Innovations de procédés technologiques et organisationnels : antécédents and complémentarité[1]

Rachel BOCQUET
IREGE, University of Savoie, France
rachel.bocquet@univ-savoie.fr
Fariborz DAMANPOUR
Rutgers University, Newark, USA
damanpour@business.rutgers.edu
Sandra DUBOULOZ
IREGE, University of Savoie, France
sandra.dubouloz@univ-savoie.fr

Résumé :

Cet article porte sur un type d'innovation largement négligé dans la littérature : les innovations de procédés, technologiques et organisationnelles. L'objectif est d'examiner les antécédents internes et externes de ces deux types d'innovations en prenant en compte leur potentielle complémentarité. Le test empirique est basé sur les données appariées des enquêtes françaises « *Changements organisationnels et Informatisation* » (COI) et «*Enquête Annuelle d'Entreprises"* (EAE) couvrant la période 2003-2007. En utilisant une méthodologie économétrique robuste en deux étapes, les résultats indiquent que ces innovations de procédés sont influencées par des antécédents similaires et sont complémentaires. Elles représentent deux facettes d'un phénomène unique. Il en résulte d'importantes implications, tant au plan académique que managérial.

Mots Clés : Innovations de procédés, innovations technologiques, innovations organisationnelles, antécédents, complémentarité

[1] This paper is also submitted for discussion at the EURAM conference which is scheduled to take place at Istanbul from 26 to 29 June 2013.

Technological and organizational process innovations: antecedents and relationships[2]

Rachel BOCQUET
IREGE, University of Savoie, France
rachel.bocquet@univ-savoie.fr
Fariborz DAMANPOUR
Rutgers University, Newark, USA
damanpour@business.rutgers.edu
Sandra DUBOULOZ
IREGE, University of Savoie, France
sandra.dubouloz@univ-savoie.fr

Abstract:

This paper argues that technological and organizational process innovations are two components of one single phenomenon and are influenced by the same antecedents. It extends prior research by examining internal and external antecedents of the two types of process innovation and providing a more robust test of their complementarity. Data come from a merged dataset of the Organizational Change and Computerization (COI) survey and the *Enquete Annuelle d'Entreprises* (EAE) of manufacturing and service firms in France for the period 2003-2007. We analyze the data by an econometric methodology, using a two-step procedure to cope with potential problems related to synchronous introduction of innovation types. The results indicate that technological and organizational process innovations are driven by similar antecedents and are complementary. We discuss the implications of the findings for research on process innovations in organizations.

Keywords: Technological process innovations, organizational process innovations, antecedents, complementarity

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Technological and organizational process innovations: antecedents and relationships

1. Introduction

Vast literature on the sources of firm-level innovation heterogeneity has mainly focused on the “technological conceptualization” of innovation (Evangelista & Vezzani, 2010). More recently, research has enriched this technological view by providing some evidence that non-technological process innovations should no longer be considered as “*second-order innovative activities*” (Reichstein & Salter, 2006: 654). The story of firms’ innovative effort thus requires the explicit inclusion of non-technological innovation and its relationship with technological innovation (Battisti & Iona, 2009). Despite these advances, few scholars have adopted such perspective. In a quantitative review of innovation literature, Keupp, Palmié, and Gassmann (2011) show that of the 342 articles reviewed[3], only 11 clearly included technological process innovations and only 7 included organizational process innovations. Becheikh, Landry, and Amara (2006) concur that also only about 1% of empirical studies of innovation in manufacturing sectors considered process innovations. The lack of research attention is surprising since both organizational and technological process innovations are adopted widely by industrial firms[4]. It thus appears essential “*to delve deeper into the black-box*” (Keupp et al., 2011: 11) of process innovations, and consider both technological and organizational types to provide a better understanding of the sources of firm-level heterogeneity (Damanpour, 2010; Fagerberg, Mowery, & Nightingale, 2012; Schmidt & Rammer, 2007).

The typologies of innovation maintain the necessity to distinguish among different kinds of innovations. Process innovations are usually grouped into technology-based (or technological) and non-technological (or organizational) and are respectively related to the technical and social systems of organizations (Edquist, Hommen, & McKelvey, 2001; Meeus & Hage, 2006). A more recent approach suggests that the distinction between innovation types should

[3] The articles have been published in the 7 following journals from 1992 to 2010: Academy of Management Journal, Academy of Management Review, Administrative Science Quarterly, Journal of Management, Management Science, Organization Science and Strategic Management Journal.
[4] Among French manufacturing firms, 47.6% have introduced organizational process innovations, 32.7% have adopted technological process innovations, and 32.6% have introduced product innovations (CIS, 2006).

not be overemphasized, advocating an integrative view of innovation types (Damanpour, 2010). Two arguments can support this view on an empirical ground. The first argument suggests that technological and organizational process innovations can be encompassed within one category because of the lack of significant differences in the effect of their antecedents (Schmidt & Rammer, 2007). However, empirical evidence in support of this view is difficult to obtain because the existing studies include a host of different internal and external antecedents. The second argument puts forward that the distinction between the two types of process innovation is somewhat artificial as they are complements rather than substitutes (Reichstein & Salter, 2006). The studies on the complementarity, however, do not examine the true nature of the link between technological and organizational process innovations (Schmidt & Rammer, 2007).

This paper intends to address these research needs. We use the arguments of the integrative view, build an empirical model of the antecedents of technological and organizational process innovations, and examine their relationships. Our goal is to see whether we can provide new evidence that the two types of process innovation are influenced by similar or different drivers, and are complementary or not. Our results would help to determine whether technological and organizational process innovations are two dimensions of the same phenomenon or are distinct.

Our empirical analysis is based on a merged dataset of the "Organizational Change and Computerization" (*Changement Organisationnel et Informatisation* COI) and the "Annual Survey of Firms" (*Enquête Annuelle des Entreprises*, EAE) covering the period 2003-2007. The final sample, which includes 7821 French firms, offers several qualities to enable us test our model. First, it provides information about adoption of two specific process innovations: Information and Communication Technologies (ICT) as technological process innovation (TPI) (Damanpour, Walker, & Avellaneda, 2009; OECD, 2005; Uchupalanan, 2000) and Lean Management practices as organizational process innovation (OPI) (Armbruster, Bikfalvi, Kinkel, & Lay, 2008; Damanpour et al., 2009; Mazzanti, Pini, & Tortia, 2006; OECD, 2005). Second, process innovations, in particular OPI, have been often grasped with crude indicators. The lack of suitable data in innovation surveys often leads researchers to measure innovation simply by asking if a firm has introduced a new or an improved process during a given period. In contrast, the COI survey precisely enumerates the adoption of TPI and OPI in 2006 with respect to 2003 allowing to capture 'newness' to the unit of adoption (Rogers, 2003). Third, the COI database provides detailed information about the internal and external antecedents of process innovations. Fourth, because our sample covers both manufacturing and service sectors, our analysis goes beyond the manufacturing firms that are still the dominant type of firms in the innovation studies.

We analyze our data by an econometric methodology and use a two-step procedure in order to cope with several potential problems that could be encountered when innovation types are introduced synchronously. In the first step, we model TPI and OPI as joint decisions by estimating a bivariate probit because both types can be affected by common elements of unobservable heterogeneity. These data are cross-sectional, so to deal with the heterogeneity problem, we carefully review the potential sources of bias. We also control for a potential causality bias created by prior innovation experience by accounting the lagged effect of past innovations on current innovations. In the second step, because TPI and OPI are highly correlated, we run a recursive bivariate probit model to estimate the relationship between exogenous and endogenous variables.

The results show that TPI and OPI are complementary and are driven by similar antecedents. These findings fall in line with the integrative view of innovation. The existence of a strong relationship between TPI and OPI provides new evidence that they cannot be studied in isolation.

The rest of the paper is organized as follows. Section 2 focuses on the concept of process innovation and reviews the literature on the antecedents and relationship between technological and organizational process innovations. Section 3 is devoted to the presentation of our data and description of the empirical models. In section 4, we present the results, and in section 5, we discuss the study's theoretical and empirical implications for future research.

2. – Theoretical and empirical background

2.1 Technological and organizational process innovations

The best known and most-often studied innovation typologies distinguish product from process innovations (Abernathy & Utterback, 1978), and technical from administrative innovations[5] (Evan, 1966). Product innovations consist of changes in the specific products/services offered while process innovations consist of changes to the mode by which products/services are created and delivered (Damanpour & Gopalakrishnan, 2001). By mixing the two main typologies, Edquist et al. (2001) proposes an integrated framework which

[5] Technical innovation is a similar term as "technological" innovation, and administrative innovations are also called "organizational", "management"), and "managerial" innovations (Birkinshaw, Hamel & Mol, 2008; Damanpour & Aravind, 2012).

divides process innovations into two categories: technological process innovations (TPI), and organizational process innovations (OPI).

Technological process innovation is defined as the introduction of a "*unit of real capital (material goods) which has been improved through technical change*" (Edquist et al, 2001: 14) or as new tools and devices in throughput technology that mediate between inputs and outputs (Ettlie & Reza, 1992). This process innovation type operates in the technical system of the organization and is related to the organization's primary work activity (Damanpour & Evan, 1984). It modifies the way products are produced by introducing changes in technology, such as physical equipment, techniques and systems (Meeus & Hage, 2006). As shown by several authors (Damanpour et al., 2009; Roberts & Amit, 2003; Uchupalanan, 2000), TPI can be associated with or be based on ICT. The ICT-based process innovations are among the most common technological process innovations examined in empirical studies (see Table 1).

Organizational process innovation is defined as a new way to organize work or by which a new organizational form is introduced (Edquist et al., 2001). It encompasses new management practices, process, policies, structures of tasks and units (Armbruster et al., 2008; Birkinshaw et al., 2008; Damanpour, 1987). It operates in the social system of the organization and contains no technological elements as such (Edquist et al., 2001; Meeus & Hage, 2006). It has to do with the coordination of human resources and other organizational systems (Damanpour & Evan, 1984; Edquist et al., 2001). The Lean Management (Womack, Jones, & Roos, 1990) inspired by the Toyota Production System (Ohno, 1988) is a well-established organizational process innovation (Armbruster et al., 2008), and are often used as proxies for OPI (Damanpour et al., 2009; Mazzanti et al., 2006; Mol & Birkinshaw, 2009; OECD, 2005; Reichstein & Salter, 2006).

Beyond their differences, technological and organisational process innovations share several common characteristics. Unlike product and service innovations that have an external focus and are primarily market driven (i.e., they are introduced to meet customer needs), both TPI and OPI have internal focus and aim to increase the efficiency and effectiveness of the organizational process (Boer & During, 2001; Utterback & Abernathy, 1975). They are mainly driven by internal objectives, such as reducing production or operational costs or labour costs, delivery time, rationalizing or increasing production yields, flexibility, performance and quality of production processes (Bergfors & Lager, 2011; Boer & During, 2001; Edquist et al., 2001; Ettlie & Reza, 1992; Knight, 1967; Sempere-Ripoll, 2012), and furthering economic (financial) or social (organizational members satisfaction and motivation) performance goals (Birkinshaw et al., 2008; Daft, 1978). Another common characteristic of TPI and OPI is the existence of a learning by doing and learning by using process, suggesting that more experienced firms in the use of capital equipment or new work practices are more able to increase their performances (Cabral & Leiblein, 2001).

Table1 illustrates the main characteristics of technological and organisational process innovations and provides the examples most quoted from the innovation literature.

TABLE 1
Definitions and characteristics of TPI and OPI examples

	Technological Process Innovation (TPI)	**Organizational Process Innovation (OPI)**
Definition	Generation and/or adoption of tools, devices, methods, and equipment that involve technological changes, are new to the concerned organization, and are intended to increase the effectiveness and efficiency of the production process.	A non-technological innovation that encompasses the generation and/or adoption of working or managerial practices, methods, techniques, and structures that are new to the organization and that are intended to increase the efficiency and effectiveness of the organizational process.
Distinctive features	Introduction of technological change (physical equipment, techniques, systems) (Meeus & Hage, 2006)	No technological elements (Edquist et al., 2001)
Common features	Newness Internal focus: to increase the efficiency and effectiveness of the organizational process (Utterback & Abernathy, 1975) Learning by doing and learning by using processes (Cabral & Leiblein, 2001)	
Selected examples from innovation literature	• High speed image processing of office documents (Damanpour & Gopalakrishnan, 2001) • Computerized loan document generation (Damanpour & Gopalakrishnan, 2001) • Implementation of new automation equipment on production line (OECD, 2005; Reichstein & Salter, 2006) • Implementation of computer-assisted design for product development (OECD, 2005) • Information and communication technology (Damanpour et al., 2009; Reichstein & Salter, 2006; Uchupalanan, 2000)	• Teamwork (Armbruster et al., 2008; Mazzanti et al., 2006) • Quality circles (Armbruster et al., 2008; Lam, 2005; Mazzanti et al., 2006; Mol & Birkinshaw, 2009) • Just-in-time (Mazzanti et al., 2006) • Total quality management (Birkinshaw et al., 2008; Damanpour & Aravind, 2012; Damanpour et al., 2009; Mazzanti et al., 2006; OECD, 2005) • Lean production or Toyota Production System (Armbruster et al., 2008; Birkinshaw et al., 2008; Damanpour & Aravind, 2012; OECD, 2005; Reichstein & Salter, 2006) • Management by objectives (Damanpour & Evan, 1984) • Divisional M-form (Birkinshaw et al., 2008; Damanpour & Aravind, 2012)

2.2 Antecedents of TPI and OPI

To pinpoint the weakness and instability of the findings on innovation antecedents, two main reasons are often advocated (Downs & Mohr, 1976; Lam, 2005; Wolfe, 1994): context and methods. Therefore, for this analysis, we consider only empirical studies that included both TPI and OPI. It should be noted that these studies do not always clearly distinguish between technological product and process innovations. But as Damanpour and Aravind (2006) note, when research on antecedents differentiate product and process, the difference in results is more a difference of degree than of direction of the effect.

At the firm level, the literature suggests that innovation adoption is mainly influenced by a set of internal factors (firm characteristics) and a set of external factors (environment characteristics) (Kimberly & Evanisko, 1981; Rogers, 1995). Some authors underline that the structural characteristics of the firm as the primary antecedents, regardless of the type of innovation (Damanpour, 1991; Kimberly & Evanisko, 1981). The characteristics of organic structure – low formalization and centralization, high complexity including high specialization and differentiation – (Burns & Stalker, 1961) have found to affect the adoption of innovations (Hage, 1999). In his meta-analysis, Damanpour (1991) shows that most organic structure components facilitate the adoption of innovations, whether technological or organizational. However, other results indicate differences depending on whether process innovations are technological or organizational. For example, high formalization and centralization have positive effect on the adoption of organizational innovations (Boer & During, 2001; Daft, 1978; Subramanian & Nilakanta, 1996), whereas low formalization and centralization facilitates the adoption of technological innovations (Daft, 1978; Kimberly & Evanisko, 1981; Subramanian & Nilakanta, 1996). High specialization favours technological innovations (Damanpour, 1987; Kimberly & Evanisko, 1981; Subramanian & Nilakanta, 1996) but not organizational innovations. Thus, empirical findings of the structural antecedents of process innovations are scarce and ambiguous.

More recent studies that examined both TPI and OPI indicate that they are influenced by similar external conditions (Battisti & Stoneman, 2010; Huang & Rice, 2012; Schmidt & Rammer, 2007); however, these studies do not integrate structural antecedents into their analyse, nor do they distinguish the technological types of innovation (product/process).

With Table 2, we offer an overview of the antecedents of both TPI and OPI, according to this internal/external segmentation.

2.3 Complementarity between TPI and OPI

A few empirical studies, explicitly consider both TPI and OPI, but they rarely discuss in detail whether their antecedents might differ. This strategy seems questionable from a complementarity perspective (Milgrom & Roberts, 1990, 1995). Despite a variety of theoretical and empirical approaches, this view suggests that the adoption of an innovative practice generates better performance only if it fits with the other innovative practices adopted. That is, even if the "traditional" antecedents of process innovations are influential, firms should have no interest in adopting technological process innovations if they have not adopted organizational process innovations and *vice versa*.

Prior studies of the interaction between innovation types focus mainly on technological product and process innovations. Several authors underline the paucity of theory and research on comparing technological and organizational innovations (Battisti & Iona, 2009; Evangelista & Vezzani, 2010; Reichstein & Salter, 2006; Sapprasert & Clausen, 2012). These authors also emphasize the difficulties associated with making strong inferences about complementarities, depending on how organizational and technological innovations get defined and measured (Battisti & Iona, 2009; Reichstein & Salter, 2006). Despite lack of sharing a common ground, the findings from these studies suggest that technological and organizational innovations are more complementary than substitute.

For example, Schmidt and Rammer (2007) explore the antecedents and effects of technological (product and process) and non-technological (marketing and organizational) innovations among German firms. Using bivariate probit models, they show that technological and non-technological innovations are driven by similar determinants[6], and represent two different aspects of one activity. In addition, Battisti and Iona (2009) show that four clusters of management practices are complementary in UK establishments[7]. Using a synthetic index of management practices, they find that the determinants of technological innovation diffusion affect the diffusion of management practices. In a similar vein, Battisti and Stoneman (2010) test for complementarity effects across a wide range of innovations in UK industry and extract two main sets of innovative factors: technological innovation (i.e. process, product innovations, machinery, equipment and computer hardware or software) and organizational innovation (i.e. management practices, new organization, new marketing concepts and new corporate strategies). These two main sets of innovations again

[6] They introduce two sets of determinants related to 1) firms' competitive environment and 2) firms' characteristics not related to the traditional structural components, such as firm size, group belonging, composition of the firm employees in terms of skilled labor, labor productivity.

[7] The four sets of practices are *Operating Management Practices* (concerning the introduction of organizational changes such as lean manufacturing, team working, or process improvements such as Just-In-Time), *Monitoring Management Practices* (concerning the tracking of performance of individuals, reviewing performance and continuous), *Targets Management Practices* (to examine whether the establishment has set targets, the type of targets and the transparency in their communication to all staff.) and *Incentives Management Practices* (capturing the presence of traditional human resource management practices as well as promotion criteria, bonuses, fixing or firing bad performers).

TABLE 2

Antecedents of TPI and OPI: results of empirical studies

ANTECEDENT		Technological Process Innovation (TPI)		Organizational Process Innovation (OPI)		Empirical Studies
		Effect	**Findings**	**Effect**	**Findings**	
INTERNAL	Firm size	Positive	Large organizations are more likely to be technologically innovative because of their financial and technical capabilities and economies of scope	Positive or No effect*	Size enhances adoption of OPI.	Kimberly and Evanisko (1981); Subramanian and Nilakanta (1996); Daft (1978)*; Schmidt and Rammer (2007); Huang and Rice (2012); Wischnevsky, Damanpour, and Méndez (2011)
	Centralisation	Negative	The importance of participative decision making for technological innovations.	Positive or Insignificant *	High levels of centralization are associated with early and consistent organizational innovations.	Kimberly and Evanisko (1981)*; Subramanian and Nilakanta (1996); Daft (1978)
	Decision making: -Bottom-up	Positive	TPI occurs more often through bottom up decision making			Daft (1978)
	-Top-down			Positive	OPI occurs more often through top-down decision making.	
	Specialization	Positive	Technological innovation tends to be more prevalent in organizations that are specialized Specialization is positively associated with the number of technical innovation and the time of adoption	Negative or Insignificant *	Organizations with high levels of specialization adopt organizational innovations late and inconsistently	Kimberly and Evanisko (1981)*; Subramanian and Nilakanta (1996)
	Functional differentiation	Positive	Technological innovation tends to be more prevalent in organizations that are functionally differentiated	Insignificant		Kimberly and Evanisko (1981)
	Formalization	Negative or Insignificant *	Low formalization is suited to TPI.	Positive	High levels of formalization are associated with consistent OPI	Subramanian and Nilakanta (1996)*; Daft (1978)
	Group belonging	Positive or Insignificant *	Belonging to a group influences the decision to adopt TPI positively.	Positive	Belonging to a group influences the decision to introduce OPI positively	Schmidt and Rammer (2007)*; Battisti and Stoneman (2010)
	R&D expenditures	Positive or Insignificant *	R&D is unimportant for TPI in both manufacturing and service sectors.	Positive or Insignificant *	R&D is unimportant for OPI in both manufacturing and service sectors.	Polder, Van Leeuwen, Mohnen, and Raymond (2010); Battisti and Stoneman (2010); Huang and Rice (2012)*

TABLE 2
Antecedents of TPI and OPI: results of empirical studies

	ANTECEDENT	Technological Process Innovation (TPI)		Organizational Process Innovation (OPI)		Empirical Studies
		Effect	Findings	Effect	Findings	
INTERNAL (continued)	Concentration	Positive	The likelihood of introducing TPI is significantly higher for firms that much of their turnover from their three most important customers.	Positive	The likelihood of introducing OPI is significantly higher for firms that much of their turnover from their three most important customers.	Schmidt and Rammer (2007)
	Prior innovation of the same type	Positive	Prior adoption of TPI positively affects the adoption of new TPI.	Positive	Prior adoption of OPI positively affects the adoption of new OPI.	Wischnevsky et al. (2011)
	Prior process innovation of the other type	Negative	Prior OPI do not influence TPI.	Negative	Prior TPI do not influence OPI.	Wischnevsky et al. (2011)
EXTRENAL	Intensity of competition	Positive	The intensity of competition is a significant predictor of TPI (effect is stronger for TPI than for OPI)	Positive	The intensity of competition is a significant predictor of OPI; the wider is the geographic scope of the market, the more likely OPI are introduced.	Kimberly and Evanisko (1981); Schmidt and Rammer (2007)
	Market concentration	Insignificant	Higher market concentration is not associated with higher rate of OPI.	Positive	Higher market concentration is associated with higher rate of OPI.	Wischnevsky et al. (2011)
	Export status	Positive or Insignificant *	Export status positively influences a firm's decision to introduce a technological process innovation.	Positive or Insignificant *	Export status positively influences a firm's decision to introduce a non-technological process innovation.	Schmidt and Rammer (2007); Battisti and Stoneman (2010)*
	Co-operation with external partners	Positive	Inter-organizational collaborations positively affect the adoption of TPI.	Positive	Co-operating firms are more likely to introduce organizational innovations.	Schmidt and Rammer (2007); Huang and Rice (2012)
	External sources employed	Positive	The degree of openness is important in determining TPI.	Positive	The degree of openness is important in determining OPI.	Huang and Rice (2012)
	Technology acquisition [8]	Positive	Technology acquisition positively affects the adoption of TPI.	Positive	Technology acquisition positively affects the adoption of TPI.	Huang and Rice (2012)
	R&D outsourcing	Insignificant	R&D outsourcing does not affect the adoption of TPI.	Negative	R&D outsourcing negatively affects the adoption of OPI.	Huang and Rice (2012)
	Public financial support	Positive	Receiving public financial support positively affects the adoption of TPI	Positive	Receiving public financial support positively affects the adoption of OPI	Battisti and Stoneman (2010)

*NOTE: When an effect is marked with the symbol *, the corresponding empirical studies are also marked with this symbol in the last column.*

[8] Expenditures on equipment, machinery, licenses, intellectual property

are complements, not substitutes for each other. Finally, Using CIS data for Italy, Evangelista and Vezzani (2010) examine the relationship between technological (product and process) and non-technological (organizational and marketing) innovation in manufacturing and services industries. They identify four distinct innovation clusters (product-oriented, process-oriented, organizational, and complex) and demonstrate their relevance for both industries. These authors find that a complex innovation strategy including product, process, marketing and organizational innovations has the strongest impact on firms' economic growth; however, they also find that an organizational innovative strategy including organizational innovation sometimes accompanied by process innovations also affects firm performance.

Whereas more convincing evidence on complementarity of innovation types has been provided by the studies that have examined clusters of innovative practices rather than stand-alone innovations,[9] the empirical evidence on the relationship between TPI and OPI is still rare namely due to lack of data. For instance, Evangelista and Vezzani (2010) could not adequately explore the "organizational innovation mode," which includes organizational and process innovations, because of the limited set of information provided by the CIS data. Moreover, studies based on CIS data often grasp process innovations, especially organizational ones, with crude indicators that not clearly identify the 'newness' aspect of the adopted practice (Becheikh et al., 2006). These studies also fail to properly control for past innovation experience, although the influence of momentum on innovation adoption has been demonstrated (Wischnevsky et al., 2011). In general, new evidence is needed to provide a better understanding of the relationship between technological and organizational process innovations (Hervas-Oliver, Sempere, & Boronat-Moll, 2012).

We focus on ICT as a technological process innovation and examined its complementarity with organizational process innovations. As discussed by Bresnahan and Trajtenberg (1995), ICT is not a traditional capital investment but a "general purpose technology" that facilitates complementary innovations. Accordingly, Hollenstein (2004) tests for reverse causality, such that new work practices such as team-work, decentralized decision-making, or job rotation might get adopted because ICT already were adopted. This reverse causality emerges in the ICT adoption behavior of Swiss firms. Hollenstein (2004) also shows that organizational structure is more sluggish to adaptation than is ICT equipment. Polder et al. (2010) offer one of the first studies that model ICT as an enabler of product, process and organizational innovation. These authors find that ICT is an important determinant of organizational innovation in both manufacturing and service firms.

[9] Such as Human Resources Management (HRM) practices (Ichniowski, Shaw, & Prennushi, 1997), decentralized workplace (Bresnahan, Brynjolfsson, & Hitt, 2002) or joint design teams with customers and suppliers (Battisti et al., 2004).

3. Data and methods

In this section, we describe the database, sample, and variables for our analysis, and we outline the method applied.

3.1. Sample

This research is based on two French surveys, the *Changement Organisationnel et Informatisation* (COI) from 2006 and the *Enquête Annuelle des Entreprises* (EAE) from 2006 and 2007. The former survey is carried out by the INSEE (National Institute for Statistics and Economic Studies) and DARES (Ministry of Labor), to provide detailed information about ICT introduced in firms' processes and the Lean Management practices adopted by firms from 2003 to 2006. Firms also indicated the external and internal conditions in which they decided to adopt OPI (lean) or TPI (ICT). The COI survey collected data from 14,508 French firms with more than 9 employees, operating in all sectors. The EAE surveys, conducted by INSEE from 1990 to 2007, instead contain financial and economic individual data for all firms located in France with more than 20 employees operating in all sectors. For our cross-sectional analysis, we selected data from 2006–2007.

After merging these two data sets, we obtained a sample of 7,821 firms. The structure of this sample is consistent with the initial COI 2006 database in terms of sector affiliation[10] and firm size. Thus, our original database provides a foundation for studying process innovations, both technological and organizational, that thus far have merited little data collection efforts (Battisti & Stoneman, 2010).

Compared with CIS data, COI data offer several particular advantages. Perhaps most notably, we obtain a more objective measure of innovation, in line with the concept of newness at the firm level (Aiken & Hage, 1971; Knight, 1967; Van de Ven, 1986). Each firm indicated whether it used new ICT and new Lean Management practices in 2003 and 2006, from among a broad list. Moreover, the variables are available for all firms, whether they are considered innovative or not.

3.2. Measures

We provide a detailed description of the variables used in our empirical analysis in Table 3.

3.2.1. Dependent variables. We derived the measures of OPI from seven indicators of Lean Management practices: (1) certification or accreditation for the quality system (ISO9001), (2) certification for environment or ethical labeling (ISO 14001), (3) set problem solving, (4) independent work groups or teams, (5) just-in-time (JIT) production, (6) traceability tools, and (7) supply chain management tools and applications. These indicators are well aligned with the key

[10] Except for trade sector, for which data were available only every two years in the EAE survey.

TABLE 3
Variables used in the empirical analysis

Variables	Label	Description	Codification
Dependent variables			
Technological Process Innovation	tpi	Adoption of at least one new ICT (Website, Local business network, Intranet, Extranet, EDI) during the period 2003-2006.	Dummy 0-1
Organizational Process Innovation	opi	Adoption of at least one new Lean Manufacturing practices (Certification for quality system, Certification for the environment labelling, Set problem solving, Independent work groups, JIT production, Traceability tools, Supply chain management tools) during the period 2003-2006.	Dummy 0-1
Independent variables			
Prior TPI adoption (2003)	sumit03	Sum of ICT adopted by the firm in 2003 (Website, Local business network, Intranet, Extranet, EDI).	Continuous 0-5
Prior OPI adoption (2003)	sumopi03	Sum of the OPI adopted by the firm in 2003(Certification for quality system, Certification for the environment labelling, Set problem solving, Independent work groups, JIT production, Traceability tools, Supply chain management tools).	Continuous 0-7
Centralization	centra6	The extent to which decision-making is concentrated in the top hierarchical. From the question : "In your company, who 1- sets operational procedures and methods, 2- determines schedules and working time, 3- distributes work in teams, 4 - carries out maintenance 5- trains employees 6- supervises work results?", we calculated the sum of the missions conducted by the hierarchy in 2006, then calculated the median (4). Takes on value 1 if hierarchy manages more than 4 missions and 0 otherwise.	Dummy 0-1
Formalization	forma6	The extent to which rules and procedures in conducting organizational activities are precisely and formally defined and/or tracked. Forma 6 has been computed from the question: "Does/Did your business have a tracking or reporting system running at least quarterly 1) to follow financial turnover? 2) to plan the business?. Takes on value 1 if the firm had a tracking or reporting system to follow financial turnover <u>and</u> plan business, and 0 otherwise.	Dummy 0-1
Specialization	specia6	Refers to the existence of personnel with specialized skills in various functional areas. The COI questionnaire asks "Is each of the following roles (design and R&D, purchases, sales and distribution, manufactures and operations, IT, human resources, accounting and finance) overseen internally? Or overseen at group or network level? Or entrusted to a subcontractor or service provider? First, we calculated the sum of the different roles overseen internally in 2006, second, the median (6). Takes on value 1 if more than 6 roles are internally overseen, and 0 otherwise.	Dummy 0-1
Strategy: cost and quality focus	qc_prio	The extent to which cost and quality standardization are of great importance for the firm strategy. Computed as an interaction variable by multiplying cost reduction and quality standardization . Takes on value 1 if cost reduction and quality standardization are of great (high or very high) importance for the firm, and 0 otherwise.	Dummy 0-1

TABLE 3
Variables used in the empirical analysis

Internal R&D	rdint	The extent to which a team is dedicated to R&D in-house. Takes on value 1 if the firm has sought an internal team for R&D, and 0 otherwise.	Dummy 0-1
Cooperation with external partners	partner6	The extent to which the firm has developed public (CNRS, universities…) and/or private (private businesses or laboratories) R&D partnerships. Takes on value 1 if the firm has developed public and /or private R&D partnerships, and 0 otherwise.	Dummy 0-1
Market characteristics	high_uncert_comp	Refers to the level of uncertainty and competition in the market in which the firm operated in 2006. A cluster analysis has been implemented to classify firms into two clusters: 1 = firms whose business is affected by a high or very high level of uncertainty and competition, 0 = firms whose business is affected by a low or very low level of uncertainty and competition. (Cluster analysis on the market characteristics: change in regulations, technological development, market doubts, raw material costs, new competitors appearing).	Dummy 0-1
Export status	iscop	The extent to which the firms made a part of its turnover abroad in 2006. Iscop variable takes on 1 if a part of the turnover is made abroad in 2006, and 0 otherwise	Dummy 0-1
Control variables			
Manufacturing sector	indus	Takes on value 1 if the firm belongs to a manufacturing sector	Dummy 0-1
Size	lg_effl	Logarithm of the number of employees.	Logarithm
Group belonging	group6	Takes on value 1 if the firm belongs to a group in 2006 and 0 otherwise	Dummy 0-1
Instrumental variables used in model 2			
Strategy : technology modernity focus	techno_prio	Is equal to 1 when technological modernity is of great (high and very high) importance for the firm, and 0 otherwise.	Dummy 0-1
Difficulty recruiting ICT specialists	itspe_diff	Takes on value 1 if the firm has difficulty recruiting ICT specialists, and 0 otherwise.	Dummy 0-1
External advice for information systems	itext	Takes on value 1 if the firm seeks external advice services to improve information system, and 0 otherwise.	Dummy 0-1

practices identified in Lean Management literature (Shah and Ward (2003). For each firm, we computed the sum of practices in use in 2003 and in 2006, then measured OPI as the difference between these two sums. This variable equals 1 if the firm adopted at least one new lean practice between 2003 and 2006, and 0 otherwise.[11] Similarly, for TPI, we used five indicators of ICT introduced in firms' processes: (1) websites, (2) local business networks, (3) intranet, (4) extranet, and (5) electronic data interchange or other IT connections. Thus, TPI equals 1 if the firm adopted at least one new ICT between 2003 and 2006 and 0 otherwise.[12]

3.2.2. Independent variables. In line with an integrative view of innovation, we considered a full set of explanatory factors, both internal (and structural) and external. Regarding the structural antecedents, we introduced three variables to reflect the main characteristics of mechanical or organic structures (Burns & Stalker, 1961), as proposed by Damanpour (1991). The first, *centra6*, measures the extent to which decision making is (mechanic) or not (organic), concentrated in the top hierarchy, as of 2006. The *forma6* variable measures the extent to which rules and procedures are formally (mechanic) or not (organic) defined and tracked. The *specia6* variable refers to the existence (or not) of personnel with specialized skills in various functional areas. Because an organic structure is more likely to support innovation adoption (Damanpour, 1987; Hage, 1999), these dummy variables should have negative effects on both TPI and OPI.

Process innovations seek to achieve lower costs and higher product quality (Damanpour, 1991; Reichstein & Salter, 2006; Utterback & Abernathy, 1975), so we created a variable, *qc_prio,* to indicate if cost or quality standardization are of greater importance for the firm strategy in 2006. We thus can explore the implications of strategic choices on the adoption of process innovations. This variable also marks a clear departure from previous empirical studies that consider process innovations as second-order innovative activities, requiring no strategic vision (Reichstein & Salter, 2006).

As an innovation input, R&D "leads to the generation of knowledge which may manifest itself in new products and improved production methods" (Polder et al., 2010: 5). For some authors, the technological bias of innovation makes the inclusion of R&D measures essential (Sempere-Ripoll, 2012). Its impact on process innovations similarly should be significant (Huang & Rice, 2012; Polder et al., 2010). To remove this ambiguity, we included a dummy variable to measure the presence of a team specifically dedicated to R&D in-house in 2006 (*rdint*).

According to Huang and Rice (2012), when firms call on external research and knowledge for the adoption of process innovations, internal R&D becomes less important. We introduce the variable

[11] We excluded 101 firms that abandoned lean practices between 2003 and 2006.
[12] We excluded the 72 firms that abandoned ICT between 2003 and 2006.

partner6, which equals 1 if the firm is engaged in external public and private R&D partnerships and 0 otherwise. The role of external context for innovation also has been more widely considered in recent studies of process innovations (Battisti & Stoneman, 2010; Huang & Rice, 2012; Schmidt & Rammer, 2007). A general consensus indicates that competition increases the likelihood of adopting innovations (Utterback, 1974). The intensity of competition might provide incentives for process innovations, both technological and organizational (Kimberly & Evanisko, 1981; Schmidt & Rammer, 2007).

The variable *high_uncert_comp* results from a cluster analysis of five market characteristics: regulatory changes (health, environment, worker rights), technology evolution, market doubts, exchange rate or raw material cost fluxes, and the appearance of new competitors.[13] It thus refers to the level of uncertainty and competition faced by the firm in 2006. The export status of the firm also relates positively to process innovation adoption (Battisti & Stoneman, 2010; Schmidt & Rammer, 2007), so we introduced a dummy variable *iscop*, equal to 1 if the firm earned some of its turnover abroad in 2006, and 0 otherwise.

In addition to these internal and external antecedents, we included two variables related to the prior adoption of lean practices and ICT tools and methods. If a firm already adopted some lean practices and ICT tools and methods before 2006, it would be less likely to adopt the same ones in 2006. The *sumopi03* and *sumtpi03* variables, respectively, indicate the sum of ICT in use in 2003 and lean practices in use in 2003.

3.2.3. Control variables. We used several variables to control for firm characteristics that may affect process innovations. These data came from the EAE survey. Firm size was the logarithm of the number of employees in 2006 (*lg_effl*); the distribution of size tends to be highly skewed. The effect of firm size on the decision to adopt an innovation has been theoretically explained and extensively empirically tested. Larger firms should be more likely to adopt process innovations, because they have more resources (financial and human) and better access to information (Huang & Rice, 2012; Kimberly & Evanisko, 1981; Schmidt & Rammer, 2007; Wischnevsky et al., 2011). We also captured whether a firm belonged to a group in 2006 with the variable *group6*; it has been positively linked to the adoption of process innovations in previous literature (Battisti & Stoneman, 2010; Schmidt & Rammer, 2007). The dummies *indus* and *service* allow us to capture sector heterogeneity.

[13] Along with this non-hierarchical cluster analysis with five market characteristics, we tested a version with two clusters of firms based on the level of certainty and competition they face. For all comparisons of variances, Fisher's test is significant at the 0.000 level. It provides good firm differentiation, in line with theoretical arguments, and the number of firms per cluster is satisfactory. In the first cluster, 3675 firms face a high or very high level of uncertainty and competition. In the second cluster, 4047 firms face low or very low levels.

In Table 4 we provide an overview of the descriptive statistics for all the variables in the empirical analysis.

TABLE 4
Descriptive statistics

Variables	**Full sample**	**TPI=1**	**OPI=1**	**TPI=1 OPI=1**	**TPI=0 OPI=0**
TPI	29.40	-	45.30	-	-
OPI	21.27	32.71	-	-	-
Internal antecedents					
Prior TPI adoption	2.63*	1.79*	2.83*	1.92*	2.86*
Prior OPI adoption	2.03*	1.88*	2.07*	1.81*	2.05*
Centralization	71.71	70.33	67.18	67.97	73.58
Formalization	77.24	77.62	86.73	85.78	74.98
Specialization	61.15	61.03	64.92	60.94	60.10
Cost Quality Focus	63.36	63.14	71.33	70.78	61.81
Internal R&D	37.38	38.15	49.84	42.72	34.04
External antecedents					
External partners	24.95	23.75	36.05	32.34	22.85
Export status	47.73	45.17	55.48	49.80	46.54
High uncertainty	47.59	47.77	53.21	53.76	46.23
Control variables					
Manufacturing	43.49	42.98	54.32	47.90	40.54
Group belonging	58.86	56.21	71.07	65.31	56.85
Size	2.04*	1.99*	2.19*	2.05*	2.01*
Number of observations	**7821**	**2253**	**1627**	**737**	**4512**

*NOTE : * mean*

3.3. Methodology

Our empirical strategy consists of two steps. First, we used a bivariate probit model to identify the antecedents of TPI and OPI and test their effects on decisions to adopt the two process innovations simultaneously (Greene, 1998; Maddala, 1983). In the integrative view, estimating the probability of process innovation using two separate probit models is too restrictive, because it supposes that the two process innovation decisions are independent. As Table 5 indicates, in our sample, 737 firms (9.62%) adopted both organizational and technological process innovations.

TABLE 5
Joint adopters of TPI and OPI

OPI	**TPI**	
	0	1
0	4512 58,9%	1516 19.80%
1	890 11,62%	**737** **9.62%**
Number of observations	7655	

It is therefore more appropriate to estimate a system of equations, rather than separate estimations for each type of innovation. Our two dependent variables are dummy variables, so we need to adopt an estimation procedure for limited dependent variables. In this case, we estimated a bivariate probit model (Maddala, 1983). For the two types of process innovations, technological (y_1) and organizational (y_2), we have

$$\begin{cases} y_1 = \beta_1 X'_1 + \varepsilon_1, \\ y_2 = \beta_2 X'_2 + \varepsilon_2, \end{cases} (1)$$

where β_1 and β_2 are coefficient vectors, X'_1 and X'_2 are the vectors of the explanatory variables, and ε_1 and ε_2 are error terms, which follow a bivariate normal distribution with zero mean and unit variance. If the covariance matrix of the two errors terms (ρ) is significantly different from 0, the two decisions are not independent of each other and should not be estimated separately. Using the White's procedure (White, 1982), we also can deal with potential heteroscedasticity problems. The econometric results of the bivariate probit model are in Table 6.

Second, we ran a recursive bivariate probit model using maximum likelihood methods (Greene, 1998; Maddala, 1983) to test the direct impact of TPI on OPI, which produced the following equation:

$$\begin{cases} y_2 = \gamma y_1 + \beta_2 X'_2 + \varepsilon_2, \\ y_1 = \beta_1 X'_1 + \alpha Z' + \varepsilon_1, \end{cases} (2)$$

where y_2 and y_1 represent the probability of OPI adoption and TPI adoption, respectively, in 2006, and X'_1 and X'_2 are the vectors of the explanatory variables. The latent variable determining the occurrence of OPI should be influenced by the dummy y_1, and γ is an estimate of the effect of TPI on the probability of OPI adoption. We include a vector of instrumental variables Z', in the second equation (Maddala, 1983). The variables Z' must correlate sufficiently with y_1 *(TPI)* and could be legitimately excluded from the y_2 equation *(OPI).* Thus, identifying instrumental variables that determine the likelihood of TPI adoption but not of OPI adoption represents one of the main difficulties of this kind of model. The first instrument, *techno_prio*, refers to the firm's technology strategy (including ICT), equal to 1 when technological modernity is important for the firm, and 0 otherwise. This variable should enhance TPI. The second instrument, *itspe_diff*, provides information about the difficulties associated with recruiting ICT specialists, equal to 1 if the firm perceives such difficulties, and 0 otherwise. According to literature on barriers to innovation, innovative firms express greater awareness of the obstacles than non-innovative ones but also can overcome them (Baldwin & Lin, 2002; Galia & Legros, 2004). Thus, we expect a positive effect of this variable on TPI. The third instrumental variable *itext* indicates if the firm calls on external advice to improve its information systems. As Huang and Rice (2012) show, this variable should increase the probability of adopting TPI. Because TPI adoption also may be influenced by unobserved characteristics that affect OPI adoption, we assume the errors terms are jointly normally

TABLE 6
Results of the bivariate probit model

Variables (X)	TPI (y_1)	OPI (y_2)	Marginal Effects *TPI=1 OPI=1*	*TPI=1 OPI=0*	*TPI=0 OPI=1*	*TPI=0 OPI=0*
Centralization	-.053 (0.036)	-0.141*** (0.037)	-0.017*** (0.005)	-0.0004 (0.009)	-0.021*** (0.007)	0.038*** (0.012)
Formalization	0.260*** (0.045)	0.255*** (0.049)	0.036*** (0.004)	0.042*** (0.010)	0.026*** (0.008)	-0.105*** (0.014)
Specialization	0.001 (0.035)	0.054 (0.037)	0.005 (0.004)	-0.004 (0.009)	0.009 (0.006)	-0.010 (0.012)
Cost Quality focus	0.089* (0.035)	0.145*** (0.038)	0.018*** (0.004)	0.009 (0.009)	0.018*** (0.006)	-0.047*** (0.011)
Internal R&D	0.247*** (0.038)	0.219*** (0.038)	0.039*** (0.005)	0.415*** (0.010)	0.020*** (0.007)	-0.10*** (0.012)
External partners	0.030 (0.041)	0.231*** (0.042)	0.023 *** (0.006)	-0.014 (0.010)	0.040*** (0.008)	-0.05*** (0.013)
High uncertainty	-0.010 (0.033)	0.126*** (0.035)	0.010 *** (0.004)	-0.014* (0.008)	0.023*** (0.006)	-0.019* (0.011)
Export status	0.048 (0.039)	0.033 (0.041)	0.006 (0.005)	0.009 (0.010)	0.002 (0.007)	-0.018 (0.013)
Manufacturing	-0.02 (0.039)	0.341*** (0.042)	0.029*** (0.005)	- 0.035*** (0.010)	0.062*** (0.007)	-0.056*** (0.013)
Size	0.22*** (0.034)	0.275*** (0.033)	0.04*** (0.004)	0.030*** (0.008)	0.032*** (0.006)	-0.103*** (0.011)
Group belonging	0.168*** (0.041)	0.226*** (0.041)	0.031*** (0.005)	0.022** (0.010)	0.027*** (0.007)	0.080*** (0.013)
Prior TPI adoption	- .0418*** (0.013)		-0.029*** (0.001)	- 0.104*** (0.003)	0.030*** (0.001)	0.104*** (0.003)
Prior OPI adoption		-0.15*** (0.011)	-0.013*** (0.001)	0.013*** (0.001)	-0.026*** (0.002)	0.026*** (0.002)
Constant	- 0.448*** (0.07)	-1.895*** (0.076)				
Number of observations			7520			
X^2			1615.69			
Log-Likelihood			-7306.15			
Rho (ρ)			0.280***			
Rate of good prediction			60.65%			

NOTES: Robust standard errors are reported in round brackets.
****, ** and * indicate significance at 0.01, 0.05 and 0.10 level, respectively.*

distributed, with means equal to 0, variance equal to 1, and correlation equal to ρ. The results we obtained from estimating this simultaneous equation model appear in Table 7.

4. Results

We estimated the system of equations defined in Equation 1 with a bivariate probit model. The percentage of correct predictions (60.65%) suggests that the model has good explanatory power, compared with the naïve prediction ratio of 25%.

The first important result refers to the statistical link between TPI and OPI. In Table 6, the correlation coefficient ρ is significantly different from 0, suggesting that they are not independent choices. Thus, the estimation of two separate models would lead to a loss of efficiency and possibly misleading results (Rouvinen, 2002).

As we expected, TPI and OPI are driven by similar antecedents but mostly internal ones. Among the structural antecedents, formalization positively and significantly affects both TPI and OPI. The effect of the two other internal antecedents—the presence of an in-house team dedicated to R&D and the formulation of a clear objective oriented toward cost and quality—are also similar for TPI and OPI. Logically, previous adoption of TPI and OPI practices has a negative effect on the new adoption of the same TPI and OPI practices; a firm has no incentive to adopt practices or tools already in use. Among the control variables, firm size has a positive impact on TPI and OPI. When the firm is part of a group, it benefits from additional resources that favor these adoptions. In contrast, we observe significant differences in the effects of the external antecedents on TPI and OPI. A firm's competitive environment, characterized by a high level of uncertainty and competition, favors OPI adoption, though the effect is not significant for TPI. Moreover, an R&D partnership with private and public bodies increases the probability of adopting OPI, but this variable has no significant effect on the probability of adopting TPI.

If we consider the antecedents' effects on the sole probability of adopting organizational and technological process innovations simultaneously, we find that most internal and external antecedents exert significant, positive effects. Among the internal antecedents, the formalization of results and procedures, presence of specialists in firms' functions, a well-defined emphasis on cost and quality, and an internal team dedicated to R&D increase the probability of joint adoption of TPI and OPI. In contrast, and as expected, the centralization of decision making at the top management level hinders TPI and OPI joint adoption. Except for firms' export status, all external antecedents have significant and positive effects on the probability of jointly adopting TPI and OPI. Large manufacturing firms belonging to a group are more likely to adopt an OPI and a TPI simultaneously.

TABLE 7
Results of recursive bivariate probit model

	Recursive Bivariate Probit		Marginal Effects (1)	
Variables *(X)*	TPI *(y_1)*	OPI *(y_2)*	TPI	OPI
Centralization	0.047 (0.036)	-0.132*** (0.038)	-0.015 (0.012)	-0.035*** (0.010)
Formalization	0.231*** (0.045)	0.243*** (0.049)	0.07*** (0.012)	0.059*** (0.011)
Specialization	-0.006 (0.035)	0.058* (0.037)	-0.003 (0.011)	0.015 (0.009)
Cost Quality focus	-0.058* (0.036)	0.141*** (0.038)	0.017 (0.011)	0.036*** (0.009)
Internal R&D	0.190*** (0.038)	0.207*** (0.039)	0.061*** (0.013)	0.054*** (0.010)
External partners	-0.011 (0.042)	0.237*** (0.042)	0.002 (0.013)	0.065*** (0.012)
High uncertainty	-0.032 (0.033)	0.127** (0.035)	-0.012 (0.01)	0.032*** (0.009)
Export status	0.046 (0.039)	0.044 (0.042)	0.015 (0.012)	0.011 (0.010)
Manufacturing	-0.014 (0.039)	0.333*** (0.043)	-0.006 (0.012)	0.087*** (0.011)
Size	0.211*** (0.034)	0.293*** (0.034)	0.069*** (0.011)	0.076*** (0.008)
Group belonging	-0.193*** (0.041)	0.238*** (0.041)	0.06*** (0.012)	0.061*** (0.010)
Technology focus	0.268*** (0.043)		0.08*** (0.012)	
External ICT advices	0.217*** (0.036)		0.069*** (0.011)	
ICT recruitment difficulties	0.132** (0.066)		0.041* (0.041)	
Prior TPI adoption	-0.439*** (0.014)		-0.14*** (0.004)	
Prior OPI adoption		-0.147*** (0.011)		-0.038*** (0.003)
TPI		**0.387*** (0.103)**		**0.125*** (0.011)**
constant	-0.66*** (0.075)	-2.067*** (0.086)		
Number of observations	7516			
X^2	1678.06			
Log-likelihood	-7255.54			
Rho (ρ)	0.04			
Rate of good prediction	56.8%			

NOTES : Robust standard errors are reported in round brackets.
****, ** and * indicate significance at 0.01, 0.05 and 0.10 level, respectively.*
(1) Because ρ is not significantly different from 0, marginal effects have been computed from separate probit models

These initial results show that the decisions to adopt TPI and OPI are not independent. However, our analysis may suffer from an omitted variable bias, because TPI might determine OPI, but the variable TPI itself is missing in the regression explaining OPI. Therefore, we estimated a recursive bivariate probit model, with which we can assess the direct effect of TPI on the probability of OPI, given that each variable is likely to affect the other (see Equation 2). The percentage of correct predictions by this model (56.8%) suggests that it offers good explanatory power compared with the naïve prediction ratio of 25%. The correlation coefficient ρ is not significantly different from 0. When we control carefully for endogeneity, TPI and OPI are no longer affected by common unobservable heterogeneity elements. However, this finding does not mean that the two decisions are independent; the results show a direct, significant, positive effect of TPI on OPI. In line with the integrative view, we thus can confirm that the two innovations are complements.

Furthermore, the antecedents of TPI and OPI in this case are similar to those we obtained by estimating Equation (1). The effects of internal antecedents remain positive and significant; the external antecedents have no impact on either TPI and OPI. The only exception is the strategic focus on cost and quality, which no longer affects TPI. This variance is not surprising though, because we observe a significant, positive effect of a strategic priority on technological modernity (instrumental variable) on TPI. In terms of the magnitude of antecedents' effect on the probability of adopting OPI, we note that TPI has a greater impact on OPI.

5. Discussion

Despite the recent emergence of empirical research on process innovations, the differences between technological and organizational process innovations remain under-explored. This study seeks to address this gap from the integrative view of innovation types and investigate whether technological and organizational process innovations can be considered as the two components of process innovation as a single phenomenon.

5.1 Antecedents of process innovations

Our results show that TPI and OPI are driven by similar internal antecedents. We observe significant and positive effects of most internal antecedents on both technological and organizational process innovations. However, we note that the impacts of structural antecedents are not all in line with the previous studies that have found structural antecedents affect TPI and OPI differently. Previous studies generally suggest that organic structure would be better for the adoption of technological innovations, while mechanic structure would fit better with organizational innovations (Daft, 1978; Kimberly & Evanisko, 1981). These findings are limited as they view organizational innovations only through the chief executives' perspective and assume that they can impose their choice to middle managers and organizational members (Kimberly & Evanisko, 1981). Moreover, previous studies ignore the potential relationship between the two innovation types, suggesting that their findings may suffer from an endogeneity bias.

More recent studies depart from this view and offer that decentralization has a positive effect on both technological and non-technological innovations. Decentralization help creating and accumulating knowledge; hence, the flattening of hierarchical structures would be a forerunning condition for the adoption of new organizational protocols (Mazzanti et al., 2006). Our results support such perspectives. For example, we found that: (1) centralization affects OPI negatively, and while the sign of the relationship is also negative for TPI, it is not significant ($p>.05$); and (2) formalization affects both TPI and OPI positively. We also found that cost and quality strategic priority positively affect TPI and OPI. In line with Cabagnols and Le Bas (2002) and Reichstein and Salter (2006), these results show that strategic priorities on product "flexibility" and "quality" and on cost are major drivers of process innovations. More generally, our analyses show that TPI and OPI are driven by internal rather than external factors, which is not surprising when we consider that the main objective of their introduction is contributing to the efficiency and effectiveness of internal organizational processes.

5.2 Complementarity of TPI and OPI

Few empirical studies have investigated both TPI and OPI. While research suggests that the two types of process innovations are interlinked (Benner & Tushman, 2002; Edquist et al., 2001; Ganter & Hecker, 2012; Schmidt & Rammer, 2007), the nature of the linkage has hitherto not been determined. Our two step empirical strategy allows us to provide further evidence on the complementarity of TPI and OPI. On the one hand, using a bivariate probit model, we show that the adoptions of these innovations are complementary. On the other hand, when we control carefully for endogeneity, data indicates that TPI has a positive effect ($p<.05$) on OPI. This provides a strong support to the integrative view of process innovation types. In line with Schmidt and Rammer (2007) and Reichstein and Salter (2006), our results indicate that OPI and TPI are complementary dimensions of process innovation and are driven by the same organizational capabilities. That is, while TPI and OPI are different (e.g., one is technology-based the other is not), they are correlative. Therefore, we suggest that future research consider process innovations in the context of socio-technical systems where OPI takes place in the social system and TPI in the technical system and the changes in the two systems should be coupled for a joint optimization of the whole system (Damanpour & Evan, 1984; Emery & Trist, 1969). Our results are also in line with the resource-based view (Barney, 1991; Penrose, 1959), which argues that the complementary assets (resources and capabilities) are required to enable firms benefit from technology or innovation strategy (Christmann, 2000; Teece, 1986). In this vein, combinative adoption of technological and organizational process innovations can be a crucial lever for firms' competitive advantage.

5.3 Limitations

Our study has several limitations that should be considered in applying its findings. First, it relies on two specific process innovations, ICT and Lean Management. Whereas ICT and Lean Management are crucial practices for the "flexible and modern manufacturing firm" and can generate increased returns if they are introduced in tandem (Milgrom & Roberts, 1990), a focus on them as the components of process innovation can partially explain firms' heterogeneity. Second, although previous research has argued for the inclusion of multiple phases of innovation adoption (Damanpour & Schneider, 2006; Pierce & Delbecq, 1977), our research do not differentiate the effects of antecedents on different phases and focuses on the adoption-decision phase only. Third, a true test of the complementarity of TPI and OPI ideally requires the examination of their joint impact on organizational outcome. A path of research might consider the impact of complementarity process innovations on firm's performance.

6. Conclusion

Despite these limitations, this paper makes several contributions to the innovation literature. First, it focuses on process innovations, an under-researched type of innovation, and includes two major components of it. In so doing, it overcomes a key limitation of innovation research, namely the technological bias. Second, our findings provide a better understanding of the internal and external factors that jointly influence TPI and OPI. The existence of a strong recursive relationship between types of process innovation provides new evidence that TPI and OPI are two dimensions of one innovation and are not distinct. Third, it extends prior studies by integrating internal and external antecedents and provides a more robust test of the complementarity of innovation types. Fourthly, for managers, our results point out the importance of joint consideration of technological and organizational innovations in formulating and implementing firms' innovation strategy. Overall, this research advocates a conceptualization of process innovation that takes into account its multidimensionality and recommends further research on the integrative rather than the distinctive view of the types of process innovation.

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