (Info _PUBLIC)	0,133	**0,865**
Technological centres (Info _TEC-CEN)	0,180	**0,805**
Commercial events (Info _EVENTS)	**0,733**	0,273
Scientific review and papers (Info _REVIEW)	**0,688**	0,363
Professional associations (Info _ASSO)	**0,611**	0,405

	Each of information sources refer to the importance of the information in order to innovate from of each source and response to the question: "In the period 2004-2006, ¿how important has been the following information sources for the innovation activities of your enterprise? Clients, suppliers, competitors, consultants, commercial events, scientific journals and magazines and papers, Professional associations, Consultants, commercial laboratories, private R&D firms, Universities, Technological centres, and Public research centres. 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	
Int_R&D_expend	*Intramural R&D expenditures per sales: it* comprises all expenditure on R&D performed within the firm, divided into the sales	Continuous
Ext_R&D_expend	*Extramural R&D expenditurse per sales: it* comprises the acquisition of R&D services, divided into the sales	Continuous
Tech_expend	*Embodied technology expenditures per sales*: it comprises expenditure on the acquisition of machinery and equipment with improved technological performance, including major software, divided into the sales	Continuous
Inno_product	Indicates if the enterprise has introduced a new or improve product innovation activities	Dummy 0-1
Inno_Organization	Indicates if the enterprise has introduced a new or improve *organisational change* during the research period	Dummy 0-1
Size	Logarithm of the annual average of full-time employees in 2006.	Continuous
Industry_NACE_code	Industry classification by NACE-93 (2-digits, 59 sectors), from 15 to 74.	Dummy 0-1

Investments in intra and extramural R&D activities are also considered for the first hypothesis. The intramural R&D expenditures per sales (*Int_R&D_expend*) comprise all expenditure on R&D performed within the firm and the extramural R&D expenditures per sales (*Ext_R&D_expend*) comprise the acquisition of external R&D services. Additionally the embodied technology expenditures per sales (*Tech_expend*) reflect the acquisition of advanced machinery, equipment and computer hardware or software. The variable *Inno_product* is included to control for the firm's innovative outputs different from process, i.e. firms which innovate in product or/and service. This variable is measured as a dummy variable and takes 1 if the firm have introduce a new or improve product or/and service during the period and 0 otherwise. Thus, this variable reflects the complementary character expected between product and process innovation. Similarly, the organizational or management innovation output (*Inno_organization*) is also considered, capturing whether the firm has introduced a new or improve organizational change during the research period (dummy variable 0-1) and addressing the second hypothesis related with the fact that process and organization innovation are usually adopted in tandem or simulatenously. Next, the moderation effects of organizational innovations and the use of external sources of innovation on the technology acquisition are represented by interaction variables as a result of the multiplication of the corresponding variables and the technology acquisition variable. Therefore for the first moderation effect we have the *Inno_organization_x_Tech_expend* variable and for the second moderation effect we have two variables, each for one type of external sources factor:

Ext_sources_fact_Industry_x_Tech_expen and *Ext_sources_fact_Science_x_Tech_expend.* Eventually, the paper also introduces the sector classification in order to control for industry differences (*Industry_NACE_code*), including 58 2-digit NACE-93 industry classification as dummies, ranging from the 14 to 74 2-digit NACE-93 codes (59 industries). The variable *Size* (control variable) is calculated as the logarithm of the annual average of full-time employees in 2006.

Table 2: Descriptive statistics and correlation matrix of variables

	Variables	Mean	Stand. Desv.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	INNO_effects																			
2	Int_sources	2,19	1,011	,25**																
3	Info _SUPL	1,72	1,070	,26**	,07**															
4	Info _CLI	1,34	1,145	,28**	,29**	,20**														
5	Info _COMP	1,06	1,028	,30**	,19**	,25**	,56**													
6	Info _CONS	,81	1,000	,23**	,17**	,18**	,31**	,35**												
7	Info _UNI	,55	,882	,15**	,17**	,08**	,27**	,26**	,41**											
8	Info _PUBLIC	,42	,765	,17**	,14**	,09**	,28**	,28**	,43**	,66**										
9	Info _TEC-CEN	,57	,901	,18**	,15**	,10**	,29**	,29**	,46**	,53**	,64**									
10	Info _EVENTS	1,07	1,043	,31**	,18**	,24**	,38**	,41**	,30**	,32**	,32**	,34**								
11	Info _REVIEW	,91	,953	,29**	,21**	,21**	,37**	,38**	,34**	,39**	,37**	,36**	,67**							
12	Info _ASSO	,74	,908	,24**	,13**	,20**	,34**	,38**	,36**	,35**	,40**	,40**	,54**	,597**						
13	Inno_product	,49	,500	,14**	,25**	0,000	,31**	,23**	,18**	,21**	,16**	,21**	,25**	,25**	,17**					
14	Inno_Organization	,601	,489	,13**	,14**	,10**	,15**	,13**	,14**	,09**	,08**	,09**	,16**	,16**	,14**	,14**				
15	Int_R&D_expen	,031	,109	,03**	,12**	-,04**	,14**	,08**	,08**	,19**	,16**	,13**	,11**	,15**	,08**	,17**	,07**			
16	Ext_R&D_expen	,005	,033	,02*	,05**	-0,01	,05**	,04**	,07**	,13**	,10**	,10**	,05**	,06**	,05**	,08**	,03**	,26**		
17	Tech_expen	,014	,0585	,07**	-0,01	,03**	-,03**	-0,00	-,057**	-,05**	-,02**	-,03**	-0,01	-,04**	-,04**	-,06**	-,04**	0,01	0,01	
18	Size	1,68	,539	,067**	,078**	,05**	,03**	,08**	,13**	,09**	,08**	,09**	,04**	,05**	,08**	,08**	,053*	-,20**	-,11**	-,124**

** significant at p<0.01

5. Results

According to Table 3 the four specifications representing the model offer a good fit (adjusted R^2 about 0.22 in the four cases). The results in Table 3, corresponding to Specification 1, indicate that the investment in internal R&D expenditures (*Int_R&D_expend)* do not influence a firm's process innovation performance. This result is repeated in all subsequent specifications. In fact, the coefficients are negative, although they are not statistically significant. Similarly, in all specifications, the variable *Ext_R&D_expend* does not work, meaning that the acquisition of R&D from external to the firm sources does not render any returns for process innovation strategies. The same result is also observed in the rest of specifications. On the contrary, there is one key variable which reflects that the acquisition of embodied knowledge (*Tech_expend*) does contribute to increase the process innovation performance (coefficient 0.076, 0.078, 0.078, 0.055 in specification 1, 2, 3 and 4 respectively; all of them significant at $p<0.01$). Then, the variable *Inno_product*, which is negative in all specifications and non-significant, indicates that the realization of product innovation strategies do not contribute to improve the process innovation performance, that is, product innovation activities are neutral and do not affect the output performance of the process innovation activities. On the contrary, the *Inno_organization* variable, which reflects whether the company has also conducted organizational or management innovation activities, does contribute positively to improve the process innovation performance, as the positive and significant coefficients show in each specification (0.051, 0.051. 0.051 and 0.045 in the first, second, third and fourth specification, respectively, p<0.01). The latter result suggests that the accomplishment of organization innovation activities does contribute to increase the process innovation performance, that is, the organization and process innovation activities are complementary.

Regarding the sources of information to innovate within a firm's search strategy, the results indicate in the four specifications that the internal sources of knowledge improve the process innovation performance (*Int_sources*, 0.156, 0.157, 0.156, 0.157, respectively, p<0.01), indicating that there is important knowledge disperse within a firm which can be organized and deployed to improve the process innovation performance positively. In addition, the external sources of knowledge variables indicate that sourcing external sources of knowledge from industrial agents (i.e., the value chain; *Ext_sources_fact_Industry*) and from science sources (i.e., universities and R&D centers; *Ext_sources_fact_Science*) are both positive and significant (in all specifications, p<0.01), meaning that there are returns and gains in the process innovation performance from the sourcing of external knowledge, and especially from the industry sources, due to the larger coefficients showed in the Table 3 (for instance, in specification 1, 0.3421 in Industry, compared to 0.101 in Science, both significant at p<0.01).

The control variable, log Size, is positive and significant in all four specifications, indicating that the larger the company, the better the process innovation performance. Lastly, the interactions show important results. First, the acquisition of embodied knowledge is positively moderated, that is, there are complementarities, by the synchronous management innovation adoption at the organization (*Inno_organization_x_Tech_expend)*, pointing out that an improvement in the process innovation performance is obtained from combining the acquisition of embodied knowledge with conducting and achieving organization innovation activities at the firm (specification 4, 0.031 at p<0.01). Second, the interaction between the acquisition of embodied technology and the use of external sources to innovate, show a different result depending on the type of external sources considered. The use of industrial or value chain sources of knowledge moderate positively (E*xt_sources_fact_Indsutry_x_Tech_expend, coefficient 0.029 at p<0.01*, specification 2) the acquisition of embodied knowledge, while the science-based sources of knowledge produce no effect (E*xt_sources_fact_Science_x_Tech_expend,* non statistically significant, specification 3) on the process innovation performance. In other words, despite the interesting external sources of knowledge to improve the process innovation performance, both from industry and non-industry sources, the acquisition of embodied technology is better complemented from knowledge from the industry or value chain (suppliers, customers and competitors), while the rest of external knowledge (mainly universities or R&D centres) do not complements the new technology acquired.

Table 3: OLS model results

	Specification 1		Specification 2		Specification 3		Specification 4	
	Stand. coef.	Stand. errors	Stand. Coef.	Stand. errors	Stand coef.	Stand errors	Stand. Coef.	Stand. errors
constant		0.067		0.067		0.0067		0.067
log (SIZE)	0.034**	0.019	0,034**	0.019	0.034**	0.019	0.034**	0.019
Int. sources	0.156**	0.010	0,157**	0.010	0,156**	0.010	0.157**	0.010
Ext_sources_fact_Industry	0.342**	0.010	0,334**	0.010	0,342**	0.010	0.342**	0.010
Ext_sources_fact_Science	0.101**	0.010	0,101**	0.010	0,101**	0.010	0.101**	0.010
Int_R&D_expend	-0.008	0.105	-0,008	0.105	-0,008	0.105	-0.008	0.105
Ext_R&D_expend	0.001	0.291	0,001	0.003	-0,001	0.291	0.001	0.291
Tech_expend	0.076**	0.164	0,078**	0.165	0,078**	0.178	0.055**	0.224
Inno_product	-0.005	0.021	-0,005	0.021	-0,005	0.021	-0.006	0.021
Inno_organization	0.051**	0.020	0,051**	0.020	0,051**	0.020	0.045**	0.021
Ext_sources_fact_ Industry x_Tech_expend			0,029**	0.182				
Ext_sources_fact_Science_x_Tech_expend					0.005	0.217		
Inno_organization_x_Tech_expend							0,031**	0,322
Industry_NACE_code	Yes		Yes		Yes		Yes	
R^2	0.22		0.22		0.22		0.22	
Adjusted R^2	0.216		0.216		0.215		0.216	
Error	0.88		0.88		0.88		0.88	
F	52.187**		52.26**		50.82**		52.18**	

Level of significance: 1% (**).
The variable *Industry_CNAE_code* has effect on the dependent variable. Industry dummies and their coefficients are not reported to save space but are available upon request. N=8923

All in all, the results point out that process innovation performance, in general, is mainly explained by non R&D efforts but a highly intensive process of dependence on external sources of knowledge, including formal and pecuniary acquisition of embodied technology and informal sources of knowledge from the industry and other external agents and events (fair trades, congresses, etc.). In short, the results indicate that introducing acquired embodied knowledge, together with the use of external and internal (to the firm) sources of knowledge and the synchronous adoption of management innovation activities, all in all, increase a firm's chances of obtaining higher process innovation performance through reducing costs and materials per produced unit and improving flexibility and capacity in process innovation activities. Neither R&D efforts nor the product innovation adoption increase a firm's process innovation performance. In addition, the interaction variables show a complementary and positive effect, which reflects that the acquisition of embodied knowledge is positively moderated and the process innovation performance is amplified when that acquisition is complemented with management innovation activities and the intensive use of external sources of knowledge from the industry or value chain.

Following Pacheco-Pires et al. (2008) and Bogers (2009), the sector heterogeneity needs to be considered and for this reason an industry dummy variable is included for each of the 59 2-digit industries (58 are included, and the NACE 55 is the baseline). An important proportion of the industries affect the process innovation effects. Results are available upon request.

6. Conclusions.

This work explores and sheds light on the process innovation phenomenon, whose study has been systematically under-researched by scholars, presenting insights about the poor attention paid to the process innovation performance variable, traditionally used as a dichotomous dependent variable instead of used as a mediator to explain a firm's performance effects. In fact, instead of merely predicting process innovators or simply understanding complementarities between product and process innovations, this paper is based on understanding the drivers that improve performance through cost reductions, flexibility and capacity improvement from process innovation activities. Based on 8,923 firms from the Spanish CIS data-based innovation survey, the results suggest that all the hypotheses are feasible, except for the one controlling the complementarities between the process and the product innovation strategy. Using a cross-fertile theoretical framework which cover the management literature, the innovation management studies and that of the operations management the paper's contributions are fivefold.

First, the paper addresses an often neglected fact: the importance of non R&D innovators or "neglected" innovators. In fact, most of the process innovation performance is explained without R&D activities. This is in line with the literature about innovation which has showed that R&D activities are more frequently used to explain the product innovation activities than that of the process innovation (Arundel et al., 2008; Huang et al., 2010; Vaona and Pianta, 2008). In the innovation management literature, different scholars have worked without considering R&D

intensity (Bougrain and Haudeville, 2002; Freel, 2003; Muscio, 2007) and confirming that the innovation process in low- and medium-tech contexts can be captured using non R&D activities (e.g. Santamaría et al., 2009). Put differently, the variables upon which the study is based are beyond those of intramural R&D expenditures, and the results show that "doing, using and interacting" (Jensen et al., 2007) is a way for firms to innovate. Therefore, in contradiction to a large stream of research (e.g. Baldwin and Lin, 2002; Mairesse and Mohnen, 2005; Reichstein and Salter, 2006), R&D efforts are not important to explain firms' determinants to achieve better productivity levels by making process innovation efforts, confirming the study of Rouvinen (2002). Thus, the first hypothesis is accepted due to the overwhelming evidence about the fact that R&D activities do not explain the process innovation performance.

Second, it is observed a strong dependence on external sources of knowledge to explain the process innovation performance, mainly through the acquisition of embodied knowledge, confirming the literature (Conte and Vivarelli, 2005; Edquist, 2001; Santarelli and Sterlacchini, 1990; Vaona and Pianta, 2008). Moreover, the results also suggested that informal external sources of knowledge from the industry and from other non-industry agents, in line with the literature (Cabagnols and Le Bas, 2002; Damanpour and Daniel Wischnevsky, 2006; Freel and Harrison, 2006; Hagedoorn, 2002; Rouvinen, 2002; Zeng et al., 2010) are also important for the process innovation activities, although the internal sources of knowledge also matter (Damanpour et al., 2009). External knowledge sources, in general, are drivers to explain the innovation process in firms, in line with other studies (Barge-Gil, 2010; Cabagnols, 1999; Reichstein and Salter, 2006; Rouvinen, 2002; Vega-Jurado et al., 2008; Von Hippel, 1988), although most of the evidence about external sources has been mainly developed for product innovation. Nevertheless, more research is needed since the majority of aforementioned studies on innovation neither address the administrative or organization aspect nor the non-R&D activities. Therefore, the fifth and sixth hypothesis are accepted.

Third, it is observed an important "implementation" effect or "learning by trying" (Fleck, 1994) effect in which the acquisition of embodied knowledge require that the organization is reprocessed to couple the new technology. This result, predicted in the literature mainly through case studies (Fleck, 1994; Flowers, 2007; Leonard-Barton and Deschamps, 1988; Voss, 1988) is empirically confirmed and extended from a manifested empirical evidence of the positive combination of the embodied knowledge acquisition and the synchronous adoption of management innovation activities in order to adapt the organization to the new type of knowledge, showing a positive and complementary effect on the process innovation performance. Complementary, this result also reinforce the evidence that the process innovation mode is congruent to the organizational one (e.g. Polder et al., 2010). Put differently, our paper confirms a hybrid innovation process made of the synchronous adoption of both technological and non-tech (organizational) activities (e.g. Damanpour and Evan, 1984). Our results confirmed those of Brynjolfsson and Hitt (2000) which pointed out the complementarities of IT investment in hardware and software, organizational change and economic performance. Specifically, our results coincide with those of Polder, van Leeuwen, Mohnen and Raymond (2010) which pointed out the empirical evidence that organizational innovation is complementary to process innovation. All in all, the second and third hypothesis are accepted.

Fourth, and closely related to the third contribution, the acquisition of embodied knowledge also is positively moderated, and thus the process performance is improved, when the use of external sources of knowledge are also synchronous with the introduction of the new technology confirming the literature (e.g. Ettlie et al., 1984; Ettlie and Reza, 1992; Robins and Wiersema, 1995; Voss, 1985). This idea reinforce the assumption that a close and intensive interaction with providers of external non-scientific knowledge from the industry (competitors, suppliers and customers) also reinforce and improve the adoption of embodied technology. Thus, the fourth hypothesis is accepted.

Fifth, the hypothesis seventh about the fact that the process innovation is positively complemented by product innovation activities is rejected and there is no evidence about the effects that the product innovation activities exert on the process innovation performance, contradicting a body of literature which claim that there is not sufficient evidence on the separation (Damanpour, 2010; Fritsch and Meschede, 2001; Pisano et al., 1997; Reichstein and Salter, 2006; Walker, 2004) and confirming a different strand of the literature which predicted no effect due to the different nature of both technological types of innovation, in the sense that product innovations are pursued to respond to customers' demand for new products or executives' desire to capture new markets, whereas process innovations are pursued to reduce delivery lead-time or decrease operational costs (Knight, 1967; Martinez-Ros, 2000; Schilling, 2005). On this chain of thought, our conclusions confirmed those of Kraft, (1990) which evidenced that introducing process innovation does not act as a spur to product innovation. Nevertheless, the fact that the process innovation variable used is the effect or performance, not jus the decision to conduct process innovation, avoid comparisons with literature devoted to predict process innovators.

Size has been found to be an important driver to explain inducements to process innovation in the literature (Cohen and Klepper, 1996; Damanpour, 2010; Klepper, 1996; Nord and Tucker, 1987; Reichstein and Salter, 2006) predicting a positive relationship among them. As Damanpour suggests (2010), researchers generally posit that size has a more positive association with process than with product innovations (e.g. Cohen and Levinthal, 1989; Fritsch and Meschede, 2001; Scherer, 1980), in line with this paper's results, contradicting other studies which do not relate innovation and size (e.g. Camisón-Zornoza et al., 2004; Rammer et al., 2009).

Lastly, the paper presents implications for scholars and policy makers. First, the policymaking efforts to foster process innovation should: (a) facilitate access to other innovative inputs in addition to just R&D, (b) support organization or management innovation as a complement for implementing the technology and thus enhance the process innovation, producing synergies which expand the process innovation performance (c) incentive the acquisition of embodied knowledge through technology equipment to counteract the lack of internal resources, (e) promoting networking in order to achieve an optimal implementation process of the new technology. Second, scholars should also include the effect of the process innovation activities beyond, or complementary, to the much more studied product innovation phenomena. In particular, scholars should also focus on non-R&D indicators, due to the facts that the R&D can not explain all type of innovation decisions and their effects. In addition, scholars should also exploit the still black-box process innovation phenomenon addressing other countries by especially comparing European Union countries.

The paper has some limitations. First, the sample is set in a technology-follower country (Spain) and it cannot be extended to other more technology advanced nations. Second, As Qian and Li (2003) pointed out, it is impossible to determine causality at a single time point. Nonetheless, this study assumes that independent variables have a causal relationship with the firm's innovative performance due to the lag period considered between the independent and dependent variables.

Endnotes:

[1] See PITEC database, at http://icono.publicaciones.fecyt.es/contenido.asp?dir=05)Publi/AA)panel

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