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**Process innovation objectives and management complementarities: patterns,  
drivers, co-adoption and performance effects**

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# Process innovation objectives and management complementarities: patterns, drivers, co-adoption and performance effects

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## Abstract

The excessive concentration of the innovation literature on product development, its drivers and effects, has almost neglected an important strategy which develops and sustains a firm's competitive advantage: process development or innovation. This is an examination of process innovation as more than a mere dependent variable for predicting innovators. It provides insights into the poor attention that process innovation variable has received as an indicator of a firm's performance. In addition, the paper relates this process with the management innovation phenomenon. Using 8,977 firms from Spain through CIS data, findings suggest: (1) most process innovation performance is explained without R&D variables; (2) process innovation process innovation was observed to have a strong dependence on external sources of knowledge, mainly via the acquisition of embodied knowledge; (3) an important "implementation" effect or "learning by trying" effect is observed in which the acquisition of embodied knowledge requires the organization to couple the new technology with existing processes; (4) the simultaneous co-adoption of management innovation positively moderates and improves process performance (5) product innovation is not related to process innovation performance. The latter result is unrelated to consideration of co-adoption of product and process innovation. Two-step Heckman procedures control for the selection process. The paper presents important implications for policymakers and scholars.

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

**JEL classification:** Q31, L25

## 1. Introduction.

Despite the recognition that firms have specific types of innovation objectives within “technical goals” (Cohen and Malerba, 2001:590), there is a tendency of excessive concentration of the innovation literature on product innovation and its effects on sales (Escribano et al., 2009; Vega-Jurado et al., 2008), to the extent that the existing literature has almost neglected an important strategy or objective which also develops and sustains a firm’s competitive advantage: process innovation activities and/or process development (e.g. Lager, 2011, European Commission, 2008;

Niehaves, 2010; Reichstein and Salter, 2006). Process innovation is defined as the introduction of new elements 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 of improving productivity, capacity, flexibility, quality, reducing costs, rationalizing production processes (Edquist, 2001; 2001; Simonetti et al., 1995) and lowering labour costs (Vivarelli and Toivanen, 1995; Vivarelli and Pianta, 2000).

Following Reichstein and Salter, (2006) process innovation is related to new capital equipment (Salter, 1960) and the practices of learning-by-doing and learning-by-using (Cabral and Leiblein, 2001; Hollander, 1965). Similarly, the 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 this vein, this paper explores and sheds light on firm's innovators whose literature is less developed (exceptions are Womack et al., 1990; Clark & Wheelwright, 1993, among others). Specifically, this paper goes beyond process innovation as a mere dependent variable which indicates whether the firm has successfully introduced new processes, extending the insights towards the effects or objectives accomplished from the introduction of new processes. Furthermore, the paper focuses on the process development and its subsequent process innovation performance (through production flexibility improvement, production capacity enhancement, labour costs reduction or efficiency using materials and energy in the production process).

To the best of our knowledge, most of literature on process innovation, with a few exceptions (e.g. Reichstein and Salter, 2006), has been conducted on predicting the introduction of new processes (Pires et al., 2008) or predicting incremental versus radical process innovation accomplishment (Reichstein and Salter, 2006), usually in tandem with product innovation (e.g. Santamaría et al., 2009). Put differently, the majority of works are based on finding the predictors which explain whether the firm engages in product, process or both technological modes of innovation simultaneously, and not on the specific effects that those innovations exert on a firm's performance. In parallel, most of the innovation management literature has been devoted to the understanding of product innovation (e.g. Taylor, 2010; Turner et al., 2010). In fact, innovation effects obtained from introducing new processes in a firm have rarely been used in the innovation literature, compared with the typical percentage of annual sales that comprises new or substantially improved products over a period of time which has been extensively researched on literature. This

has biases firms' performance towards product innovators rather than embracing process innovators.

In complement, process innovation is related to management innovation, in the sense that the management systems usually complement the technical ones (e.g., Womack et al., 1991). Following Polder et al. (2009, p. 23) it is evidenced that “*product and process innovation only lead to higher productivity when performed together with an organizational innovation*”. This result is confirmed by previous literature (Luria, 1987; Ettlie, 1988; Nabseth and Ray, 1974; Thompson, 1967), suggesting that management practices and its related organizational capabilities do complement process innovation. In particular, it is confirmed that 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). In this vein, process innovation is going to be explored in tandem with the management innovation. All in all, this paper covers the following gaps: (1) the paper presents an attempt to offer new insights on understanding the introduction of new processes in firms, its antecedents and performance effects on processes objectives; (2) the paper also investigates the complementary role of the process and the management innovation.

The paper contributes to literature in the following ways. First, the paper provides insight about the antecedents of the almost neglected process innovation and its results on process (production) objectives. Second, the paper also contributes to the management innovation literature by exploring its complementary role with the technological mode by analysing the complementarities between process and management innovation adoption. In order to accomplish the latter, the paper links the disconnected strands of literature based solely on the adoption of the technical strategy (technology strategy literature) with that of the management adoption (management and organizational learning strand). Therefore, with this paper's contributions it is expected that the *conversation* about the technical innovation will be improved and expanded by addressing process innovation activities and their complementarities with the organizational innovation.

In general, our findings point out that the innovation pattern of the process innovators does not use R&D (internal or external) activities in order to explain returns from process innovation (based on production flexibility, production capacity, lower labour costs or materials and energy reduction). On the contrary, process effects are highly influenced by search strategies to source external knowledge, mainly from the acquisition of embodied knowledge and knowledge from the industry. In addition, process effects are amplified by engaging simultaneously in the adoption of new management practices, finding a significant and positive relationship between the process and the management activities. Finally, the combination of the acquisition of embodied knowledge with

the introduction of new management practices yields significant returns from process development, that is, an interaction effect is captured. In addition, as showed in Appendix A and B, the product effects, even for process innovators, showed a different pattern of innovation.

The study is based on 8,977 process innovators using data from the CIS in Spain, from 2006 EUROSTAT data. The structure of the paper is as follows. In the second section literature is revised and the hypotheses are formulated. Then, in the third section the empirical design is presented, while in the fourth section findings are showed and discussed. Finally, the conclusion is presented in the last section.

## **2. Theory development and hypothesis**

### **2.1 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 (administrative) activities complementary support each other (Damanpour & Evan, 1984; Damanpour, 1987). Ettlíe (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 from combining technical and non-technical innovation in tandem is supported in literature (e.g., Battisti & Stoneman, 2010; Damanpour et al., 2009; Damanpour and Evan, 1984). In particular, 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; Ettlíe and Reza, 1992; Womack et al., 1990). Edquist et al., (2001) includes within process innovation activities two distinct but related activities: technological process innovation and organizational process innovation. *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, literature on management has evidenced that the application of process technology in industries depends on changes in structure and administrative practices (Ettlíe, 1988; Nabseth and Ray, 1974; Thompson, 1967). Besides 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 all of them 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, Luria (1987) evidenced that the changes in organizational structure or process technology alone did not yield any significant cost reductions in automobile component plants. Nevertheless, the majority of this literature is based on case studies or specific industries (e.g., Womack et al., 1990; Ettlie, 1988; Luria, 1987; Thompson, 1967). Few studies have shown those complementarities between process innovation and organization innovation using CIS data (e.g., Polder et al., 2010). Therefore, more general evidence is needed. All in all, it is stated that the process and management innovation are usually observed in tandem and that the effects or objectives achieved from the process activities will be amplified when the introduction of new management practices accompany the introduction of new processes. Thus, the first hypothesis is stated as follows:

**Hypothesis 1. A firm's complementary adoption of process and organization innovation simultaneously will positively affect process innovation performance.**

Specifically, technological process innovation is related to the incorporation of new capital equipment (Salter, 1960), processing machines, industrial robots or IT equipment (Edquist, 2001; OECD, 2005) or just capital embodied technology (Rouvinen, 2002) usually obtained from the purchase of advanced machinery or computer hardware and software (Huang et al., 2010; OECD, 2005). 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 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 focused 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. Thus, the acquisition of machinery is carried out with the purpose to adopt embodied knowledge into a firm's innovation process, as previously mentioned. However, to the best of our knowledge, solely the *technology strategy* literature presents some evidence about the implementation of technology 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) 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 *learning by trying* is different from the *learning by doing* (progressing up the learning curve, Arrow, 1962) and *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 actual outcomes depend on how the new processes brought from 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). Thus, capturing value from process innovation activities needs to make process innovation a unique occasion for restructuring and creating coupling arrangements (Cohen and Zysman, 1987) with internal and external change processes. Similarly, Bresnahan et al. (2002) highlighted the complementary nature of information technology and workplace reorganization to innovate. The latter work showed that IT investments only result in improvements in firm



performance when they are combined with new work practices and investments in human capital. In addition, from 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). Therefore, we expect that the returns on process innovation from embodied technology acquisition, which is a prominent driver of process innovation, will be amplified when organizational changes follow, complement and couple the introduction of technology in a firm. Thus, the second hypothesis is stated as follows:

**Hypothesis 2. The technology acquisition effect on process innovation performance is positively moderated by simultaneous co-adoption of organization innovations**

### **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). The method and types of questions in CIS are described in the Organisation for Economic Co-operation and Development (OECD, 2010). CIS were widely piloted and tested before implementation, and since their first use in the early 1990s, the questions have been continuously revised. CIS are often described as “subject-oriented” because they ask firms directly whether they were able to produce an innovation. Following Reichstein and Salter (Oslo manual: OECD, 2005) the CIS questionnaire itself draws on previous generations of research on innovation, including a Yale survey and the SPRU innovation database (2006, p. 661). Stockdale (2002) contains an overview of the methodology and basic descriptive findings of the survey. CIS data are increasingly being seen as a key data for the study of innovation at firm level in a large number of studies across countries in Europe, Canada, and Australia (Klevorick et al., 1995; Pavitt et al., 1987).

In order to pursue the purpose of this research the final sample was based on process innovators firms (8,977 firms), defined as firms having introduced at least one new or improved process in the research period and being innovation active (innovation expenditures >0), regardless of having also conducted product or organization innovation activities. Nevertheless, the total firms available in the population (28,649) are used to conduct robustness checks using two-step Heckman processes to control for potential selection biases (only using process innovators).

This study takes process innovation output as a mediator, following Crossan and Apaydin (2010) suggestion, and not as a mere dependent variable. On one hand, the dependent variable captures the effects on processes from the introduction of new processes is quite a novel approach. First, on

one hand, process effects are obtained from four variables addressing the effects on processes, fact which is different from a firm's overall performance or productivity, and permits us to isolate better the effect of undertaking process innovation activities. The resulting punctuations from the factor analysis (PCA) represent the first (*Process\_effects* variable) dependent variable. These 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 were ordered responses, represented on a scale from zero (absence, no effect) to 3 (maximum). Following this procedure, one single component from the analysis, through its punctuations, represents the dependent variable which explains 60.21 % of the variance (KMO = 0.7172,  $p < 0.01$ ).

Second, on the other hand, the independent or explicative variables comprise a wide range of information sources of innovation, R&D internal and external expenditures, product and organization innovations, together with industry and size as control variables. Then, 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 that a firm taps into, 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 0.8607 and a 56.6% of explained variance, see Table 1. The first component obtained from this PCA (*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 component (*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. In Table 1 it is showed the list of variables representing the stated hypothesis and Table 2 shows the descriptive statistics and correlation matrix of these variables.

**Table 1.** Table of variables for the analysis

	Meaning	Codification
Dependent variable: <i>Process_effects</i>	Process innovation factors effects on Process and Product aspects of firms are the result from a PCA applied to the sample (KMO 0.7172; Variance explained: 60.21%). Resulting from the following variables measuring the effect on firms of process innovation on: - Higher production flexibility (product or service)	Continuous, from punctuations from factor analysis

	<ul style="list-style-type: none"> <li>- Higher production capacity</li> <li>- Lower labour cost per unit</li> <li>- Fewer materials and energy per produced unit</li> </ul> <p>Each effect has been measured in a four range scale: no effect = 0; Low effect = 1; Medium effect =2; High effect = 3</p>																																		
Int_sources	<p>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.).</p> <p>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</p>	0-3 interval.																																	
Ext_sources_Industrial Ext_sources_Science	<p>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: 56.6%)</p> <ul style="list-style-type: none"> <li>- External_sources_Industrial: corresponds to clients, suppliers, competitors, consultants, commercial events, scientific journals and magazines, and professional associations</li> <li>- External sources_Science: corresponds to consultants, commercial laboratories, private R&amp;D firms, universities, technological centres, and public research centres.</li> </ul> <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr> <th>Information sources</th> <th>External_sources_fact Industry</th> <th>External_sources_fact Science</th> </tr> </thead> <tbody> <tr> <td>Suppliers (Info _SUPL)</td> <td><b>0,550</b></td> <td>-0,101</td> </tr> <tr> <td>Clients (Info _CLI)</td> <td><b>0,666</b></td> <td>0,191</td> </tr> <tr> <td>Competitors (Info _COMP)</td> <td><b>0,711</b></td> <td>0,178</td> </tr> <tr> <td>Consultants, commercial laboratories, private R&amp;D firms (Info _CONS)</td> <td>0,333</td> <td><b>0,575</b></td> </tr> <tr> <td>Universities (Info _UNI)</td> <td>0,160</td> <td><b>0,812</b></td> </tr> <tr> <td>Public research centres (Info _PUBLIC)</td> <td>0,158</td> <td><b>0,860</b></td> </tr> <tr> <td>Technological centres (Info _TEC-CEN)</td> <td>0,202</td> <td><b>0,799</b></td> </tr> <tr> <td>Commercial events (Info _EVENTS)</td> <td><b>0,738</b></td> <td>0,258</td> </tr> <tr> <td>Scientific review and papers (Info _REVIEW)</td> <td><b>0,694</b></td> <td>0,348</td> </tr> <tr> <td>Professional associations (Info _ASSO)</td> <td><b>0,622</b></td> <td>0,387</td> </tr> </tbody> </table> <p>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?"</p> <p>Clients, suppliers, competitors, consultants, commercial events, scientific journals and magazines and papers, Professional associations, Consultants, commercial laboratories, private R&amp;D firms, Universities, Technological centres, and Public research centres.</p> <p>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</p>	Information sources	External_sources_fact Industry	External_sources_fact Science	Suppliers (Info _SUPL)	<b>0,550</b>	-0,101	Clients (Info _CLI)	<b>0,666</b>	0,191	Competitors (Info _COMP)	<b>0,711</b>	0,178	Consultants, commercial laboratories, private R&D firms (Info _CONS)	0,333	<b>0,575</b>	Universities (Info _UNI)	0,160	<b>0,812</b>	Public research centres (Info _PUBLIC)	0,158	<b>0,860</b>	Technological centres (Info _TEC-CEN)	0,202	<b>0,799</b>	Commercial events (Info _EVENTS)	<b>0,738</b>	0,258	Scientific review and papers (Info _REVIEW)	<b>0,694</b>	0,348	Professional associations (Info _ASSO)	<b>0,622</b>	0,387	Continuous, from punctuations from the second factor analysis carried out
Information sources	External_sources_fact Industry	External_sources_fact Science																																	
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Professional associations (Info _ASSO)	<b>0,622</b>	0,387																																	
Int_R&D_expend	<p><i>Intramural R&amp;D expenditures per sales measured in a 5 points scale:</i> (0: 0; 1: &lt;=5%; 2: 5% &lt; x &lt;=10%; 3: 10% &lt; x &lt;=50%; 4: &gt;50%)</p>	0-4 scale																																	
Ext_R&D_expend	<p><i>Extramural R&amp;D expenditures per sales: it comprises the acquisition of R&amp;D services per sales measured in a 5 points scale.</i> (0: 0; 1: 0% &lt; x &lt;=5%; 2: 5% &lt; x &lt;=10%; 3: 10% &lt; x &lt;=50%; 4: &gt;50%)</p>	0-4 scale																																	
Tech_expend	<p><i>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.</i> (0: 0; 1: 0% &lt; x &lt;=5%; 2: 5% &lt; x &lt;=10%; 3: 10% &lt; x &lt;=50%; 4: &gt;50%)</p>	0-4 scale																																	
Inno_product	Indicates if the enterprise has introduced a new or improve product or services during the research period	Dummy 0-1																																	
Inno_process	Indicates if the enterprise has developed a new or improve process during the research period	Dummy 0-1																																	
Inno_organization	Indicates if the enterprise has introduced a new or improve <i>organisational change</i> 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																																	
Process_industry	Indicates if the industry sector of the firm belongs to the process industries group. Process Industries CNAE: 5;6;8;10;11;17;19;20;21;22;23;24.1;24.2;24.3;5;36;37;38 (See Lager, 2011)	Dummy variable (0-1)																																	

Inno_problems	Equal to 1 if one of the four following problems on getting output innovation on the research period: <ul style="list-style-type: none"> <li>- On-going innovation activities at the end of in 2006</li> <li>- On-going innovation activities at the end of in 2006, suffering important delays</li> <li>- Innovation activities abandoned on the early phases</li> <li>- Innovation activities abandoned before starting</li> </ul>	Dummy variable (0-1)
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As aforementioned, investments in intra and extramural R&D activities are also considered. 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 acquisition of embodied knowledge (*Tech\_expend* variable, *Embodied technology expenditures per sales*: it comprises expenditure on the acquisition of machinery and equipment with improved technological performance, including major software, per sales) following Vega-Jurado et al., (2008) procedure is measured into an ordered 5 points scale to better capture its influence (0: 0; 1:  $0% < x \leq 5%$ ; 2:  $5% < x \leq 10%$ ; 3:  $10% < x \leq 50%$ ; 4:  $>50%$ ).

The variable *Inno\_product* is included to control for the firm's innovative products, 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 effects 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 observed in tandem, i.e., complementary. Next, the moderation effect is represented by an interaction variable as a result of the multiplication of the new management practices variable and the technology acquisition variable. Therefore for this moderation effect we used the *Inno\_organization\_x\_Tech\_expend* variable. 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). NACE 55 was selected as baseline for dummies specification. In addition, we also control for the typical "process industries" which are mainly dedicated to the introduction of new processes (see Lager, 2011:22), such as mining, forest or utilities (*Process\_industry* variable). The variable *Size* (also a control variable) is calculated as the logarithm of the annual average of full-time employees in 2006.

Table 2 Descriptive statistics and correlation matrix

		Mean	Std.Dev	1	2	3	4	5	6	7	8	9	10	11
1	log (SIZE)	3.883	0.013	1.000										
2	group	0.269	0.005	0.431*	1.000									
3	Int_R&D_expend	0.514	0.010	-0.267*	-0.024*	1.000								
4	Ext_R&D_expend	0.122	0.005	-0.161*	0.028*	0.439*	1.000							
5	Tech_expend	0.311	0.008	-0.183*	-0.101*	-0.014	0.026*	1.000						
6	Int. sources	2.192	0.011	0.074*	0.127*	0.225*	0.091*	-0.031*	1.000					
7	Ext_sources_fact_Industry	0.000	0.011	0.057*	0.044*	0.149*	0.047*	-0.007	0.233*	1.000				
8	Ext_sources_fact_Science	0.000	0.011	0.097*	0.142*	0.273*	0.210*	-0.072*	0.150*	0.000	1.000			
9	Inno_organization	0.602	0.005	0.050*	0.047*	0.106*	0.048*	-0.046*	0.144*	0.196*	0.076*	1.000		
10	Inno_product	0.487	0.005	0.073*	0.076*	0.309*	0.124*	-0.082*	0.256*	0.248*	0.195*	0.145*	1.000	
11	Process_Industry	0.198	0.004	-0.039*	-0.055*	-0.052*	-0.030*	0.094*	-0.002	0.040*	-0.018	-0.042*	0.029*	1.000
12	Inno_problemas	0.283	0.007	0.105*	-0.015	-0.221*	-0.109*	-0.015	-0.075*	-0.036*	-0.098*	-0.008	0.555*	0.039*

\*significant at  $p < 0.01$ 

In general, 90% of the process innovators (8,977 firms) are SMEs. In fact, only 1,774 firms (20% of the sample) belong to “process industries”. 60% of the process innovators also innovate in organization, i.e., introducing new management practices, and 49% (4,369 firms) do the same in product innovation. Therefore, it is observed a preference for accompanying process with organization.

## 4. Results and discussion

### 4.1 Findings

Our sample is based on a threshold (i.e. whether or not firms innovate on process), our results could suffer from additional sort of selection bias. The only respondents to these questions are the technological innovators, not only the process but also the product innovators. Therefore left censoring may arise when firms in do not accomplish process innovations but product innovation and also claimed that from that product innovation introduction some process effects has been obtained. In order to tackle this problem we run a Heckman’s two-stage selection model where, in the first stage, the inverse Mills ratio is obtained from a *Probit* regression (to predict whether or not a firm innovates on process) using all available observations in the population (28,649 firms). For the second stage, the inverse Mill ratio is included, as an additional variable, to explain the variation in innovation performance of the selected sample (8,977 firms, the process innovators). Table 3 incorporates the two-step Heckman procedure to control for selection bias of using process innovators (8, 978 out of the 28,649 which form the total population). The dependent variable measures the innovation performance as the impact of the introduction of new processes on firms through process effects or objectives (higher production flexibility; higher production capacity; lower labour cost per unit; fewer materials and energy per produced unit). The existence of the inverse Mill’s ratio in the equation, when significant, control the coefficients obtained in the

regression. When non-significant, it has no effect. We carry these analyses for the *Process\_effect* dependent variable. In this particular case, the inverse Mill ratio turns out to be non-significant at the 5% level suggesting that the sample selection (process innovators firms) is not an issue when the depended variable is *Process\_effects*. The specification used to predict the probability to innovate in process (*Inno\_process*) includes the following variables: *Int\_R&D\_expend*, *Ext\_R&D\_expend*, *Tech\_expend*, *Inno\_product*, *Inno\_Organization*, *Size*, *Group*, *Industry\_NACE\_codes*, *Process\_industry* and *Inno\_problems* (the latter related with facts which hamper innovation in process) . Other variables related with technological innovations such as internal and external sources of innovations are not included because only the technological innovators answer these questions in the survey (See procedures in Heckman, Mothe and Nguyen-Thi, 2010). See table 3.

According to tables 4 (*process\_effects* as dependent variable), which contains the OLS results, the three specifications offer a good fit (adjusted  $R^2$  ranging from 0.20 to 0.21). Following Pacheco-Pires et al. (2008), and Bogers (2009), and Mothe and Nguyen-Thi (2010), 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 process innovation effects. Results about the industry effect are available upon request.

The results in table 4 about process effects, corresponding to Specification 1, indicate that the investment in internal R&D activities (*Int\_R&D\_expend*) to innovate do not influence process effects. 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 sources does not render any process returns from process innovation strategies. The result is also observed in the rest of specifications. On the contrary, there is one key variable which reflects the acquisition of embodied knowledge, *Tech\_expend* which does contribute to increase process innovation performance (coefficient 0.135, 0.151 and 0.98 in specifications 1 to 3, respectively; all of them significant at  $p < 0.01$ ). Then, the variable *Inno\_product*, which is negative in all specifications (except the second) and statistically insignificant, indicating that the realization of product innovation strategies do not contribute to improve process innovation effects, that is, product innovation activities are neutral and do not affect process effects. On the contrary, the *Inno\_organization* variable, which addresses whether the company has also conducted organizational or management innovation activities, does contribute positively to improve process innovation performance, as the positive and significant coefficient shows in each specification

(0.102, 0.086, 0.081, respectively,  $p < 0.01$ ). The latter result suggests that the accomplishment of organization innovation activities does contribute to increase process effects from process innovation, that is, the organization and process innovation activities are complementary. Regarding the sources of information within a firm's search strategies, which benefit process innovation performance, the results indicate in the three specifications that the internal sources of knowledge improve process innovation performance (*Int\_sources*, 0.157, 0.1574, 0.15732, respectively,  $p < 0.01$ ), indicating that there is important knowledge dispersed within a firm which can be used and deployed to improve 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 centres; *Ext\_sources\_fact\_Science*) are both positive and significant (in all specifications,  $p < 0.01$ ), meaning that there are returns and gains in process innovation performance from the sourcing of external knowledge, and especially from the industry sources, due to the larger coefficients shown in the tables 4 (for instance, in specification 1, 0.343 in Industry, compared to 0.096 in Science, both significant at  $p < 0.01$ ). The control for the specific "process industries" does not yield any effect in process effects but the general industry effect is important and significant. The goodness of fit, through the  $R^2$  adjusted, accounts for a range between 0.20 and 0.22.

The control variable, log Size, is positive in all specifications (with 0.038 value in most of the specifications;  $p < 0.01$ ), indicating that the larger the company, the better the process innovation performance. Lastly, the interaction shows important results. Thus, the acquisition of embodied knowledge is positively moderated, that is, there are complementarities, by the innovation management activity performed at the organization (*Inno\_organization\_x\_Tech\_expend*), pointing out that an improvement in process innovation performance is obtained from combining the acquisition of embodied knowledge with co-adopting simultaneously organization innovation activities at the firm (specification 3, 0.065 at  $p < 0.01$ ).

Table 3 Two-step Heckman procedure to control for selection problems.

	Probit model (INNO_PROCESS)		OLS Model Process_effect	
	Coef.	Std. Err.	Coef.	Std. Err.
constant	-1.695**	0.059	-0.801	0.122
log (SIZE)	0.157**	0.009	0.040**	0.010
group	0.061**	0.024	-0.037	0.024
Int_R&D_expend	0.019	0.015	-0.002	0.014
Ext_R&D_expend	0.058*	0.025	-0.016	0.022
Tech_expend	0.987**	0.027	0.141**	0.023
Inno_organization	0.847**	0.019	0.112**	0.032
Inno_product	0.786**	0.023	0.008	0.032
process_industry	-0.148	0.136		

inno_problems	-0.467**	0.024		
Int. sources			0.157**	0.010
Ext_sources_fact_Industry			0.343**	0.010
Ext_sources_fact_Science			0.096**	0.010
<b>Inv Mill</b>			<b>0.018</b>	<b>0.050</b>
Industry_NACE_code	Yes		Yes	
N	28649		8977	
chi2	10,901			
R2	0.306		0.2221	
Adjusted R <sup>2</sup>			0.2178	
Error			0.00	
F			52.01	

Table 4 OLS Model. Dependent variable: Process\_Effects

	Specification 1		Specification 2		Specification 3	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
intercept	-0.763**	0.068	-0.557**	0.043	-0.751**	0.068
log (SIZE)	0.038**	0.009	0.033**	0.009	0.038**	0.009
group	-0.039	0.024	-0.045	0.024	-0.038	0.024
Int_R&D_expend	-0.002	0.013	-0.034	0.012	-0.002	0.013
Ext_R&D_expend	-0.016	0.022	-0.018	0.022	-0.016	0.022
Tech_expend	0.135**	0.013	0.151**	0.013	0.098**	0.019
Int. sources	0.157**	0.010	0.1574**	0.010	0.157**	0.010
Ext_sources_fact_Industry	0.343**	0.010	0.350**	0.010	0.343**	0.010
Ext_sources_fact_Science	0.096**	0.010	0.104**	0.010	0.096**	0.010
Inno_organization	0.102**	0.020	0.086**	0.020	0.081**	0.021
Inno_product	-0.001	0.021	0.018	0.021	-0.002	0.021
Inno_organization_x_Tech_expend					0.065*	0.026
Industry_NACE_code	yes				yes	
Process_Industry			0.038	0.024		
R <sup>2</sup>	0.222		0.2071		0.2227	
Adjusted R <sup>2</sup>	0.218		0.2061		0.2187	
Error	0		0		0	
F	53.1		212.87		52.48	

Level of significance: 1% (\*\*). Sample 8,977 firms which introduced at least new processes (these firms may also introduce new products or management practices) (*Industry\_NACE\_code*), including n-1 2-digit NACE-93 industry classification as dummies, ranging from the 14 to 74 codes. Code 55 is the baseline. 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. In addition Process\_industry control for typical process industries, as aforementioned in table 1.

In order to isolate the process effects of simultaneous co-adoption of product and process activities by firms, we restrict the sample (8,977) to only “pure” process innovators, that is, firms which only introduced new processes and not new products. Put differently, we restrict the technological innovation to just process innovators. We also conducted selection process control by running a Heckman two-step procedure. Two-step Heckman procedure to control for selection problems in the subsample of the pure process innovators, when measuring process effects. There is not found any selection problem, that is, the Inv. Mill is insignificant (Inv Mill’s ratio 0.33;  $p > 0.05$ ). The 4,608 firms which only introduced new processes show a similar pattern of innovation to the previous sample (8,977 process innovators which may also have introduced new products). In order to isolate the pure process innovators, we construct a new dependent variable following a similar procedure as the aforementioned, getting a single component from a PCA (59.9% of the



variance explained and KMO= 0.7015) for the reduce (4,608) sample. In table 5, the results showed a similar pattern of innovation for the pure process innovators (4,608) compared to the process innovators (8,977). Basically, and in line with the previous findings, it is observed that R&D activities (both internal and external) do not influence any process effect. Similarly, the acquisition of embodied knowledge (*Tech\_expend* variable) does yield significant and positive returns on process effects (0.123, 0.137, 0.085 respectively in all three specifications,  $p < 0.01$ ). In line with previous results, the search strategies are also positive and significant. That is, the external sources of knowledge (from the industry and from the science sources) are both significant and positively related to process effects. The size effect is also positive and significant (first and third specification, 0.032 and 0.031,  $p < 0.05$ ) and the *Group* variable is negative and significant, indicating that the pure process innovators do not yield any effect from belonging to an industrial group. Finally, the introduction of new management practices (*Inno\_organization* variable) is positively significant (0.075, 0.058, 0.0453, respectively,  $p < 0.01$ ). In addition, the interaction effect (*Inno\_organization X Tech\_expend* variables) is also positive and significant (0.082,  $p < 0.05$ ). The effects from the industry are significant (*Industry\_NACE\_code* variable) and also the effect from the process industries (specification 2, 0.0138  $p < 0.05$ ). See table 5.

Table 5 OLS Model. Dependent variable: Process\_Effects

	Firms which only introduce new processes (without co-adoption of product innovation objective): “pure” process innovators					
	Specification 1		Specification 2		Specification 3	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
constant	-0.570**	0.0824	-0.351**	0.0578	-0.552**	0.0826325
log (SIZE)	0.032*	0.0131	0.021	0.0130	0.031*	0.0131
group	-0.078*	0.0346	-0.079*	0.0341	-0.076*	0.0346
Int_R&D_expend	-0.002	0.0236	-0.032	0.0222	-0.002	0.0236
Ext_R&D_expend	0.039	0.0407	0.037	0.0405	0.039	0.0407
Tech_expend	0.123**	0.0170	0.137**	0.0168	0.085**	0.0228
Int. sources	0.152**	0.0122	0.153**	0.0123	0.152**	0.0122
Ext_sources_fact_Industry	0.381**	0.0138	0.386**	0.0138	0.380**	0.0138
Ext_sources_fact_Science	0.073**	0.0158	0.085**	0.0155	0.074**	0.0157
Inno_organization	0.075**	0.0269	0.058*	0.0267	0.0453	0.0294
Inno_organization_x_Tech_expend					0.082*	0.0327
Industry_NACE_code	Yes				Yes	
Process_Industry			0.138*	0.0340		
N	4608		4608		4608	
R <sup>2</sup>	0.239		0.2212		0.24	
Adjusted R <sup>2</sup>	0.2311		0.2195		0.232	
Error	0		0		0.000	
F	30.47		130.54		30	

Dependent variable: process\_effects, (KMO = 0.7015; 59.98% variance)

Level of significance: 1% (\*\*); 5% (\*). Sample 4,608 firms which only introduced new processes (pure process innovators) and not product (*Industry\_NACE\_code*), including n-1 2-digit NACE-93 industry classification as dummies, ranging from the 14 to 74 codes. Code 55 is the baseline. 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=4,608 In addition *Process\_industry* variable controls for typical process industries, as aforementioned in table 1.

All in all, the results of the innovation pattern and process effects on both samples, i.e., process innovators (8,977) and just pure process innovators (4,608), are pretty similar. Put differently, the R&D (internal or external) activities do not explain any return from process activities on process effects (based on production flexibility, production capacity, lower labour costs or materials and energy reduction). Then, process effects are highly influenced by external sources of knowledge, mainly from the acquisition of embodied knowledge and the knowledge from the industry. In addition, process effects are amplified by engaging simultaneously in the adoption of new management practices, finding a significant and positive relationship between the process and the management activities. Complementary, the combination of the acquisition of embodied knowledge with the introduction of new management practices yields significant returns from process innovation, that is, an interaction effect is captured. Finally, the introduction of new products do not yield any return on process effects.

Nevertheless, the introduction of new processes can also yield effects on products. We control for this possibility in Appendix A. The results showed that the pattern of innovation regarding the product effects or objectives is pretty different from the process one, but the main findings and hypothesis are sustained. See Appendix A.

## **4.2 Discussion**

In general, the results point out that process innovation effects from the introduction of new processes, are 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 introduction of new management practices, all in all, increase a firm's chances of obtaining higher performance from its process innovation strategies 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 activities increase or alter the chances that a firm has to improve its 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 process innovation performance is amplified, when that acquisition is complemented with the introduction of new management activities. So, how these results fit into literature?

As Reichstein and Salter (2006) states, a central difficulty in the context of disentangling process innovation pattern 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. In spite of the lack of effort that scholars have devoted to this particular task, the evidence is quite controversial. On 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. The reason for this possible non-existing relationship between R&D 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). Our evidence is in line with the fact that process innovation is more related to performing non-R&D activities (European Commission, 2008; Hervas-Oliver et al., 2011; Huang et al., 2010), as observed and confirmed in Appendix A and B. As Arundel et al., 2008 points out describing the Innobarometer in 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.”* Nevertheless, our results are novel and not really comparable to the previous literature, in the sense that we do not relate R&D or non-R&D activities to process innovation accomplishment, that is, whether firms perform or not process innovation, but process effects or performance from the introduction of new processes. The subtleties are quite different and thus our findings suggest that the R&D activities do not yield superior process effects which improve the firm’s performance.

Our paper is in line with previous studies about sourcing knowledge from external sources. In this line, as evidenced in our results, sourcing knowledge is positively related to the innovation process (e.g., Damanpour et al., 2009). 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). 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; Ettlíe et al., 1984; Ettlíe and Reza, 1992; Rouvinen, 2002; Voss, 1985) are important.

Overall, the results confirm the stated hypothesis, showing the following contributions. First, the introduction of new management practices is positively related to process effects performance, that is, the new management innovation practices also improve process effects. This results are in line with the previous management literature (Ettlíe, 1988; Nabseth and Ray, 1974; Thompson, 1967) which stated that the non-tech adoption (management innovation, *Inno\_organization* variable), in line with Lam (2005) concept of *organizational innovation*, is a precondition to ensure innovation in organizations through the relevant and key organizational characteristics which enhance a firm's innovation (e.g. R. Hall, 1992; R. Hall, 1993; Henderson & Cockburn, 1994). In other words, it is empirically evidenced that the adoption of a more systemic approach to innovation through the technical (process) and non-technical mode (management) together gives a firm a superior performance, confirming previous literature (Polder et al, 2009; Lauria, 1987). However, this result does not mean a cause-and-effect of one over another, but a positive synergistic gain which is supported in literature. Put differently, literature does not provide a cause-effect logic and following Damanpour et al. (2009, p. 658) it is recognized that the relationship between the technical and the non-technical systems in the social-technical systems theory is a correlative relationship representing a "coupling of dissimilarities" (Damanpour & Evan, 1984; Scott, 1992). Summarizing, the concentration on either the technical or the non-technical solely would result in a low performance level, as Herbst (1974) stated.

Second, we observed an "implementation" or "learning by trying effect", that is, the acquisition of embodied knowledge is positively moderated, and subsequently process effects are amplified, when that acquisition is complemented with the introduction of new management activities. This result confirms previous literature which suggested that 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; Ettlíe and Reza, 1992; Markus and Robey, 1988; McCann and Galbraith, 1981). Therefore, the

acquisition of technology is going to be successful and process effects optimize when that acquisition is coupled with the organization and, in this case, the introduction of new management practices which support the new technology. Then, size has been found to be an important driver to explain inducements to process innovation in 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).

Finally, the introduction of new products does not yield any return on process effects. Put differently, there is no evidence about the effects that the product innovation activities exert on process innovation activities 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) of product or process innovation. In fact, the previous literature has studied the co-adoption of product and process, while our study has gone as step further to assess whether the product innovation exerts or not process effects. Regardless the co-adoption, to introduce new products does yield necessarily effects on the process activities.

## **6. Conclusions.**

This paper focuses on the impact that the introduction of new processes exert on process innovation performance (measured through its effects on a firm's production flexibility, production capacity enhancement, labour costs reduction or a better efficiency using materials and energy in the production process) using CIS data. In this vein, this work explores and sheds light on process innovation phenomenon, whose study has been systematically under-researched by scholars. This work especially presents insights about the poor attention paid to process innovation variable, traditionally used as a dichotomous dependent variable, instead of being used as a mediator to explain a firm's performance. In fact, instead of merely predicting process innovators or simply understanding complementarities between product and process innovations, this paper is based on understanding process innovation drivers which enhance productivity. Based on 8,977 firms which recorded to have introduced at least one new process, using Spanish CIS data-based innovation survey, the results suggest that the two stated hypotheses are feasible. In particular, the

two stated hypothesis are accepted and the conclusions are as follows. First, regarding the second hypothesis, 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 literature mainly through case studies (Fleck, 1994; Flowers, 2007; Leonard-Barton and Deschamps, 1988; Voss, 1988) is empirically confirmed and extended from manifested empirical evidence of the positive combination of the embodied knowledge acquisition and the synchronous organization innovative activities to adapt the organization to the new type of knowledge, showing a positive and complementary effect on process innovation performance. Complementary, this result also reinforce the evidence that process innovation is related to the organizational one (e.g. Polder et al., 2010). Put differently, our paper confirms a hybrid innovation process form made of technological (process) 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. For example, Bresnahan, Brynjolfsson and Hitt (2000) found that greater levels of information technology investment are associated with changes in the work practices. Similarly, it is evidenced that organizational effects of computers depend on the extent to which firms couple computer investment with organizational redesign and other managerial decisions (Hunter et al., 2000; Murnane et al., 1999). 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.

Using a cross-fertile theoretical framework which covers the management literature and the innovation management studies, the paper’s additional conclusions are also important. First, the paper addresses an often neglected fact: the importance of non R&D innovators or “neglected” innovators. In fact, most of process innovation performance is explained without R&D variables. This is in line with literature about innovation which has showed that R&D activities are more frequently used to explain the product innovation activities than that of 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, and the results show that “...*incremental problem solving and experimentation [which] take[s] place on the shop floor and are closely associated with production beyond well-defined R&D*

*programmes...*” (Albaladejo and Romijn, 2000). 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). Second, a strong dependence is observed on external sources of knowledge to explain process innovation performance, mainly through the acquisition of embodied knowledge, confirming 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 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 process innovation activities, although the internal sources of knowledge also matter. External knowledge sources, in general, are drivers to explain the innovation process in firms, in line with other studies (Barge-Gil, 2010; Cabagnols, 1999; Escribano et al., 2009; Reichstein and Salter, 2006; Rouvinen, 2002; Vega-Jurado et al., 2008; Von Hippel, 1988).

Second, our findings pointed out that process innovation are not influenced by product innovation activities. Therefore, there is no evidence about the effects that the product innovation activities exert on process innovation activities 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 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 novelty on this work, beyond the majority of literature, is the fact that process innovation variable use is the effect or performance, not just the decision to conduct process innovation.

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 R&D, (b) support organization or management innovation as a complement for implementing the technology and thus enhance process innovation, producing synergies which

expand process innovation's performance (c) incentive the acquisition of embodied knowledge through technology equipment to counteract the lack of internal resources, (e) promoting networking in order to search knowledge. Second, scholars should also include the effect of 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 cannot explain all type of innovation decisions and their effects. In addition, scholars should also refine and exploit the still black-box process innovation phenomenon.

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. For future studies, a more in-depth analysis of the role of non R&D innovators when studying process innovation strategy should be done by especially comparing European Union countries.

#### **Appendix A: robustness check**

As Lager (2002) points out, one of the process development objective is also prompted by the needs or the company's own product development. Therefore, the introduction of new processes not only improves the needs of production but also produce effects on the products. This paper sheds light on it. Technological process innovation is the adoption of technologically new or significantly improved production methods. These methods may involve changes in equipment, or production organization, or a combination of both, and may be derived from the use of new knowledge. The methods may be intended to produce or deliver technologically new or improved products, which cannot be produced or delivered using conventional production methods, or essentially to increase the production or delivery efficiency of existing products (OECD, 2005:32). Thus, the paper checks also on product performance (measured through achieving wider range of product or services, increasing the market share or obtaining a higher quality of products or services). As done before for the *process\_effects* variable, the same is repeated for *product\_effects* of the process innovators, taking into account that the introduction of new processes can also affect the product effects, due to their interrelationship. Again, the resulting punctuations from a PCA represent the product effects (by process innovators) dependent variable and are obtained from three different variables from the CIS questionnaire (See table A-1). The *Product\_effects* variable captures the effects on products from the introduction of new processes by pure process



innovators. Pure process innovators are used in order to better isolate process development activities while being in line with the paper’s real and scope. Thus, these checking are done on the 4,609 firms and not in the general sample (8,977) because there are product innovators (which simultaneously undertake process activities) and then the product effects are not only influenced by the introduction of new processes. In this line of thought, we also control for selection process for the general sample (8,977 firms) , specifically in order to evaluate the *product\_effects* variable in the pure process innovators (only technological adoption of process innovation, not product one, that is, 4,609 firms). The Inv Mill is not significant at 5% (-0.123,  $p > 7\%$ ). Therefore, there is not selection process and the OLS for capturing the innovation pattern over the product effects (*product\_effects* variable) is carried out without the Inv Mill ratio. See table A-2 for analysing pure process innovators and the product effects.

**Table A-1 PCA analysis for product effects by pure process innovators.**

Dependent variable: Product_effects	Process innovation factors effects on Product aspects of firms are the result from a PCA applied to the sample (KMO 0.7013; Variance explained: 74%). Resulting from the following variables measuring the effect on firms of process innovation on: <ul style="list-style-type: none"> <li>- Wider range of product or services</li> <li>- Increase market share</li> <li>- Higher quality of products or services</li> </ul> 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
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As observed in table A-2, in general, the overall fit is good, (R2 ranging around 0.27 to 0.29,  $p < 0.01$ , in the three specifications) and the general results are pretty similar to the ones showed for process effects, with some key exemptions. First, in general, there is a similar pattern of innovation regarding the introduction of new management practices and the acquisition of embodied knowledge, together with the effects yielded by the external sources. The acquisition of embodied knowledge (*Tech\_expend* variable) does yield product effects from the technological innovation (at  $p < 0.01$ ). Then, the introduction of new management practices does influence the product effects (all coefficients positive and significant,  $p < 0.01$ ). The internal and external sources of knowledge affect in a positive way the product effects (similar to the results obtained for process innovation) and the industry effect is also important, together with the “process industries”, which yield a positive effect on the dependent variable (0.120,  $p < 0.05$ ), confirming Lager (2011) evidence. On the other hand, the differences are as follows. First, the size variable is observed to be negative and significant ( $p < 0.01$ ) for all specifications. The Group variable is negative and significant at  $p < 0.05$ . Second, the intramural R&D expenditures are positive and significant in all specifications at  $p < 0.05$ , meaning that the introduction of new processes produce effects on the product performance by investing in internal R&D activities (*Int\_R&D\_expend* variable). This is a

really important result which differ from the previous one observed for process effects in which investment in intra-mural R&D does not produce any effect on process performance. Third, the interaction effect of introducing new management practices to complement the acquisition of embodied knowledge (Inno\_organization x Tech\_expend) does not yield any result. See results at A-2.

Table A-2 OLS Model. Dependent variable: Product\_Effects

	Firms which only introduce new processes (not products): “pure” process innovators					
	Specification 1		Specification 2		Specification 3	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
constant	-0.304**	0.0791	-0.111*	0.0556	-0.303**	0.0794
log (SIZE)	-0.033**	0.0126	-0.043**	0.0125	-0.033**	0.0126
group	-0.069*	0.0333	-0.080*	0.0328	-0.069*	0.0333
Int_R&D_expend	0.075*	0.0227	0.071*	0.0214	0.075*	0.0227
Ext_R&D_expend	0.063	0.0391	0.037	0.0389	0.063	0.0391
Tech_expend	0.106**	0.0163	0.119**	0.0162	0.105**	0.0219
Int. sources	0.141**	0.0118	0.145**	0.0118	0.141**	0.0118
Ext_sources_fact_Industry	0.409**	0.0133	0.415**	0.0133	0.408**	0.0133
Ext_sources_fact_Science	0.149**	0.0151	0.165**	0.0150	0.149**	0.0151
Inno_organization	0.131**	0.0258	0.109**	0.0257	0.131**	0.0283
Inno_organization_x_Tech_expend					0.001	0.0314
Industry_NACE_code	Yes				Yes	
Process_Industry			0.120**	0.0327		
N	4608		4608		4608	
R <sup>2</sup>	0.29187		0.2788		0.2987	
Adjusted R <sup>2</sup>	0.2915		0.2773		0.2913	
Error	0		0.000		0.000	
F	41.32		177.74		40.450	

\*significant at p<0.01; \*\*significant at p<0.05

Following our findings it is evidenced that the product effects require the investment in R&D activities, confirming previous studies (Arundel et al., 2008; OECD, 2010; Huang et al., 2010; Hervás-Oliver et al., 2011) which pointed out that the product innovation requires R&D activities. Finally, the results showed in this appendix have pointed out how different are the process and the product objectives and their respective innovation patterns. Summarizing the Appendix’s results, it can be stated that the introduction of new management practices by process innovators also enhance product effects, although it does not leverage the effects from investing in embodied knowledge. Put differently, social technologies improve and enhance both product and process objectives, but the “learning by trying” effect from new embodied knowledge acquisition and its effect on product objectives is not leveraged by the social technologies introductions. In fact, that effect is only accomplished by process innovators pursuing productivity effects.

## Endnotes:

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