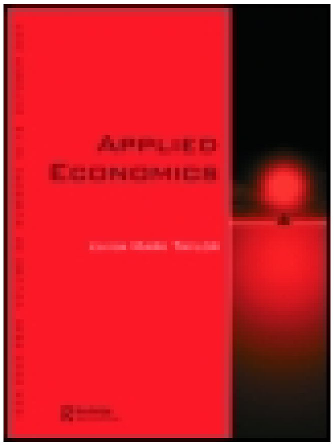

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Assessing complementarity in organizational innovations for technological innovation: the role of knowledge management practices

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Assessing complementarity in organizational innovations for technological innovation: the role of knowledge management practices

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We empirically investigate the pattern of complementarity among four organizational practices. Firm-level data were drawn from the Community Innovation Survey, carried out in Luxembourg. Supermodularity tests confirm the crucial role of organizational innovation in raising firms' technological innovation. The pattern of complementarity across organizational practices differs according to the type of innovation (i.e. product or process), as well as according to whether the firm is in the first stage of its innovation process (i.e. being innovative or not) or in a later stage (i.e. sales of new products).

Keywords: complementarity; organizational innovation; substitution; supermodularity; technological innovation

JEL Classification: D23; O32

I. Introduction

Empirical research devotes limited attention to innovation strategies implemented in organizational fields other than technological innovations. Yet organizational innovation encompasses 'the implementation of a new organizational method in the firm's business practices, knowledge management, workplace organization or external relations that has not been previously used by the firm' (OECD, 2005). Therefore, we consider four types of organizational innovation to identify the complementarities that knowledge management practices might have with business practices, workplace organization and external relations; we also note the resulting impacts on technological innovation performance. Firms introducing synergistic organizational innovations should have a competitive advantage over noninnovative firms, as well as over firms that adopt a narrow, singular approach to innovation (e.g. Miravete and Pernias, 2006; Evangelista and Vezzani, 2010; Gunday *et al.*, 2011).

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Some empirical studies acknowledge the existence of synergistic effects as a result of the simultaneous adoption of complementary organizational practices, though their results remain controversial (Ichniowski *et al.*, 1997; Cappelli and Neumark, 2001). The recent literature explicates some of the complementarities, but most analyses focus on organizational practices associated with a new workplace organization (Ichniowski *et al.*, 1997; Cappelli and Neumark, 2001), human resource management practices (Laursen and Mahnke, 2001) or external relations (Arora and Gambardella, 1990). Other forms of organizational innovation, such as outsourcing, partnerships, subcontracting and business work practices (e.g. quality management, reengineering, lean management), have not received sufficient attention, nor have they been studied in combination.

With this article, we highlight the complementary/substitution effects of product/process innovations on the one hand and of two stages of the innovation process on the other hand. The notion of complementarity refers to the beneficial interplay of the design elements of a system, in which doing more of one thing increases the returns from doing more of another thing (Milgrom and Roberts, 1990, 1995). Several studies investigate the complementarities between internal R&D expenditures and external technology sourcing (e.g. Audretsch *et al.*, 1996; Love and Roper, 2001; Cassiman and Veugelers, 2006; Schmiedeberg, 2008), process and product innovations (Miravete and Pernias, 2006) or different obstacles to innovation (Galia and Legros, 2004; Mohnen and Röller, 2005). Allowing for effects of unobserved heterogeneity, Lucena (2011) found that the organizational designs firms use to combine internal and external R&D activities produce beneficial complementarities for knowledge creation (measured as product innovation). Leiponen (2005) adopted a different view to analyse the complementarities between employees' skills and firms' innovation activities, which enhance profitability. To build complementary capabilities or absorptive capacity, she recommends that firms develop human skills. We adopt different lenses and predict instead that firms should combine various organizational innovation practices to achieve process/product innovation.

Industrial organization, strategic management and innovation literature has persistently investigated possible complementarities among various organizational practices, noting that sets of strategic activities could lead to sustainable competitive advantages, and strategies can act as substitutes or complements of one another. Advances in this notion came from studies of supermodularity in lattices and a formal model of complementarity (Milgrom and Roberts, 1995; Topkis, 1998). Supermodularity is the mathematical equivalent of the idea that the gain achieved from increasing all components is greater than the sum of gains obtained from each individual increase (Milgrom and Roberts, 1990). Mathematical tools that reflect lattice theory have been applied in economics and management to develop models of this so-called Edgeworth complementarity, in which the implementation of one practice increases the marginal or incremental return of other practices. However, the implementation of one practice may also decrease the marginal or incremental returns of other practices, which implies that the practices are substitutable. Milgrom and Roberts (1990, 1995) suggested that adopting a new organizational practice improves firm performance only if the new practice aligns with the firm's other choices. Supermodularity theory, in emphasizing organizational and strategic factors, proposes a simple model to explain the move from Fordist firms based on mass production to more modern, lean, flexible firms. Supermodularities (or complementarities) in modern manufacturing firms should lead to greater profits. Moreover, firms should have no interest in adopting an organizational practice if they have not undergone a thorough overhaul of their entire organizational design.

Recent studies of organizational performance seek to establish potential complementarities between more than two organizational practices adopted simultaneously (for a review, see Carree *et al.*, 2011). However, empirical research on the complementarities among different innovation strategies remains scarce. We consider the relationships of four organizational practices (business practices, knowledge management, workplace organization and external relations) and their synergistic effects on technological innovation throughout the innovation process. We predict that firms face a substantial challenge to organize their innovation processes in a holistic fashion, as interrelated, strategic organizational activities, such that when they exploit the synergies across new organizational practices more effectively, they generate more technological innovation. A firm's capacity to combine strategic organizational activities is a crucial determinant of innovation performance; it can lead to sustained performance differences, because it produces specific, unique skills for the firm that make it more difficult for competitors to imitate its organizational capabilities (Teece, 1986).

We also investigate the relationships between organizational and technological innovations in detail, focusing on the complementarities in organizational innovation practices and their impacts on technological innovation. Our objective is to analyse both the effect of organizational innovation and the conditions under which certain organizational practices influence the firm's technological performance. Accordingly, we suggest ways to improve technological innovation performance, by implementing and combining certain types of organizational innovation practices. Despite recognition of the crucial role played by organizational practices in technological innovation, the scarce research available mainly focuses on sub-practices within groups of organizational strategies (e.g. external R&D relationships, work practices). We propose a more comprehensive set of complementarity hypotheses to account for the synergies among complementary activities; failing to take these synergies into account may cause the firm to suffer both value creation and performance losses, without achieving its full potential.

In the next section, we detail the role of organizational innovation in technological innovation processes and provide an overview of complementarities in organizational practices. Section III describes the data set, from the Luxembourg Community Innovation Survey (CIS), and the focal variables. In Section IV, we introduce the methodology we used to test for complementarities. After we present the estimation results in Section V, we conclude in Section VI.

II. Complementarities of Knowledge Management and Other Organizational Practices: Theoretical Foundations and Hypothesis Development

Previous research cites an essential role of organizational innovation in the development of technological innovation capabilities (Camisón and Villar-López, 2014); we search for complementarities across organizational innovation practices for technological innovation performance. Complementarity between two organizational innovation practices means that investing in one (e.g. knowledge management) increases the value of investing in another (e.g. external relations). From a theoretical perspective, and because we focus on synergies between knowledge management and the three other organizational practices (business practices, workplace organization and external relations), our complementarity hypotheses reflect the resource-based view (RBV) and its extension, the knowledge-based view (KBV) (Grant, 1996).

The RBV of the firm is an influential theoretical framework for understanding the creation and sustainability of competitive advantage and thus explaining why firms perform differently (Barney, 1991). According to the RBV, any firm is a combination of resources and capabilities that may provide it with sustainable competitive advantages (Amit and Schoemaker, 1993). Resources, or stocks of available factors that are owned or controlled by the firm, get converted into final products or services through the use of a wide range of other firm assets and organizational practices (Barney, 1991; Amit and Schoemaker, 1993). Capabilities reflect the firm's capacity to deploy resources. The application and use of capabilities enable the firm to perform its necessary activities (Lin *et al.*, 2013). Knowledge – or what it knows about customers, products, processes, mistakes and successes – resides in databases, is accumulated through shared experiences and best practices or is gathered from internal and external sources. This resource is core to the organization's ability to innovate and central to the development of new products.

The KBV focuses on knowledge as the most strategically important resource for a firm (Grant, 1996). Fundamentally, knowledge management consists of the creation and application of knowledge as a resource (Spender, 1996). Effective knowledge management may contribute to better performance through several business processes, such as the implementation of best practices and continuous improvement, operational problem solving, functional integration and new product development. In turn, a firm can be conceptualized as an institution for creating and integrating knowledge (Grant, 1996); this knowledge is embedded in multiple entities within the firm, such as individual employees, the organizational culture, routines, policies, systems or documents. To reap the benefits of knowledge management for innovation, the firm must develop an organizational capability to integrate and exploit knowledge.

Just as knowledge processes in organizations are integrally linked (Kraaijenbrink, 2012), such that complementary assets are required to support technological innovation (Teece, 1986), we posit that various organizational practices should be used together to complement knowledge management (e.g. partnering with other organizations, intraorganizational learning) and thereby enhance the firm's capability to integrate, reconfigure, gain and use knowledge (Leonard-Barton, 1992) for technological innovation (and thus organizational and financial performance). It is not the firm's existing knowledge that is the source of competitive advantage but its ability to apply that knowledge effectively to create favourable conditions for producing better value. Organizational knowledge and its management thus relate to organizational learning–unlearning and innovation (Albino *et al.*, 2001) and the underlying knowledge management practices. Organizational practices reflect the application and use of knowledge. They consist of operational systems, local abilities and know-how, which are necessary for day-to-day problem solving. Intangible, firm-specific, socially complex and causally ambiguous organizational practices (e.g. total quality management) can provide sustainable competitive advantages. Further evidence that a firm's innovation performance and competitive advantage are functions of complex inimitable resources embedded within the organization (Barney, 1991) comes from the work of Alegre *et al.* (2013), who find a positive, significant link between the integration of various knowledge management practices and (mainly product) innovation performance.

The extant literature on organizational practices has treated them separately though, disregarding their interactions and synergies. Because of this approach, little is known about their relative importance or how they work together. In line with Kraaijenbrink (2012), who finds that greater interactions among knowledge processes are associated with new product development success, we argue that knowledge management practices should be combined with other organizational innovation practices to enhance technological innovation performance.

Our underlying hypothesis is that organizational combinations enable the development of a knowledge-based capability, often defined as a dynamic process and reflected in the concept of absorptive capacity. It involves three major activities: knowledge acquisition, knowledge assimilation or dissemination and knowledge application or transformation (Cohen and Levinthal, 1990; Nonaka, 1994). Zahra and George (2002) also added an exploitation dimension, which is the output of the process. Building absorptive capacity requires implementing organizational practices that refer to (1) external relations to acquire knowledge, (2) the workplace organization for the assimilation and dissemination of that knowledge, (3) business practices that represent the materialization and application of knowledge and (4) knowledge management systems that ensure the realization of the first three steps.

Acquiring knowledge about the current business system or new opportunities to enable the organization to analyse and interpret knowledge (Zahra and George, 2002) might involve internal and external sources, including employees, professional associations, patients and suppliers. We focus on external sources reached through external relations; this organizational practice enables the firm to acquire knowledge. Next, the firm must disseminate its acquired knowledge to make it useful. By distributing knowledge throughout the entire organization, it becomes possible to integrate different perspectives on the same knowledge (Zahra and George, 2002), which helps firms transform and refine their knowledge, reduce knowledge redundancy or remove outdated knowledge (Grant, 1996). The existing knowledge management literature has not detailed the underlying mechanisms by which this dissemination might be realized though. Workplace organization practices are mechanisms that allow firms to distribute knowledge across the entire organization. Finally, knowledge application occurs when firms incorporate disseminated and refined knowledge into their operations (Cohen and Levinthal, 1990). Efforts to retrieve and use the existing knowledge, from the previous two stages, result in enhanced knowledge assets (Li *et al.*, 2012) and the creation of better products and processes (Spender, 1996).

In turn, we detail the predicted interactions between knowledge management on one hand and external relations (to facilitate knowledge acquisition), workplace organization (to enable knowledge dissemination) and business practices (to apply knowledge) on the other hand.

External relations (partnerships, outsourcing, subcontracting) allow firms to access external knowledge. A firm's knowledge depends not only on its internal learning activities but also on the learning activities of various actors outside the firm (Cohen and Levinthal, 1990). Interfirm cooperative agreements are one of the major modes used by firms to access knowledge. In the same vein, R&D outsourcing, which refers to the performance of R&D tasks of clients by various types of organizations, has considerably increased in importance. According to the KBV, such external relations serve as instruments to access knowledge resources that can subsequently be redeployed with the existing resources, thus benefiting firms' innovative capabilities. Cassiman and Veugelers (2006) provided evidence that internal and external R&D are complementary innovation activities, so that the marginal return to internal R&D increases with the intensity of R&D outsourcing. Moreover, they show that innovation success depends on the combination of various innovation activities, within the appropriate context. Adequate knowledge management, such as systems of knowledge, information exchange or interpretation, is thus required to reap the benefits of external partnering and knowledge acquisition. Firms must search for the right partners (R&D partners, clients, suppliers) and external relations to access complementary knowledge and resources (Miotti and Sachwald, 2003), according to their objectives. Drawing on the KBV and absorptive capacity perspectives, innovation in such organizational practices may support better external knowledge integration and thus product innovation. We hypothesize:

Hypothesis 1: Knowledge management and external relation practices are complementary and positively associated with technological innovation when they are combined and simultaneously implemented.

Workplace organization practices include teamwork, decentralization, integration and new decision making, such that they are linked to human (formal and informal) relations, as well as organization and firm design. They allow the firm to assimilate knowledge through dissemination across the entire organizational structure. Practices such as teamwork (Cohen and Bailey, 1997) and integration increase the amount of shared knowledge and thus knowledge transfers to other organizational units. The workplace needs to be organized in such a way that some degree of overlap exists between the sender and recipient, to facilitate the efficient transfer of knowledge (Grant, 1996). Drawing on the KBV, De Luca and Atuahene-Gima (2007) examined the interplay among market knowledge, its integration and the firm's product innovation performance. The KBV stipulates that it is not knowledge *per se* but rather its integration that affects competitive advantage (Grant, 1996); thus, knowledge integration and interpretation mechanisms should mediate the links among knowledge dimensions, cross-functional collaboration and product innovation performance (De Luca and Atuahene-Gima, 2007). Jaspers *et al.* (2012) found that interindustry architectural innovations likely benefit from organizational forms that facilitate intense coordination between specialists and timely decision making and conflict resolution, which suggests valuable insights for managers who must make multiple decisions simultaneously rather than in isolation, as well as for configurational theorists. In particular, multiple organizational dimensions can be aligned to produce a synergistic effect. Therefore, we elaborate the following hypothesis:

Hypothesis 2: Knowledge management and workplace organization practices are complementary and positively associated with technological innovation when they are combined and simultaneously implemented.

Business practices (or process improvement techniques) include organizational innovation practices such as total quality management (TQM), lean management, process re-engineering and supply chain management. They relate to knowledge implementation and application in concrete techniques that allow for process improvement. The relationship between business practices and knowledge management has been conceptualized in different ways. For example, knowledge management has been seen as an enabler of TQM (Honarpour *et al.*, 2012). Hung *et al.* (2010) empirically examined the relationship among knowledge management, TQM and innovation and found a significant association between knowledge management and TQM. In the KBV, organizational knowledge is a source of competitive advantage, to the extent that the process management system enables knowledge creation. Quality management is a source of knowledge creation that may result in competitive advantages (Linderman *et al.*, 2004), if effectively implemented. Efficient knowledge management in supply chains can also enhance firm innovation and creativity in rapidly changing environments (Sambasivan *et al.*, 2009). Molina *et al.* (2004) noted the impact of TQM on the degree to which firms transfer knowledge, and Loke *et al.* (2012) found that integrating TQM and knowledge management can increase knowledge creation and thus innovation and organizational performance. In line with these works, we propose the following hypothesis:

Hypothesis 3: Knowledge management and business practices are complementary and positively associated with technological innovation when they are combined and simultaneously implemented.

III. Methodology for Testing Complementarities

The concept of complementarity refers to the presence of system effects and synergies of alternative activities; it has been used widely to study innovation processes. Organizational practices are complements if their simultaneous implementation pays off more than the isolated adoption of each of them. We analyse the contribution of different combinations of practices to firm innovation performance. This analysis (also known as a 'performance' approach) is based on the objective function of the firm.[1] The main idea is that the simultaneous implementation of different activities should prove to be more valuable than implementing each of them separately. The test of complementarity is thus performed by regressing a measure of firm performance on a set of interaction terms among the considered activities, interpreted as complementarity parameters. Comparing the impacts of alternative combinations of activities stemming from this estimation allows us to identify their complementarity effects. It is also possible to obtain supportive evidence of complementarity (substitutability) from significant and positive (negative) coefficients, observed for the interaction terms. Formally, this approach reflects supermodularity (Milgrom and Roberts, 1995; Topkis, 1998): When activities are complementary, the objective function is supermodular. The definition of supermodularity provided by Milgrom and Roberts (1995) requires only a nonnegative (rather than positive) impact of one practice on the marginal returns of another practice.

Applying this approach, Mohnen and Röller (2005) estimated the innovation function directly and investigated whether policy decisions (i.e. obstacles to innovation that are affected by policies) are complementary. Lokshin *et al.* (2008) studied the complementarity among product, process and organizational innovations and their impacts on labour productivity. Ichniowski *et al.* (1997) used this approach to test for complementarity among different human resource management practices. With a sample of 36 homogeneous steel production lines, they found that using innovative work practices, such as teams, flexible job assignments or training, leads to higher output and product quality. Cassiman and Veugelers (2006) also investigated complementary innovation activities (e.g. in-house R&D, external technology sourcing) and their impacts on firm performance. Recently, Cavaco and Crifo (2014) also applied this technique to study the complementarity between various dimensions of corporate social responsibility in the determination of firms' financial performance.

We test for complementarity in innovation activity and innovation performance by estimating the probability of observing a (product or process) innovation activity, then calculating the 'innovation function' related to product innovation. These two estimations include alternative combinations of organizational practices as explanatory variables. The analysis focuses on the relation between innovation performance and different practices of organizational innovation, such that we compare the impact of alternative combinations of practices on firm innovation activity and performance.

We first considered firms' innovation activity and estimated the function, which takes the following form:

[1] An alternative approach, known as a correlation or adoption analysis, is presented in Appendix B. It does not provide a sufficient condition to conclude that a complementary relationship exists among different activities though. It offers some suggestive evidence of complementarity among the four organizational practices, but this evidence requires confirmation by a 'performance' approach.

$$P_i^* = \sum_{j=0}^{15} S_j\gamma_j + X_i^{'}\alpha + \varepsilon_i \quad (1)$$

where P_i^* is the latent variable corresponding to the probability to innovate as a product or process. According to the performance approach and similar to the one of Mohnen and Röller (2005), we inserted a set of state dummy variables S_j into the model. Because 4 organizational practices were considered, this set corresponds to 16 dummy variables, *s0_0_0_0, s0_0_0_1, . . . , s1_1_1_1*, where the 4 indices denote the 4 practices: business practices, knowledge management, workplace organization and external relations. For each dummy *sk_l_m_n,* the four indices (*k,l,m,n = 0,1*) represent the presence or absence of each of the four practices. For example, *s1_0_1_0* indicates that business practices and workplace organization are present but knowledge management and external relations are not. Furthermore, X_i represents the set of explanatory variables, including controls for firm-level heterogeneity, such as firm size, sectors of activities and foreign ownership, as well as variables that have previously been identified as relevant determinants of innovation performance at the firm level, such as the intensity of internal and external R&D and obstacles to innovation. Because Equation 1 pertains to both product and process innovation, we used a biprobit model to estimate this equation.

For innovation performance, following Mohnen and Röller (2005), we used the following model:

$$I_i = \sum_{j=0}^{15} S_j\delta_j + W_i^{'}\beta + \upsilon_i \quad (2)$$

where I_i is the innovation performance of firm i, measured as the share in its sales of innovative products (PERFOR), and W_i is the set of control variables, including firm size, sectors of activities, foreign ownership and obstacles to innovation. This model pertains only to product innovation; no similar information is available on process innovation. Moreover, only 266 firms (of 568) innovated in products, so we used Heckman's two-step selection model to control selection bias related to product innovation activity. In this model, the second step corresponds to the performance model in Equation 2, and the first step corresponds to a probit estimation of the probability of having a product innovation (or propensity to innovate), as given in Equation 1.

Next, we performed supermodularity and submodularity tests for complementarity and substitutability, respectively, in organizational practices. For innovation activity, these tests were based on consistent estimates of coefficients γ_j (Equation 1). As Mohnen and Röller (2005) indicated, complementarity between each pair of practices should satisfy the following constraints[2]:

(practices 1 and 2) $\gamma_{8+s} + \gamma_{4+s} \leq \gamma_{0+s} + \gamma_{12+s}$ where $s = 0,1,2,3$,
(practices 1 and 3) $\gamma_{8+s} + \gamma_{2+s} \leq \gamma_{0+s} + \gamma_{10+s}$ where $s = 0,1,4,5$,
(practices 1 and 4) $\gamma_{8+s} + \gamma_{1+s} \leq \gamma_{0+s} + \gamma_{9+s}$ where $s = 0,2,4,6$,
(practices 2 and 3) $\gamma_{4+s} + \gamma_{2+s} \leq \gamma_{0+s} + \gamma_{6+s}$ where $s = 0,1,8,9$,
(practices 2 and 4) $\gamma_{4+s} + \gamma_{1+s} \leq \gamma_{0+s} + \gamma_{5+s}$ where $s = 0,2,8,10$,
(practices 3 and 4) $\gamma_{2+s} + \gamma_{1+s} \leq \gamma_{0+s} + \gamma_{3+s}$ where $s = 0,4,8,12$.

The substitutability between each pair of practices should satisfy the analogous inequalities, which take opposite signs.

The hypotheses indicating that pair 1–2 is strictly supermodular are:

H_0: $h_0 < 0$ and $h_1 < 0$ and $h_2 < 0$ and $h_3 < 0$ (null hypothesis)

H_1: $h_0 \geq 0$ or $h_1 \geq 0$ or $h_2 \geq 0$ and $h_3 \geq 0$ (alternative hypothesis)

where $h_s = -\gamma_{0+s} + \gamma_{4+s} + \gamma_{8+s} - \gamma_{12+s}$, $s = 0,1,2,3$. The test is based on Kodde and Palm's (1986) Wald test for inequalities. The tests for the other pairs were defined analogously. Similarly, testing for the strict submodularity for the 1–2 pair reflected the following hypotheses: H_0: $h_0 > 0$ and $h_1 > 0$ and $h_2 > 0$ and $h_3 > 0$, and H_1: $h_0 \leq 0$ or $h_1 \leq 0$ or $h_2 \leq 0$ and $h_3 \leq 0$.

We performed the same tests of complementarity and substitutability for innovation performance

[2] Practices 1–4 denote business practices, knowledge management, workplace organization and external relations, respectively.

based on consistent estimates of Equation 2. These tests were defined analogously, replacing γ_j with δ_j. When estimating Equation 2, the variable *s0_1_0_1* was excluded from our regressions due to collinearity. The tests therefore included the additional constraint $\delta_5 = 0$.[3]

IV. Data and Variables

The empirical analysis is based on firm-level data drawn from the Luxembourgish Community Innovation Survey (CIS6) carried out in Luxembourg in 2008 by the Luxembourg Institute of Socio-Economic Research on behalf and under the methodological responsibility of the National Statistical Institute (STATEC). The objective of this survey was to collect data on firms' innovation behaviour over the three-year period from 2004 to 2006, according to OECD (2005) recommendations. It provides general information about firms (sector of activity, group belonging, number of employees, sales, geographic market), technological and nontechnological innovations, perceptions of factors that hamper innovation activities and subjective evaluations of the effects of innovation. The data set also comprises information about sources of information and various types of R&D cooperation for innovation activities.

For the purposes of this article, we used a subsample of firms with at least 10 employees that operated in the manufacturing or service sectors. Because our data set includes both manufacturing and service firms, we adopted a *synthesis* approach, which allows innovation to take place in manufacturing *and* in services (Gallouj and Weinstein, 1997; Love and Mansury, 2007).[4] We thus obtained a sample of 568 representative firms.

The first dependent variable is *innovation performance*, measured as the percentage of the total turnover earned from product innovations that are new to the firm (Mohnen and Röller, 2005; Cassiman and Veugelers, 2006). The second dependent variable is the *propensity of innovation in product*, a binary variable that indicates whether the firm introduced a product innovation or not. The third dependent variable, *propensity of innovation in process*, is binary and indicated whether a firm was a process innovator (see Appendix A for the definition of the variables).

The CIS provides data on organizational innovation implemented by firms during 2004–2006. Four categories of organizational innovation appear in the survey: (1) new business practices for organizing work and procedures (i.e. supply chain management, business reengineering, quality management, lean production and education/training systems), (2) new knowledge management systems (i.e. new systems facilitating exchanges of information, knowledge and skills within the firm or designed to collect and interpret information), (3) new workplace organization methods (i.e. new systems of employee responsibilities, team work, decentralization and integration or de-integration of departments) and (4) new methods for organizing external relations (i.e. first use of alliances, partnerships, outsourcing or subcontracting). Four binary variables were constructed to reflect each practice.[5]

We also included classical technological innovation determinants in our model. For *R&D intensity*, we measured the sum of expenditures on intramural (in-house) R&D and extramural R&D in 2006, divided by the total turnover in 2006. Firms rated the degree of competition of the market on a Likert scale from 0 (no effective competition) to 3 (very intensive). On the basis of this information, we constructed a *competition intensity* variable. Two binary variables reflected the appropriability conditions: *strategic protection* is equal to 1 if respondents rated the importance of strategic protection methods, namely, secrecy, complexity of design and lead-time advantage over competitors, as 'crucial' and 0 otherwise. *Formal protection* is equal to 1 if the score for the importance of formal protection methods, that is, patents, trademarks, registration of design patterns or copyrights, is 'crucial' and 0 otherwise.

Traditional control variables also appear in our model. *Firm size* is measured by the natural logarithm of the number of employees. We introduced a dummy variable, *group belonging*, which took a

[3] Tests also can be performed on the selection equation for product innovation using the Heckman's selection model to estimate Equation 2. We do not have to present them here, because they are consistent with those based on Equation 1, as applied to product innovation.

[4] Doing so would result in missing observations, which could seriously affect the quality of the regressions.

[5] Modelling complementarities in terms of supermodular functions on lattices highlights that 'design choices, if they can even be adapted at will, represent discrete rather than continuous variables' (Ennen and Richter, 2010, p. 214).

value 1 if the firm was independent (reference), 2 if it belonged to a domestic group, 3 if it was part of a European group and 4 if it was part of an extra-European group. Eight *sectors of activities* were included, reflecting the two-digit NACE classification: (1) high and medium high-tech manufacturing industry; (2) medium low-tech industry; (3) low-tech industry; (4) transport and communication; (5) financial intermediation; (6) computer activities; (7) R&D – engineering activities and consultancy, technical testing and analysis and (8) wholesale trade (reference).

V. Results and Discussion

Our data set contained 568 observations, such that it is of moderate size. However, to keep our results robust, we computed the bootstrap standard errors for estimated coefficients, to avoid any possible finite sample size bias.

The dependent variables in Equations 1 and 2 are, respectively, the percentage of sales attributable to innovative products and the probability of being a product innovator. Therefore, consistent estimates for the parameters of interest can be obtained by the maximum likelihood estimation, which accounts for censoring in innovation performance (Mohnen and Röller, 2005). The inverse Mill's ratio included in the model for correcting left-censoring was not significant though, so the estimated results for the sales of innovative products were not influenced by censoring. A simple Tobit model instead served to estimate innovation performance. The results are given in Table 1.

To analyse the complementary relationship of the four organizational practices, we assessed the impact of organizational practices on the probability that the firm would be a product and process innovator, using a biprobit model. The results are given in Table 2.

The results in Tables 1 and 2 show that the probability of being a product or process innovator strongly depends on R&D intensity, in line with previous empirical findings that indicate the crucial role of internal R&D expenditures in innovation processes. Specifically, they condition knowledge creation and firms' capacity to absorb external knowledge (Crepon *et al.*, 1998). However, R&D intensity did not have any impact on innovation

Table 1. Estimation results for product innovative performance

Variable	Coefficient (SE)
Intensity of R&D	0.003 (0.004)
Intensity of competition	−0.001 (0.012)
Formal protection	−0.011 (0.018)
Strategic protection	0.011 (0.018)
Size	−0.011 (0.006)*
Belonging to a Luxembourgish group	−0.005 (0.021)
Belonging to a European group	−0.005 (0.024)
Belonging to other country group	0.016 (0.031)
High and medium high technology industry	0.012 (0.030)
Medium technology industry	0.038 (0.033)
Low technology industry	0.014 (0.026)
Transport and communication	0.028 (0.032)
Financial intermediations	0.046 (0.021)**
Computer activities	0.026 (0.033)
R&D – engineering activities and consultancy	−0.004 (0.024)
s0_0_0_1	0.003 (0.036)
s0_0_1_0	0.121 (0.055)**
s0_0_1_1	0.031 (0.033)
s0_1_0_0	0.100 (0.040)**
s0_1_1_0	−0.017 (0.039)
s0_1_1_1	−0.079 (0.031)***
s1_0_0_0	0.014 (0.024)
s1_0_0_1	0.023 (0.035)
s1_0_1_0	0.052 (0.044)
s1_0_1_1	0.016 (0.038)
s1_1_0_0	0.036 (0.037)
s1_1_0_1	0.004 (0.040)
s1_1_1_0	0.021 (0.027)
s1_1_1_1	0.058 (0.027)**
Intercept	0.058 (0.083)
Number of observations	266
Mill's ratio	0.048 (0.048)

Notes: The dependent variable is innovative performance, measured as the share of sales of innovative products. Estimation results obtained from the Heckman two-step selection model (the first step corresponds to the selection equation for product innovation and the second step corresponds to the performance equation for product innovation). Dummy variables *sk_l_m_*n (where $k,l,m,n = 0,1$) correspond to the possible combinations of the four binary variables, representing four organizational practices (k = business practices, l = knowledge management, m = workplace organization, n = external relations). Variable s0_1_0_1 was excluded from the regression because of collinearity. Number of observations: 568. Number of uncensored observations: 266.

*, ** and *** denote significance at the levels of 10%, 5% and 1%, based on bootstrap standard errors with 100 replications.

Table 2. Estimation results for product and process innovations

Variable	Product innovation Coefficient (SE)	Process innovation Coefficient (SE)
Intensity of R&D	0.204(0.028)***	0.110(0.019)***
Intensity of competition	−0.010(0.096)	0.157(0.096)
Formal protection	0.465(0.205)**	−0.086(0.209)
Strategic protection	0.408(0.168)**	0.370(0.168)**
Size	0.123(0.071)*	0.036(0.069)
Belonging to a Luxembourgish group	0.200(0.205)	−0.074(0.180)
Belonging to a European group	0.216(0.192)	0.210(0.187)
Belonging to other country group	0.689(0.368)*	0.162(0.260)
High and medium high technology industry	0.105(0.301)	0.462(0.273)*
Medium technology industry	−0.323(0.255)	0.367(0.280)
Low technology industry	−0.637(0.245)***	0.369(0.256)
Transport and communication	−0.662(0.271)**	0.215(0.261)
Financial intermediations	−0.006(0.253)	0.533(0.299)*
Computer activities	−0.370(0.375)	−0.000(0.337)
R&D – engineering activities and consultancy	−0.177(0.281)	−0.197(0.307)
s0_0_0_1	1.347(2.003)	−0.318(2.733)
s0_0_1_0	0.158(0.344)	0.007(0.415)
s0_0_1_1	0.297(0.435)	0.614(0.373)*
s0_1_0_0	0.900(1.385)	−0.075(2.546)
s0_1_0_1	−5.017(0.701)***	−5.124(0.582)***
s0_1_1_0	1.371(1.379)	0.462(0.458)
s0_1_1_1	−0.586(2.434)	−5.945(0.654)***
s1_0_0_0	0.512(0.308)*	0.308(0.270)
s1_0_0_1	−0.533(2.427)	0.028(2.106)
s1_0_1_0	0.295(0.320)	0.813(0.254)***
s1_0_1_1	1.057(1.555)	1.193(0.422)***
s1_1_0_0	0.586(0.394)	0.890(0.343)***
s1_1_0_1	1.346(2.323)	0.155(1.816)
s1_1_1_0	0.599(0.243)**	0.688(0.238)***
s1_1_1_1	0.237(0.249)	0.662(0.199)***
Intercept	−1.471(0.437)***	−2.292(0.422)***
Number of observations	568	
$a\tanh\rho$	0.540(0.113)***	
LR χ^2 (1)	31.267***	

Notes: The dependent variables correspond to the probabilities of product innovation and process innovation. Estimation results are obtained from a biprobit regression. Dummy variables *sk_l_m_*n (where *k,l,m,n* = 0,1) correspond to the possible combinations of the four binary variables, representing four organizational practices (*k* = business practices, *l* = knowledge management, *m* = workplace organization, *n* = external relations). Number of observations: 568. $a\tanh\rho = 0.5 \ln[(1+\rho)/(1-\rho)]$ corresponds to the covariance between the two error terms of Equation (1) for product innovation and process innovation. The likelihood ratio (LR) χ^2 (1) test is for $\rho = 0$.
*, ** and *** denote significance at the levels of 10%, 5% and 1%, based on bootstrap standard errors with 100 replications.

performance, measured as the percentage of new products in sales. Firm size correlated positively with the likelihood of product innovation but negatively with the extent of innovation. This result – the larger the firm, the greater its propensity to innovate in products but the weaker its innovative performance – is in line with previous empirical findings (Mohnen and Röller, 2005). Strategic protection methods are strongly and positively associated with the likelihood of product or process innovation but have no impact on product innovation performance. As expected, firms that make intensive use of formal innovation protections, such as patents, trademarks or registration of design patterns, exhibit a higher probability to innovate in goods and services.

Turning to organizational innovation practices, when adopted separately, workplace organization and knowledge management have significant positive impacts on product innovation performance, whereas business practices have a significant positive impact on the propensity to innovate in products. The simultaneous implementation of business practices, knowledge management and workplace organization increases the propensity to innovate in both processes and products; no effects of such combinations appeared for innovation performance. However, some similarities between practices emerged. For example, firms that implemented all four organizational practices jointly were significantly more likely to be process innovators and to achieve higher innovation performance.

Although these results offer some indications of the effects of different combinations of organizational practices on innovation output, it is important to recall that the individual significance and signs of the coefficients alone cannot provide information about complementarity or substitutability across different organizational practices. Testing for complementarity requires checking the linear inequality restrictions and the joint distribution of several restrictions (Mohnen and Röller, 2005; Love and Roper, 2009). In our case, assessing complementarity or substitutability between organizational practices required joint testing of four inequality constraints for each pairwise comparison. The results of supermodularity and submodularity tests are given in Tables 3 and 4.

Similar to Mohnen and Röller (2005), we used the values provided by Kodde and Palm (1986) for the lower and upper bounds of the tests at the 10% significance level. The degrees of freedom (df) equalled 1 plus the number of equality restrictions ($q + 1$) for the lower bound and the total sum of equality and inequality (p) for the upper bound. For the model in Equation 1, pertaining to product and process innovations, the lower and upper bounds at the 10% level were 1.642 (df = 1) and 7.094 (df = 4), respectively. The null hypothesis H_0 is rejected if the test statistic is higher than the upper bound but accepted if the test statistic is lower than the lower bound (and it is inconclusive for values between the two bounds). For Equation 2, involving product innovation performance, the lower and upper

Table 3. Supermodularity and submodularity for product innovation performance

Wald test	Pair 1–2	Pair 1–3	Pair 1–4	Pair 2–3	Pair 2–4	Pair 3–4
Supermodularity	0.121 ^{A}	0.441 ^{A}	0 ^{A}	9.565 ^{R}	0.759 ^{A}	0.499 ^{A}
Submodularity	11.982 ^{R}	11.016 ^{N}	11.173 ^{R}	0.665 ^{A}	1.428 ^{A}	3.938 ^{N}

Notes: Tests are based on consistent estimates for the equation of product innovative performance (Heckman's model). The lower and the upper bounds of the test are, respectively, 3.808 (df = 2) and 8.574 (df = 5). ^{A} The null hypothesis H_0 is accepted (if the test statistic is lower than the lower bound), ^{R} H_0 is rejected (if the test statistic is higher than the upper bound), ^{N} no conclusion (otherwise).

Table 4. Supermodularity and submodularity for product and process innovation

	Wald test	Pair 1–2	Pair 1–3	Pair 1–4	Pair 2–3	Pair 2–4	Pair 3–4
Product	Supermodularity	2.896^{N}	9.003^{R}	2.210^{N}	0.914^{A}	17.149^{R}	1.875^{N}
	Submodularity	5.845^{N}	0.793^{A}	6.362^{N}	3.333^{N}	0.374^{A}	1.720^{N}
Process	Supermodularity	1.278^{A}	7.193^{R}	0.495^{A}	1.833^{N}	49.453^{R}	0.604^{A}
	Submodularity	52.739^{R}	0.539^{A}	59.184^{R}	0^{A}	0^{A}	0.241^{A}

Notes: Tests are based on consistent estimates of product and process innovations (biprobit regression). The lower and the upper bounds of the test at the 10% level (see Kodde and Palm, 1986) are, respectively, 1.642 (df = 1) and 7.094 (df = 4). ^{A} The null hypothesis H_0 is accepted (if the test statistic is lower than the lower bound), ^{R} H_0 is rejected (if the test statistic is higher than the upper bound), ^{N} no conclusion (otherwise).

bounds at the 10% level were 3.808 (df = 2) and 8.574 (df = 5), respectively.[6]

The results in Tables 3 and 4 indicate that the pattern of complementarity between organizational practices depends on the type of innovation, product or process. With regard to the propensity to innovate, the equation offered significant evidence of complementarity between business practices and knowledge management (pair 1–2) on process innovation. The product innovation results were inconclusive. The findings thus partially validated hypothesis 3: firms combining these two practices tend to benefit more from flexibility, adaptability and knowledge increases, which in turn can lead to higher capacities to introduce process innovations, including new methods for producing goods or services and new operations for purchasing, accounting or computing. The results also revealed a complementary effect of knowledge management and work organization (pair 2–3) on product innovation, in line with hypothesis 2.

Regarding the propensity to innovate in products, we found some similarities with the result for the propensity to innovate in processes. The joint implementation of knowledge management and external relations (pair 2–4) decreased the propensity to innovate in both products and processes, indicating a substitution effect of pair 2–4, in contrast to hypothesis 1. These two organizational practices were jointly substitutable for determining whether a firm was innovative; the implementation of one of them in each pair should be sufficient to motivate the firm to innovate. The other combinations offered clear evidence of substitution for both product and process innovations, such as between business practices and workplace organizations (pair 1–3). The benefits of low levels of hierarchy, high levels of delegation, broad skills, teamwork and job rotation decreased when firms implemented these practices jointly with workplace organization (lean production, supply chain management, business reengineering, TQM). This finding reflects the high costs that firms must incur to implement the practices simultaneously, which impedes rather than stimulating firm innovation capacities.

The patterns of complementarity may also differ according to whether the firm is in the first step of its innovation process (i.e. product innovator or not) or a subsequent step (i.e. product innovative performance). We found a complementary relationship between business practices and knowledge management (pair 1–2) for product innovative performance, though a similar test was inconclusive for the probability to be a product innovator. The benefits of positive synergies between business practices and knowledge management were limited to the latter stage of the innovation process. Innovative products are successfully adopted by the market, and firms thus achieve higher performance from these new products, when they also integrate organizational practices, such as supply chain management, quality management or business reengineering with their knowledge management. The pattern of complementarity was the same for the relationship between business practices and external relations (pair 1–4) and between workplace organization and external relations (pair 3–4). Complementarity was observed in a later stage of the innovation process, but the test results were inconclusive for the first stage.

The relationship between business practices and workplace organization (pair 1–3) instead was complementary in the second stage of the innovation process but substitutable in the first stage. This result, as predicted by competence-based theory, highlights that in modern business environments (Milgrom and Roberts, 1995), strategic costs and quality management, which are critical to firms' commercial success, must be implemented jointly by high performance work organizations that simultaneously facilitate knowledge integration, information exchange and mutual learning. Firms that jointly implemented knowledge management and workplace organization (pair 2–3) were more likely to introduce product innovation; this combination seems to reduce product innovation performance though (Laursen and Mahnke, 2001). That is, synergies from teamwork, employees' responsibilities, decentralization and internal knowledge management are likely more fruitful in a more upstream technical and engineering stage (i.e. conception and introduction of new or significantly improved goods or services) than in a downstream product stage (launching and commercializing goods or services on the market).

[6] For product and process innovations (Equation 1), the degrees of freedom for the lower bound equalled 1, because there was no equality restriction; for product innovative performance (Equation 2), they equalled 2, because of the equality restriction $\delta_5 = 0$, as detailed previously.

VI. Conclusion

The objective of this article was to determine whether different organizational innovation practices are complements or substitutes, in particular with knowledge management, for technological innovation performance. We used the supermodularity theory proposed by Milgrom and Roberts (1990, 1995), which makes it possible to create supermodular functions to demonstrate the effect of complementarity between organizational strategies in technological innovation. The empirical study was based on a firm-level data set drawn from the Luxembourg Community Innovation Survey (CIS6). To our knowledge, this study is the first to assess the firm's organizational innovation management from an integrative and holistic viewpoint by analysing the pattern of complementarity of different organizational practices through their impact on firms' innovation, taking into account the two stages of innovation processes.

Overall, our results provide some important evidence for the relationship among organizational practices. First, we reveal the crucial role of organizational innovation by providing empirical evidence in favour of the impact of complementary organizational practice management on raising firms' innovation, which also offers support for previous theoretical studies (Teece, 1986; Stieglitz and Heine, 2007).

Second, the patterns of complementarity among organizational practices differ according to the type of innovation (product or process), though some similarities also arose. For example, the joint implementation of knowledge management and workplace organization is substitutable in terms of probability to innovate in products, and it is complementary in terms of the probability to be a process innovator. Therefore, the two types of innovation are subject to different organizational management tools.

Third, the pattern of complementarity across organizational practices differs according to whether the firm is in the first or a later stage of its innovation process. Whereas complementarity among organizational practices seems to be more frequent for product innovation performance, the results for the propensity to innovate in products indicate multiple substitutable relationships or else inconclusive evidence. Business practices, when implemented simultaneously with knowledge management, workplace organization or external relations, pay off more than an isolated adoption in terms of product innovation performance. However, we find a substitutable relationship between business practices and workplace organization for the propensity to innovate. As a logical explanation, we propose that business practices *per se* do not help firms become innovators (i.e. other determinants are much more important). Instead, such practices are key when it comes to the success of innovative products: supply chain management ensures a management-efficient relationship with suppliers and customers, TQM offers value to consumers by enhancing the quality of products and lean management may contribute to lowering product costs, for example.

These results highlight the complexity of managing organizational practices to increase firms' innovation. They also highlight the combinations of organizational innovation practices that reinforce technological innovation performance. Some practices should be adopted simultaneously to achieve an optimal effect, whereas others are productive on their own, and still others are counterproductive. Managers therefore must be aware of the various effects of organizational innovation practices for technological innovation. Studying the relationships among individual elements or factors, and organizational innovation practices in particular, therefore offers valuable insights (Ennen and Richter, 2010). The present study can help firms allocate their limited resources to appropriate organizational innovation practices to enhance their subsequent technological innovation, especially by combining knowledge management and other organizational innovations appropriately.

Finally, our study is not exempted from limitations, and the empirical evidence we offer should be considered preliminary for several reasons. First, the theoretical framework for complementarities in organizational innovation remains under construction; research has focused almost exclusively on the complementarities between technological innovation on one hand and work and human resource practices on the other hand. Second, as Armbruster *et al.* (2008) suggested, it would be interesting to compare our results with other large-scale surveys that use different measures of organizational and technological innovations, to generalize our results to other types of organizational practices. This extension could help solve the issue of partial overlap between some of the sub-organizational dimensions contained in the CIS categories.[7] Third, our results are static in nature and tentative; causal directions cannot be established in the absence of longitudinal dynamic studies. Therefore, the question of unobserved heterogeneity cannot be addressed with our static, quantitative data. The definition and categories for organizational innovation have also changed with each CIS survey, and CIS6 is the only one to isolate knowledge management practices. Additional research might address this gap by using a dynamic, panel data model to analyse complementarities between technological and organizational – or more generally speaking, nontechnological – innovations. Fourth, this study focused on organizational strategies and their complementary effects on technological innovation. Our mixed results are therefore partly due to the limited number of organizational practices that we take into account. Further studies could include a wider set of nontechnological innovation practices, such as marketing, management or strategic innovations, together with resources, strategies and external factors (e.g. demand conditions, institutional environment; cf. Ennen and Richter, 2010), to reflect the original idea of the supermodular modern manufacturing firm (Milgrom and Roberts, 1990). A study of multiple elements should yield more complementarity effects, which are largely system-specific phenomena (Ennen and Richter, 2010). Our present analysis represents a small step along the path to achieving greater knowledge about the variety of innovation patterns and complementarities, especially between organizational and technological innovations. Much work remains to be able to explicate the complementary effects of different types of innovation.

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Appendix A. Definition of Variables

Variables	Description
Innovation performance	Percentage of the total turnover in 2006 from goods and service innovations introduced during 2004 to 2006 that are new to the firm
Propensity to innovate in products	Equal to 1 if the firm introduced new or significantly improved goods or/and services during the three years 2004 to 2006, 0 otherwise
Propensity to innovate in processes	Equal to 1 if the firm introduced new or significantly improved production processes, distribution methods, or support activity for goods or services during the three years 2004 to 2006, 0 otherwise
Organizational innovation practices	
Business practices	Equal to 1 if the firm introduced new business practices for organizing work or procedures (i.e. supply chain, business re-engineering, lean production, quality management), 0 otherwise
Knowledge management	Equal to 1 if the firm introduced new knowledge management systems to use or exchange better information, knowledge, skills within the firm or to collect and interpret information from outside the firm, 0 otherwise
Workplace organization	Equal to 1 if the firm introduced new methods of workplace organization for distributing responsibilities and decision making (team work, decentralization, integration or de-integration of departments), 0 otherwise
External relations	Equal to 1 if the firm introduced new methods of organizing external relations with other firms or public institutions (partnerships, outsourcing, subcontracting), 0 otherwise
Innovation activities	
R&D intensity	Sum of expenditures for intramural (in-house) R&D and extramural R&D in 2006 divided by the total turnover in 2006
Competition context	
Competition intensity	Rate the degree of competition of the market on a Likert scale from 0 (no effective competition) to 3 (very intensive)
Appropriability	
Formal protection	Equal to 1 if the score for the importance of formal protection method patents, trademarks, registration of design patterns or copyrights is 'crucial' and 0 otherwise
Strategic protection	Equal to 1 if the score for the importance of strategic protection method secrecy, complexity of design or lead-time advantage over competitors is 'crucial' and 0 otherwise
Size, group, sector	
Size	Logarithm of the number of employees
Group belonging	Equal to 1 if not part of a group (reference); equal to 2 if part of a national enterprise group; equal to 3 if part of a European enterprise group; equal to 4 if part of an extra-European enterprise group
Sectors	High and medium high-tech manufacturing industry; medium low-tech manufacturing industry; low-tech manufacturing industry; transport and communication; financial intermediation; computer activities; R&D – engineering activities and consultancy, technical testing and analysis and wholesale trade (reference)

Appendix B. Correlation between Organizational Practices ('adoption' Approach)

The intuition for this approach is based on the idea that complementarities create a force in favour of a positive correlation between two activities. If alternative activities are complementary, we would expect rationally behaving firms to exploit this opportunity, investing in these activities at the same time and in the same direction. However, Athey and Stern (1998) noted that two activities could be correlated without being complements and that a potential correlation may be hidden by the influence of a common set of exogenous factors. To address this problem, we calculated the conditional correlations on the basis of the residuals of the reduced-form regressions of the activities on a common set of exogenous variables. The presence of positive (negative) conditional correlation coefficients may imply complementarity (substitutability) between two activities.

This approach is the simplest and thus the most popular among empirical researchers to test for complementarity (Arora and Gambardella, 1990; Ichniowski *et al.*, 1997; Galia and Legros, 2004; Bocquet *et al.*, 2007). Its advantage is that it provides supportive evidence of complementarity if activities are adopted simultaneously, without requiring any performance measure. Despite this advantage and its relatively simple implementation, it does not provide a sufficient condition to conclude that a complementarity relationship exists between activities. Complementarity instead implies, under some conditions, a positive correlation; the reverse is not always true (Catozzella and Vivarelli, 2007).

We evaluate the complementary relations between different organizational practices by exploring the factors that determine the introduction of different organizational innovation practices, conditional on a set of observable characteristics related to the firms. We perform a multivariate probit model that includes four equations to estimate the four organizational practices. With this method, we can investigate the correlation between organizational practices, conditional on a set of explanatory variables.

The results for the multivariate probit model for the complete sample of 568 observations are provided in Table A1. Using this estimation, we computed the conditional pairwise correlations among the residuals of the four practices (see Table A2). After controlling the firm-specific effects, the correlation coefficients became positive and highly significant. These results are similar for unconditional correlations across the four practices (see Table A3). The correlation coefficient is particularly high between business practices and knowledge management, as well as between workplace organization and knowledge management. Overall, the adoption approach therefore provides some suggestive evidence of complementarity across the four considered organizational practices.

Table A1. Results of the multivariate probit model for organizational practices

	Business practices	Knowledge management	Workplace organization	External relations
Intensity of competition	0.131*	0.201**	0.096	0.144*
	(0.078)	(0.080)	(0.074)	(0.086)
Size	0.249***	0.153***	0.185***	0.169***
	(0.051)	(0.048)	(0.049)	(0.051)
Belonging to Luxembourgish group	0.250	0.351**	−0.028	0.235
	(0.163)	(0.161)	(0.160)	(0.168)
Belonging to European group	0.049	0.064	0.053	−0.029
	(0.148)	(0.148)	(0.142)	(0.157)
Belonging to other country group	0.108	0.212	0.229	−0.256
	(0.206)	(0.203)	(0.201)	0.228
High and medium high technology industry	−0.007	−0.279	−0.010	0.259
	(0.228)	(0.229)	(0.219)	(0.236)
Medium technology industry	−0.159	−0.378*	−0.207	−0.371
	(0.212	0.211	(0.207)	(0.242)
Low technology industry	0.070	−0.210	0.137	−0.155
	(0.227)	(0.227)	(0.218)	(0.246)
Transport and communication	−0.433**	−0.420**	−0.362*	−0.076
	(0.203)	(0.201)	(0.194)	(0.216)
Financial intermediations	0.127	0.046	0.026	0.116
	(0.220)	(0.216)	(0.212)	(0.232)
Computer activities	0.329	0.566**	0.046	0.365
	(0.242)	(0.243)	(0.237)	(0.260)
R&D – engineering activities and consultancy	0.177	0.116	−0.046	0.115
	(0.245)	(0.247)	(0.244)	(0.270)
Intercept	−1.669***	−1.723***	−1.259***	−2.017***
	(0.350)	(0.355)	(0.333)	(0.385)
Number of observations	568			
Log likelihood	–1132.25			
Wald $\chi^2(48)$	112.31 (.000)***			

Notes: *, ** and *** denote significance at the levels of 10%, 5% and 1%. *p*-Values are given in parentheses.

Table A2. Conditional correlations between organizational practices

	Business practices	Knowledge management	Workplace organization	External relations
Business practices	1.000			
Knowledge management	0.730***	1.000		
Workplace organization	0.661***	0.730***	1.000	
External relations	0.523***	0.520***	0.601***	1.000

Note: *** denotes significant at 1% level.

Table A3. Unconditional pairwise correlations between organizational practices

	Business practices	Knowledge management	Workplace organization	External relations
Business practices	1.00			
Knowledge management	0.54	1.00		
Workplace organization	0.47	0.48	1.00	
External relations	0.32	0.26	0.35	1.00