The Fateful Triangle

Complementarities in performance between Product, Process and Organizational Innovation in France and the UK

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Abstract: This paper explores the relationships among product, process and organizational innovation, examining the *complementarities-in-performance* between these forms of innovation, within a supermodularity framework. Drawing upon two rich samples of French and UK manufacturing firms using CIS4 (2002-2004), we explore whether firms can find a beneficial interplay between different forms of innovation. Since unconditional tests are often inconclusive about these complementarities, we implement a new procedure involving a pairwise relation conditional on the presence/absence of a third form. Using this approach, we find complementarities between product and process innovations in French and UK firms and between organization and product innovations in French firms, but no complementarities between all three forms of innovation. Using different sub-samples, we show that the presence of complementarities depends on the national context as well as on firm size and firm capabilities, which gives support to the contingency perspective.

Keywords: Innovation, Product Innovation, Process Innovation, Organizational Innovation Complementarities, Supermodularity, UK, France

JEL codes: C12, D24, L25, O31

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1. Introduction

This paper explores the relationship between product, process and organizational innovations in order to better understand the complementarities between different forms of innovation. Milgrom and Roberts's (1990, 1995) seminal contributions provoked increased research interest in the complementarities in economics and management. This body of work explores conditions when the sum is more than its parts, and examines the beneficial interplay between different parts in a system (Athey & Stern, 1998). The complementarities perspective does not constitute a theory of organizational design or performance, but rather is an approach that provides a better understanding of relational phenomena and how relationships between parts of a system create more value than the system's individual elements (Ennen & Richter, 2010). The complementarities perspective helps to enrich our understanding of how different practices and strategies are combined and recombined, and how such combinations shape subsequent performance.

Complementarities research uses two broad approaches to measure and understand complementarities: we term them *complementarities-in-use* and *complementarities-in-performance*. *Complementarities-in-use* arise from the linking between two sets of activities such that employment of one practice often requires the addition of some other practice. In this case, there is a good fit between these practices, suggesting a mutual and beneficial interaction. Researchers investigating complementarities in use have sought to identify relatedness in the use of different practices and to show that certain practices tend often to be linked. *Complementarities-in-performance* explores the effects on performance of the use of different practices in combination. This group of studies directly tests the economic value to the firm of combining different activities or practices, and shows that their joint application can produce economic benefits that are greater than the individual parts.

Using UK and French Community Innovation Survey 2005 data, we explore the effects on performance of the presence of different combinations of three forms of innovation. We test for complementarity by applying a supermodularity framework and proxying performance by sales per employee. Our approach builds on techniques developed in Mohnen and Röller (2005) and implemented by Leiponen (2005), Cassiman and Veugelers (2006), Cozzarin and Percival (2006) and Miravete and Pernias (2006). To test these complementarities, we implement a conditional test procedure involving pairwise relations conditional on the presence/absence of the third form. We investigate the complementarities between the different forms of innovation: product, process and organization and then explore differences across sub-samples from two countries, from different size groups, and among high-R&D and low-R&D intensive firms. The results show that complementarities between innovation forms are highly contingent. We find that firms derive benefits from the combination of product and process innovations, and from the combination of organizational and product innovations, but gain no advantage from a combination of all three forms of innovation. We show also that the national context and firm characteristics matter. UK firms appear less able than French firms to exploit the complementarities between different forms of innovation, and smaller firms and less R&D intensive firms are less able to profit from the complementarities between different forms of innovation than large firms and R&D intensive firms. Our paper is among the firsts to investigate simultaneously the complementarities between technological and organizational innovations within the supermodularity framework. The results help to enrich the understanding of the relations between different forms of innovation obtained by previous research methodologies (Schmidt and Rammer, 2007; Mol and Birkinshaw, 2009; Battisti and Stoneman, 2010; and Evangelista and Vezzani, 2010).

The structure of the paper is then as follows. The section 2 presents the evolution of the literature on complementarities and the associated methodologies. Section 3 describes the data set and the econometric methodology and section 4 the results. A final section concludes.

2. Complementarities in the innovation literature

2.1 The classical literature on complementarities among innovations

The recent focus in the innovation literature on complementarities is not new. Since

Schumpeter (1934), it has been widely acknowledged that there are strong complementarities between forms of innovation. For example, innovation scholars have highlighted that radical innovations often involve changes in products and in production processes (Freeman & Soete, 1997; Utterback, 1994) as well as changes to the marketing, delivery and geographic scope of sets of production or service activities. This characteristic of innovation suggests that studies that focus on one form of innovation, for example product, process or organization innovation may overlook important relationships between these forms. In order for the firm to benefit from innovation it may be necessary to make changes to other parts of its innovation efforts, including the system of production or delivery and the organizational structure that supports the innovation (Pisano, 1990). The importance of different forms of innovation is reflected in Teece's (1986) profiting from innovation framework, which emphasizes that the returns from innovation usually accrue to organizations that hold valuable and rare complementary assets. Organizational coherence is critical to ensure the benefits of complementarity, but the complexity of a complementarity strategy has also the advantage of protecting against imitation and may provide a lasting competitive advantage (see Rivkin (2000)).

Empirical research on the complementarities between different forms of innovation is being enabled by data provided by the Community Innovation Surveys. Several studies focus on the *complementarities-in-use* between product and process innovation (Martínez-Ros & Labeaga, 2009) and show that new products may require changes to production processes or vice-versa. For a sample of UK manufacturing firms, Reichstein and Salter (2006) found that the overlap between the two forms of innovation was greatest when the level of novelty of the innovations was high. However, their methodology has some limitations since it is based on correlation among residuals. These limitations include omitted variables and endogeneity problems, and lack of evidence of the impact of these combinations of innovations on performance (Athey & Stern, 1998).

In 2005, the CIS3 collected information on a wider range of innovative efforts, renewing research interest in the relationship between product/process innovation and 'non-technological' innovation. According to the Oslo manual (OECD, 2005), non-technological innovation covers "new or significantly amended forms of organization, business structures or practices, aimed at step changes in internal efficiency or effectiveness or in approaching markets and customers". The concept of 'non-technological innovation' remains associated with 'organizational' or 'managerial' innovation, and has spawned a wide range of research on its causes and consequences and its relation to other forms of innovations (see Schmidt and Rammer, 2007; Ballot, Fakhfakh, Galia and Salter, 2011; 2013).

Recently researchers have focused on *complementarities-in-performance* using interaction terms and cluster methodologies. Some studies investigate interaction terms in a performance equation.[1] Schmidt and Rammer (2007) use German CIS4 data to investigate the link between non-technological innovation and profit margins. They find that the propensity to introduce technological and non-technological innovations is similar and that these forms are closely related. They find also that the effects of non-technological innovation on the firm's profit margins are much smaller than the effects of technological innovation, but that the combination of technological and non-technological innovation has a positive impact on profit.

Sapprasert and Clausen (2012) explore the impact of organizational innovation for a sample of Norwegian firms, using information from two waves of the CIS and published data on performance. They find that "firms can better reap the rewards of reorganization by jointly reorganizing with technological innovation", indicating that there is strong complementarity between organizational and technological innovation (Sapprasert and Clausen 2012: 1298). They use a dummy for the joint occurrence of technological and non-technological innovation to capture this complementarity, and the associated outcome is a score based on six effects of organizational innovation. However, this approach of using interaction terms between more than two forms of innovation may not be not suited to testing for complementarities because it requires to take into account all possible interactions, which can lead to severe multi-collinearity problems and make interpretation difficult.

Cluster analysis is another methodology frequently used to study complementarities in innovation. Firms are grouped according to form of innovation, with or without factor analysis. Using this approach, Battisti and Stoneman (2010) explore the relationships among different forms of innovation. They find that organizational innovation plays an important role in shaping the innovative activity in UK firms. Their two-step cluster analysis shows that firms

[1] For purposes of brevity, we do not include work on the effects of different forms of innovation (including non-technological innovation) on performance that does not consider formal interactions between these forms of innovations (Mol and Birkinshaw, 2009) or when it excludes technological innovation (Shaparov and Kattuman, 2010).

that are innovative in one dimension tend to be more innovative in other dimensions, suggesting a degree of complementarity between different forms of innovation. A study of Spanish firms by Hervas-Oliver *et al.* (2012) also finds evidence that the development of organizational innovations increases amplify the likelihood of introducing a process innovation. Evangelista and Vezzani (2010) in a study of Italian firms explore the performance of firms using four different strategies of innovation, which correspond to different combinations of product, process and organizational innovations. Although they do not formally test for complementarities, they find that those firms whose development strategies involve more than one form of innovation grow faster than those firms that concentrate on one form of innovation. Evangelista and Vezzani (2012) explore the impact of technological and organizational innovations on employment in six EU countries, exploiting CIS4 microdata and using a clustering method. They find that a combination of product, process and organizational innovation has the strongest impact on employment.

Although useful, the results of these cluster and factor approaches discussed above may fail to directly test the effect of complementarities on performance. According to Shaparov and Kattuman (2010), "[t]he clusters or factors are linear combinations of the underlying practice variables and their use as explanatory variables in a performance equation will not capture any non-linear interaction effects between practices". However, it is these non-linear interaction effects that are at the heart of the complementarity concept.

2.2 The supermodularity approach

To overcome the limitations associated with the approaches discussed above, we use a methodology based on the supermodularity framework. Milgrom and Roberts (1990) propose mathematical tools based on lattice theory (Topkis, 1978; 1998) to develop economic models of Edgeworth complementarity and Milgrom and Roberts (1995) propose a simple model to explain the move from the Fordist ("mass production") firm to the "modern" lean, flexible firm. Complementarity implies that the main factors have to switch together to very different values, including the extreme case where new factors appear (such as the flexible machines) in order to make the new organization of the firm more efficient than the Fordist firm.

A major problem with the analysis of complementarities in empirical analysis was the need for the divisibility of the choice variables, the smoothness and continuity of the objective function. This was a major obstacle for considering changes in organisation and introduction of innovations, which are often discrete. Milgrom and Roberts (1990) show that lattice theory refers to the possibility of ordering: doing more than one thing increases the returns to doing more of another. Smoothness, concavity and even continuity are not necessary. In the simplest case in which two factors x and y take two values, 0 and 1, the complementarities are expressed by the following condition on the objective function f(x, y):

$$f(1,1) - f(1,0) > f(0,1) - f(0,0)$$

Such a function is said to be strictly supermodular in x and y.

This framework has been applied to find complementarities between practices in a range of settings, including human resources management, strategy, resources, knowledge management, advanced manufacturing technology (see Ennen & Richter, 2010 for a summary of this literature).

In the literature on innovation, two seminal empirical papers have implemented the methodology of supermodularity in the field of innovation, although they have not dealt with the complementarities between forms of innovation. Mohnen and Röller's (2005) study examines the factors that affect innovation, using micro data on four countries from CIS1 for 1992. They consider four obstacles to innovation: risk and finance, knowledge-skill within the enterprise, knowledge-skill outside the enterprise, and regulation. Their results suggest several complementarities between pairs of obstacles with the probability of becoming an innovator as the objective function, and more substituabilities if the objective function is intensity of innovation.[2] Cassiman and Veugelers's (2006) paper tests the complementarity in performance between internal R&D and external knowledge acquisition, for a sample of 269 Belgian firms. They find complementarity and show also that this complementarity has a stronger effect on performance if the sample is reduced to firms that rely heavily on basic R&D, that is, firms are more reliant on information from research institutes and universities than information from suppliers and customers.

A small number of studies exploit supermodularity methods to estimate the *complementarities-in-performance* between forms of innovation. Miravete and Pernias (2006) test for the existence of complementarity between product innovation, process innovation and scale of production (measured by output) for a set of 432 Spanish firms in the ceramic tile industry.

[2] Cozzarin and Percival (2006) and Percival and Cozzarin (2008) investigate complementarities in performance among four variables and Leiponen (2005) applies supermodularity tests to three variables, but do not deal with the different forms of innovation presented above.

They conclude that the significant association between product and process innovation is due mostly to unobserved heterogeneity. Polder, van Leeuwen, Mohnen and Raymond (2010) use the supermodularity approach in a three-step model within the CDM framework. They first explain the level of R&D expenditure and Information and Communication Technologies (ICT) usage then use a trivariate probit to explain product, process and organizational innovations by R&D and ICT. These three forms of innovations are then used in the production function, which corresponds to total factor productivity, and then the authors conduct tests for complementarities. Their model is estimated using Dutch firm data; the main result is that product and process innovations, and process and organizational innovations, are complementary, but that product and organizational innovations are substitutes.

Doran (2012), using Irish CIS 2006 data, tests the complementarities between four forms of innovation: products new to the market, products new to the firm, process innovation, and organizational innovation. Doran tests for pair-wise complementarities and substitutions and out of six possible innovative combinations, finds strict[3] complementarity for new to the market product and organizational innovations, and new to the firm product and process innovations, and weak complementarity between process and organization innovations. Doran finds no evidence of substitutability. He interprets the strict complementarities between the two distinct combinations as winning synergies. Organizational innovation is required to facilitate new to the market product innovation, while process innovation accompanies new to the firm innovation (the causality probably goes both ways). There is some logic in the fact that new to the market innovation requires some reorganization within the firm and that new to the firm innovation, which is a weaker form of innovation, in fact imitation, does not. These are interesting results, but need to be extended since the method employed raises some questions. For example, the sample size (562 firms) limits interpretation because the 16 combination forms include only a small number of firms. It is likely that very few firms will introduce innovations according a given combinatorial form. Also, tests for endogeneity of the combination forms would be helpful. Another problem is that the highest effect on performance is obtained for the ‘no innovation’ case, which is a strange result.

The present paper seeks to extend this literature in three ways. First, by implementing a new test for complementarities based on *conditional* complementarities we are able better to

[3] See Appendix 1 to the present paper for the distinction between strict and weak complementarity.

identify if and which pairs of complementarities exist, which adds to the toolkit for assessing complementarities between different forms of innovation. Second, since most studies of complementarities among forms of innovation focus on single countries, the generalizability of their findings to other institutional set-ups or national systems of innovation is unclear. Our focus on the UK and France allows us to identify what is shared (or not) in terms of complementarities across different innovation systems. Third, in examining the importance of firm size and R&D intensity as conditioning factors shaping the ability of firms to profit from complementarities, we provide a richer contextual understanding of the patterns observed in previous studies and clearer identification of some of the mechanisms that allow firms to gain from complementarities.

3. Data, variables description and econometric methodology

3.1. Data and variables description

We use data from CIS4 for France and the UK, which is a firm-level survey that ask organizations to provide information on the level and type of their innovative efforts. Although respondents are provided with definitions of innovation and examples, the survey data are based on self-reported information from firm managers and therefore contain subjective elements (OECD, 2005). CIS data are comprehensive and detailed. They cover all sectors of the private economy, and capture information on many different aspects of firm's innovative efforts and have become crucial for economics and management studies on understanding the innovation process (Smith, 2005; Mairesse & Mohnen, 2010).

The 2005 UK Innovation Survey was implemented by the Office of National Statistics in April 2005, covering the 2002-2004 period, and sent to 28,000 firms. Although voluntary, it received 16,446 responses, a response rate of 58%. The sample was based on a census of firms with over 250 employees and a stratified sample of small and medium sized firms. It covers only firms with over 10 employees. Overall, the pattern of responses mirrors that of the original population in terms of size, sector and regional distribution

CIS4 in France was carried out by SESSI (Ministry of Economics, Finances and Industry) in 2005 and covers the 2002-2004 period. Like the UK survey, it focused on firms with over 10 employees, a stratified sample of firms under 250 employees and census of large firms. The survey population includes 25,000 firms, drawn from the manufacturing, services and construction sectors. Response to the CIS is mandatory in France and the response rate was 86%, including 8,438 firms from manufacturing sector. As expected, with such a high response rate, the sample closely mirrors the original population.

In order to ensure consistency, we focus on only manufacturing firms, as service firms appear to have different patterns of innovation. In total, we have 9,318 firms, with 3,627 for the UK and 5,691 for France, for the analysis. When we come to the complementarity tests, we only include the subset of firms that were active in technological innovation (either innovating, trying or abandoning trying), as only firms active in technological innovations completed the entire French questionnaire. We are then left with 5215 firms, 2014 for the UK and 3201 for France. Although the CIS surveys are based on a core questionnaire, there are slight differences between the UK and French versions. In the case of overlapping information, wherever possible, we have developed mirrored variables across the two surveys. In some cases this is not straightforward since the nature of the questions differs, especially for organizational innovation (see discussion below).

We focus on three innovation forms: product, process and organizational innovation (see Table 1 for statistics on the variables). Product innovation was taken from a question on both surveys that asked whether the firm had developed a product that was new to their market. This form of product innovation is closer to the definition of innovation than a new-to-the-firm innovation, which is considered to be imitation. A process innovation is defined as the use of new or significantly improved methods for the production or supply of a good or service.

To measure organizational innovation, our approach builds on the techniques in Schmidt and Rammer (2007) and Mol and Birkinshaw (2009). Organizational innovation is measured using the responses to questions on the French and UK CIS about ‘wider innovation’ (UK) and ‘organizational and marketing innovations’ (France).

In the UK questionnaire, ‘wider innovation’ is meant to refer to “new or significantly amended forms of organization, business structures or practices, aimed at step changes in internal efficiency or effectiveness or in approaching markets and customers”. Respondents are provided with four items; we exploit three of these items that correspond to the items in the

French survey. They are: 'implementation of advanced management techniques, *e.g.* knowledge management systems, Investors in People'; 'implementation of major changes to your organizational structure'; and 'implementation of changes in marketing concepts or strategies', with examples for each. The French survey goes into more detail on 'organizational and marketing innovations', and includes nine items covering different aspects of this broad concept. We used four of these nine items: 'a new or significantly improved system of knowledge management', 'important modifications of work organization within the firm', 'significant modification design and packaging of goods or services' and 'new methods or significant modifications of sales or distribution methods', which match with the items in the UK survey. Firms doing any of these four actions are considered 'organizational innovators'.

We used this broad measure of organizational innovation to ensure that the action was consistent with the approach used in the CIS for product and process innovation. In the survey, product and process innovation are also defined broadly and firms need to declare only a single innovation in either category over the three-year period to be labelled respectively as a product or a process innovator. We adopted this strategy also for pragmatic reasons to help to ensure a reasonable number of firms for each of our eight potential combinations of forms of innovation.

The measure of organizational innovation in the CIS is a rather simplistic and incomplete measure of a broad and rich concept (Damanpour & Evan, 1984; Damanpour, 1991; Birkinshaw, Hamel & Mol, 2008). Also, the 2nd version of the Oslo Manual (OECD, 1997) and many policy documents (OECD, 2010) refer to this form of innovation as 'non-technological innovation', which is somewhat confusing since it is defining something by what it is not rather than what it is.

Our measure of firm performance is based on the sales per employee in 2004, the last year covered by the survey, in order to reduce the possibility of a simultaneity bias. Although highly imperfect as a measure of performance, it is used in many other studies of the effects of innovation on performance using CIS data (Crépon, Duguet & Mairesse, 1998; Griffith *et al.*, 2006; Roper, Du & Love, 2008).

We also include a number of control variables to exclude alternative explanations. First, since large firms are likely to be more productive than smaller firms, we control for firm size measured as the log of employment. Second, research shows that R&D expenditure is often associated with productivity so we include a measure of the firm's R&D intensity for 2004. Third, investment in training may allow firms to increase performance by upgrading employee skills. We introduce a control variable for whether the firm invests in staff training. Fourth, we capture whether the firm has formal collaborations for innovation. Such relationships may allow the firm to draw on the resources and capabilities of other organizations and have been shown to shape firms' abilities to profit from innovation. Fifth, researchers have shown that openness to external sources improves the firm's ability to innovate. Following Laursen and Salter (2006), we introduce a control variable for external sources of knowledge in the innovation process. This variable is based on the ten common sources of external knowledge in the two surveys. Sixth, we capture the financial, knowledge and market obstacles that firms face in their innovation activities. These variables are constructed based on the approach in Mohnen & Röller (2005), by creating three groups of two items from the question on the CIS about the barriers to innovation. The firm is assigned 1 if it indicates that this type of obstacle was an 'important' or a 'very important' barrier. Seventh, to profit from innovations firms need take steps to protect their knowledge. We include two control variables to capture strategic and legal methods of protection used by the firm. Both variables are constructed by counting the number of different mechanisms used by a firm for strategic and legal types of appropriability. Eighth, research shows that international-oriented firms are higher performers in terms of innovation and productivity than firms that focus on local or domestic markets. We include a control for whether the firm is involved in the international market. Ninth, we control for whether the firm is part of a large group, which may allow it to draw on the resources and knowledge of other group members not available to independent firms, which may result in better performance. Tenth, we control for industry differences by including ten manufacturing sector dummies.

3.2. Econometric Methodology: testing complementarity-in-performance

Our approach to investigating the complementarities among forms of innovation is based on the *complementarity-in-performance concept* within the supermodularity framework. We regress our performance measure on the eight combinations of innovations. These are defined from (0, 0, 0), when none of the three forms of innovation (product, process and organization) is introduced; to (1, 1, 1) where all the three forms of innovation are introduced together. The estimated coefficients of these combinations are used to perform the complementarity (substitutability) tests. We consider the possible endogeneity of these combinations of innovation forms.

A supermodularity test is implemented in order to test for *complementarity-in-performance* between the three forms of innovations.

There is a risk of selection bias because subsequent estimations are on the sub-sample composed of (product and/or process) innovating firms, firms that are trying to innovate, and firms that have tried and abandoned, so that the decision to engage in technological innovation cannot be considered as exogenous. The choice of this sub-sample is dictated by the lack of information on key explanatory variables for those firms that did not innovate and did not try to introduce a product or process innovation, according to the French survey. This may lead to a bias in our results. We use a Heckman regression to explore the effects of each of the eight innovation combinations on firm performance. Our selection here is based on firms that are active in technological innovation (either innovating, trying to innovate or abandoning efforts to innovate) versus firms that are not active in technological innovation. Building on Mairesse and Mohnen (2005) the selection equation includes group membership (group), selling in the international market, and the three kinds of obstacles to innovation (financial, knowledge or marketing). This guarantees the exclusion restrictions. In all the specifications used, the Likelihood Ratio (LR) test rejects the absence of selection problem. This justifies use of the Heckman selection procedure.

We perform an endogeneity test of the combinations of forms of innovation using a regression based Hausman test (Wooldridge 2002). We run a multinomial logit on the exclusive combinations of innovation forms by controlling for selectivity using a Mill’s ratio, where R&D, training, size, cooperation, openness, obstacles and appropriability are the explanatory variables. The residuals associated with each combination are added to the performance equation using a Mill’s ratio. We tested for the joint significance of these residuals and found no endogeneity. When not controlling for the selection, we find endogeneity. The somewhat surprising result of no endogeneity is obtained mainly because participation in technological innovation activity is already controlled for.

We estimate a linear model in which the dependent variable proxies for firm performance, that is, log of sales per employee. This performance specification allows us to test for complementarity between the three forms of innovation using the supermodularity approach.

We test first for *unconditional complementarity* for each pair of innovation forms, that is, whatever the status of the third form of innovation (presence or absence). Second, we implement a new approach by testing for *conditional complementarity* for each pair of innovation forms, that is, distinguishing between presence and absence of the third form of innovation. In the case of both tests, we test also for substitutability for each pair of innovation forms.

3.3 Unconditional complementarity

To test for supermodularity in each pair of innovations, that is, [product and process], [product and organization] and [process and organization], we need to test for a pair of inequality restrictions. For example, to test for complementarity between product and process innovation, we need to test the following two restriction constraints simultaneously (*R1* when organizational innovation is absent and *R2* when organizational innovation is present):

$$H0: \begin{cases} W110+W000-W010-W100 > 0 \text{ R1 (absence of organizational innovation)} \\ W111+W001-W011-W101 > 0 \text{ R2 (presence of organizational innovation)} \end{cases}$$

$$H1: \begin{cases} W110+W000-W010-W100 \leq 0 \text{ (absence of organizational innovation)} \\ W111+W001-W011-W101 \leq 0 \text{ (presence of organizational innovation)} \end{cases}$$

If the first two restrictions are simultaneously accepted, the performance function is supermodular in product and process. For the reasons described below, in this paper we say that product and process are *unconditional complements*. In other words, product and process complementarity occurs independently of the absence or presence of organizational innovation.

We have also to test for *unconditional complementarities* for the two other pairs of innovations forms [product and organization] and [process and organization]. To test for *unconditional substitutability* between product and process innovation, we have to test the same restriction constraints as above by replacing '>' with '<' in H0.

In order to test these pairs of inequality conditions for *unconditional complementarity* and for *unconditional substitutability* we apply the distance or Wald test. Like Mohnen and Röller (2005), we follow Kodde and Palm (1986) who compute lower and upper bound critical values for this test. As indicated in Appendix 1, critical values for the two constraints are: the 5% level, lower bound (df=1) = 2.706 and upper bound (df=2) = 5.138; and the 1% level, lower bound (df=1) = 5.412 and upper bound (df=2) = 8.273. We accept H0 if the LR statistic is smaller than the lower bound. We reject H0 if the LR statistic is larger than the upper bound. If the LR statistic is between bounds, the outcome is within the region of uncertainty.

To conclude that complementarity or substitutability are present, we have to test separately for supermodularity and submodularity and combine the outcomes of these tests. According to Appendix 1, if we accept supermodularity while simultaneously rejecting submodularity, then we can say there is strict complementarity. If supermodularity is supported and submodularity is in the region of doubt, there is weak complementarity. Similarly, if submodularity is supported and supermodularity is rejected, there is strict substitutability. If submodularity is supported and supermodularity is in the region of uncertainty, there is weak substitutability. In all three remaining cases, the test is inconclusive.

3.4 Conditional complementarity

In order to overcome the inconclusive interpretations of *unconditional* tests in many of our samples, we apply a novel and more detailed test for complementarity, that is, *conditional complementarity*, which we define as complementarity between two forms of innovation conditional on the introduction or not of the third form of innovation. For example, testing for *conditional complementarity* between product and process implies testing complementarity conditional on the absence and, separately, on the presence of organizational innovation.

In that case, either of the two following restrictions *C1* or *C2* must be accepted:

$$C1: \begin{cases} H0: W110+W000-W010-W100 > 0 \text{ (absence of organizational innovation)} \\ H1: W110+W000-W010-W100 \leq 0 \text{ (absence of organizational innovation)} \end{cases}$$

$$C2: \begin{cases} H0: W111+W001-W011-W101 > 0 \text{ (presence of organizational innovation)} \\ H1: W111+W001-W011-W101 \leq 0 \text{ (presence of organizational innovation)} \end{cases}$$

As we need to test the complementarities for each other pair of innovations forms, we have to test for conditional complementarity between product and organizational innovation conditional on the absence or presence of process innovation. This applies also to process and organizational innovation. We applied similar methods to test for *conditional substitutability*. Based on the results of these tests for *conditional complementarity* and *conditional substitutability*, we can provide a visual representation of the multiple relationships (see triangles in Figure 1).

--- *Insert Figure 1 about here* ---

4. Results

Table 1 shows that French firms, on average, are slightly more productive and are larger and invest more in R&D than UK firms. Cooperation is more in common among French firms than among UK firms and French firms face more financial obstacles than UK firms. French firms are more active in the international market and more often belong to a group. UK firms are more likely to provide training for their employees, access a broader range of sources for innovation, and tend to protect their innovations more aggressively.

--- *Insert Table 1 about here* ---

Among the three forms of innovation (Table 2), process innovation is the most frequent in the pooled sample (68% of firms introduced process innovations), followed by . organizational innovation (64% of firms) and product innovation (51%). We found important differences in innovative performance between France and the UK. In particular, French firms are more liable to introduce process innovations than UK firms: three out of four French firms introduced process innovation during the period compared to only half of UK firms, while 61% of UK firms and 66% of French firms introduced organizational innovation.

--- *Insert Table 2 about here* ---

The simultaneous introduction of all three forms of innovation, was the most frequent of the exclusive combinations of innovation forms, which suggests some degree of complementarity among product, process and organization innovation. This applied to 26% of firms in the pooled sample, 21% of UK firms and 30% of French firms. The next most frequent combination is process and organizational innovations - 21%, 16% and 24% respectively for the pooled, UK and French samples. Introduction of no innovations applies to 8.5% of the pooled sample, 11% of the UK sample and 6.5% of the French sample. The percentage of firms, introducing only one form of innovation is only 5% to 12% in each country. The most frequent single form of innovation in both the UK and France is process innovation.

The results of the performance function estimation - (log of) performance measured by sales per employee, regressed on a set of explanatory variables plus the eight combinations of innovation are presented in Table 3. All the exclusive forms of innovation combinations have a positive and significant effect on performance. The mere attempt (not successful) to introduce a technological innovation (W000) has a positive effect; introducing all forms of innovation at the same time (W111) has the greatest effect, for each country. The results do not show a monotonic increase in performance with the addition of forms of innovation. Firm size has no influence, probably suggesting constant returns to scale, while R&D has the expected positive effect on performance. Financial and knowledge obstacles have a negative sign but are not always significant, while market obstacles are always significant and have a negative effect. Appropriability methods appear to have no effect on performance.

--- Insert Table 3 about here ---

Complementarities-in-performance tests are based on the estimated coefficients W_{ijk} and the results are presented in Table 4. We briefly discuss the results of the *unconditional* tests since they are mostly inconclusive, and then focus on the *conditional* tests. We first apply the traditional *unconditional* Kodde-Palm LR test (see Appendix 2-1 and 2-2). For the samples at the Nation level, the tests are inconclusive. When we consider samples split by the types of firms (large / small and medium firms; and low R&D / high R&D intensive firms), we only find one result, namely weak substitution between process and organizational innovations for large UK firms (Appendix 2-2). We do not find the classic complementarity between product and process innovation.

--- Insert Table 4 about here ---

These mostly inconclusive results for pairwise relations allow us not to test for *unconditional* complementarity and substitutability among the three forms of innovation occurring simultaneously, since for global supermodularity (submodularity) to hold, the three pairwise complementarities (substitutions) are necessary. This is in line with the literature that finds no significant results for more than two factors. These findings suggest that *conditional* tests might be more informative.

Turning to the relationships among product, process and organization, the results are presented graphically by triangles in Figure 2 and in detail in Table 4. For the UK case, we can identify three main results. First, product and process innovation appear to be conditional complements if (and only if) organizational innovation is not introduced. This result is consistent with previous research showing complementarity between product and process innovations. It can be interpreted as the technical necessity, in many cases, of introducing a process innovation in order to develop a product that is new to the market. However, it appears that simultaneous organizational change is not a requisite. Second, we find no relation between product innovation and organizational innovation. Third, we find a substitution effect between process innovation and organizational innovation if the firm also introduces a product innovation. This suggests that the better performing UK firms tend to focus on product and process innovations rather than introducing all three forms of innovation. This result could be explained by the cost involved in simultaneously introducing all three forms of innovation, and/or the complexity of that enterprise.

For French firms, the results are similar for *conditional complementarities* between product and process innovation when organizational innovation is absent. Also product and organizational innovations are conditional complements if firms do not introduce process innovations. This is in the line with Chandler (1962).[4] Finally we find a substitution effect between process innovation and organizational innovation if the firm also introduces a product innovation. Hence, French firms tend to adopt one of two strategies: product/process innovation or product/organizational innovation. Neither strategy dominates.[5]

The difference between high performance innovation strategies between countries as well as among firms within a country is not a problematic result. It provides empirical confirmation of a well-established management theory, contingency theory. Contingency theory states that the most appropriate structure for a firm is the one that best fits a given operating contingency (Burns & Stalker, 1961; Mintzberg, 1981). This means that there are no ex-ante theoretical and empirical reasons to find a) global complementarity among all "positive" (*i.e.* innovation) strategies, and b) a unique best complementarity strategy for all the firms in our sample, which contradicts the main findings of the supermodularity theory.

--- *Insert Fig. 2 about here* ---

Unfortunately, the CIS data do not provide sufficient information to explore why French firms have a choice of complementarity strategies compared to UK firms. It might be that French firms, which have a long tradition of social conflict and multi-level bargaining (at the firm and /or at the industry level), require greater organizational change to accompany their technological innovations. In contrast, in the UK, managerial decisions are less influenced by labour regulations, with the result that technological innovations can be implemented without major organizational change. However, without more information on the work practices of

[4] Lam (2010) for a survey of literature on innovative organizations and typologies of firms.

[5] This can be tested using the following procedure. Recall that C1 (p. 19) correspond to the linear restriction for the conditional complementarity between product and process in the absence of organization innovation. Let

UK and French firms and more refined measures of organizational innovation, this argument remains highly speculative.

One way to explore the different results for the UK and France in more detail is to consider the samples splits - by size and by R&D intensity. This may identify contingencies associated with the complementarities between different forms of innovation. We conducted an additional analysis to determine how the complementarities among product, process and organizational innovations are shaped by the firm's resources and capabilities. We use firm size and relative R&D expenditure respectively to proxy for resources and capabilities.

In the case of firm size, we distinguish between small and medium sized firms (less than 250 employees) and large firms (more than 250 employees). Figure 3 shows that the complementarities-in-performance between the forms of innovation differ. To compare them, we count the number of each type of conditional relation for the sum of the two samples (UK, France). For small and medium firms, we find three complementarities, six non-relations and three substitutions. For large firms, we find one complementarity, eleven non-relations and no substitutions. This suggests that the patterns of firm strategies are different according to the size of the firms. The substitutions apply only to small and medium sized firms and refer to process and organizational innovations. In two out of the three cases, product innovation is also present. This can be explained by the high cost of introducing product, process and organization innovation for small and medium sized firms. In the UK, a focus on product-process innovation has the highest performance payoff for small and medium sized firms. In France, product/process combinations along with product/organization combinations provide the greatest performance benefits.

Among the corresponding conditional strategies for large firms, the pattern is different. For UK firms, but not French firms, we find process-organization innovation complementarity. It appears that large UK firms profit from a combined organizational change and process innovation strategy, and this benefit applies when product innovation is present. It is likely that the resources available to large firms in the UK are sufficient to meet the managerial costs and challenges associated with innovating across the board.

--- *Insert Fig. 3 about here* ----

C1* be the corresponding test of conditional complementarity between product and organizational innovations when there is no process innovation. Dominance is obtained by testing whether C1> (or <) C1*.

For the role of R&D capabilities in shaping the value from combinations of different forms of innovation, the results are interesting. R&D capabilities are captured by a higher/lower level of R&D expenditure per employee than the industry average, scored according to a ten-industry classification index. For the high R&D intensive firms, we find two conditional complementarities, ten non-relations, and no substitutions. For the low R&D intensive firms we find one conditional complementarity, eight non-relations, and three substitutions.

--- *Insert Fig. 4 about here* ---

The differences in strategies when measured as above show no *substitutability-in-performance* for the high R&D intensive firms, and some substitutability for the low R&D intensive firms. This is a coherent result since high R&D intensive firms probably experience higher levels of competition in their market segment and need more sophisticated innovation strategies. The choice of complements is different for France and UK, perhaps reflecting wider national differences. UK high R&D intensive firms focus on product-process innovation complementarity, while corresponding French firms favour product-organizational innovations. Low R&D intensive UK firms show no complementarity, while similar French firms favour product-organization innovations.

5. Discussion and conclusions

There is a pattern of diversity among firms in relation to the simultaneous introduction of the different forms of innovation and to their effects on performance. This suggests that no strategy is winning in all circumstances, and it seems that the effectiveness of the various strategies is dependent on the institutional context and firm characteristics.

A preliminary step in our study has been to look at the raw statistics on the exclusive combinations of innovation forms. Observation of the raw data shows that around 26% of firms in the sample introduced all three forms of innovation during the three-year period analysed, a large but not huge percentage. The second and third most frequent combinations of innovations are process-organization and process only. The no innovation category includes only 8.5% of firms which tried to innovate in product and/or process but were not successful in their innovation efforts in any form (including organization). These statistics question the simple economic theory of strategic complementarities based on Milgrom & Roberts (1990), which suggests a polarization between the two extreme strategies of all forms of innovations if the costs allow, and no innovation if they are prohibitive. CIS data show a more mixed picture of firms adopting a range of strategies based on their capabilities and environment.

The central objective of the paper is to assess *complementarities-in-performance.* We proceeded to three steps in the analysis. We estimated a performance equation using a Heckman ordinary least square to control for firms that did not try to innovate in product and/or process. The equation shows that firm performance is enhanced by any innovation effort or by a combination of innovation forms, and even more by a combination of all three forms of innovation. The results are robust to the possible presence of endogeneity of these combination forms, which we tested for but did not find. However, the higher coefficient of the combination of all forms is not proof of the complementarity effects on performance of the joint introduction of all forms of innovations. In fact, studies that use interactions terms, such as Supprasert and Clausen (2012), do not necessarily prove the complementarity effects of performance. These findings provide encouragement to proceed to formal tests for complementarities and substitutions.

The next two steps in the analysis correspond to the two types of tests for supermodularity and submodularity. In the second step, we show that *unconditional pairwise complementarities* in performance do not appear either in the national samples or in the sample splits. We find no *unconditional pairwise substitutions* except a weak substitution between process and organizational innovations for the large UK firms group. Thus, in our case, there is no global supermodularity, which is in line with Polder, van Leeuwen, Mohnen and Raymond (2010) and Doran (2012). These results also contradict interaction and clustering approaches that provide positive results for *complementarities-in-performance* from the introduction of all three forms of innovation. Our results suggest that, for many firms, the associated costs and/or the complexity involved in introducing all three forms of innovation in the same three-year period may be higher than the benefits.

The third step considers the *conditional pairwise complementarities* and *substitutes* in performance for firms introducing different combinations of innovation forms. These are summarized by the (double) triangles of pairwise relations. The first result of these tests is that no strategy of complementarity/substitution is always the most productive. However, substitutions appear to be less common than complementarities. The second result, based on the study of sub-samples, is that both the national context and the characteristics of the firm, proxied here by firm size and firm capabilities (in-house R&D relative to the sector mean) significantly influence the ability of the firm to gain from introduction of multiple forms of innovation.[6] This suggests that a contingency perspective on the benefits and costs of complementarities among different forms of innovations may be required. Moreover, the complementarities between two forms of innovation are usually conditional on the presence/absence of the third form. The third result concerns the combinations of innovations or strategies selected. Among the set of possible conditional strategies, at the national level, two strategies dominate. One strategy is based on product-process innovation, which is shown to be beneficial for both French and UK firms. Our methodology confirms the results derived from less demanding methods, such as cluster analysis (see Battisti and Stoneman, 2010 for the UK). The other strategy of introducing product and organizational innovation is beneficial for French firms (Doran (2012) finds the same effect for Irish companies).

In considering all the sub-samples, complementarities are more frequent than substitutions. We find that high R&D intensive UK firms compared to low R&D intensive firms appear to benefit more from complementarity strategies. This is in line with the idea that the former firms need more sophisticated innovation strategies to compete in the market. This difference is not significant for French firms. These results suggest reducing the focus on the presence of global complementarities in large–scale samples of national firms and concentrating on a more refined understanding of why and when firms are able to profit from different forms of innovation activity.

It would be useful to have more fine grained information on non-technological forms of innovation, described here as ‘organizational innovation’. The measures currently used by innovation surveys fail to capture the rich and diverse features of organizational innovation. Future innovation surveys should seek to refine the questions related to non-technological forms of innovation and to harmonize them with measures used for advanced human resource practices or organizational change.

There are several possibilities for future research. First, subject to data availability, firm performance could be investigated based on value added, firm growth, return on assets, survival and profits. Different combinations of forms of innovation activities may drive different

[6] R&D intensity might be a characteristics of the market segment in which the firm is competing and an element of the external context.

performance outcomes. Second, different waves of CIS surveys could be used to consider the timing of innovation forms to improve our understanding of how firms profit from the interplay among different forms of innovation. For instance, does product innovation precede process innovation? Does process innovation require subsequent organizational innovation? Third, using firm panel data would allow us to control for unobserved individual heterogeneity and should produce more robust and reliable results.

The stringent tests of complementarities on the innovation survey data improve our understanding on how and when firms would gain from introducing multiple forms of innovation. The investigation in this paper highlights the contingencies that shape the benefits and costs to firms of introducing more than one form of innovation.

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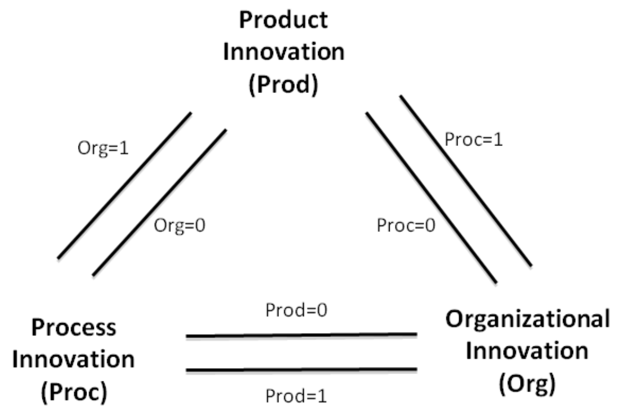


Fig. 1: Exploring the Fateful Triangle:

Testing *conditional complementarity* and *conditional substitutability*

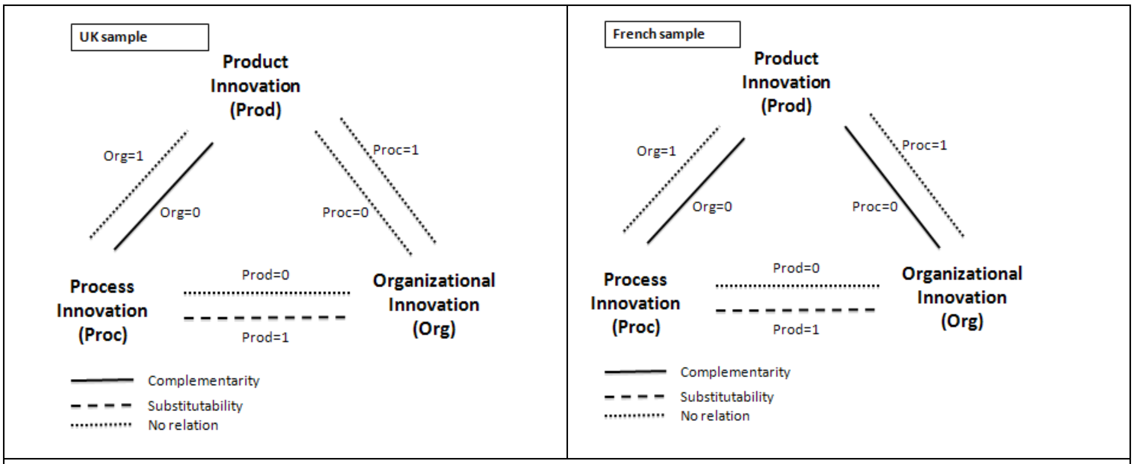


Fig. 2: Exploring the Fateful Triangle: Testing conditional *complementarities-in-performance* between forms of innovations

Table 1: Definition of variables and descriptive statistics (firms with technological innovating activities – Product, Process or Project – and all firms[1])

Name of variables	*Description*	*Pooled* 5215 firms *(9318 firms)*	*UK* 2014 firms *(3627 firms)*	*France* *3201* firms *(5691 firms)*
Product innovation	If the firm introduces a product that is new-for-the-market (0,1)	50.74 % *(28.40 %)*	49.35% *(27.40 %)*	51.61% *(29.03 %)*
Process innovation	If the firm introduces a new process (0,1)	67.69 % *(37.88 %)*	55.16% *(30.63 %)*	75.57% *(42.50 %)*
Organizational innovation	If the firm introduces an organizational innovation (0,1)	63.97 % *(46.39 %)*	60.43% *(43.64 %)*	66.20% *(48.15 %)*
Project of technological innovation	If the firm has abandoned and/or still ongoing innovation projects (0,1)	8.23 % *(4.77 %)*	11.37% *(6.58 %)*	6.44% *(3.62 %)*
Firm performance	Sales per employee (in 2004 in Euro and logs)	4.97 *(4.87)*	4.79 *(4.70)*	5.08 *(4.97)*
Size	Log of number of FTE employees	4.69 *(4.33)*	4.41 *(4.11)*	4.87 *(4.46)*
R&D	Amount of internal R&D expenditures per employee (in Euros and logs)	0.81 *(N.A.)*	0.59 *(N.A.)*	0.95 *(N.A.)*
Training	Dummy for firms investing in training for innovation (0,1)	61.82 % *(N.A.)*	65.39 % *(N.A.)*	59.58 % *(N.A.)*
Cooperation	If innovation cooperation arrangements with other firms or institutes (0,1)	42.45 % *(N.A.)*	33.11 % *(N.A.)*	48.33 % *(N.A.)*
Openness	Number of 'important' or 'very important' sources of innovation: internal, suppliers, customers, consultants competitors, universities, public research institutes, conferences, scientific and trade publications, and professional and industry associations (0-10)	4.13 *(N.A.)*	4.69 *(N.A.)*	3.78 *(N.A.)*
Financial obstacles	If lack of finance inside or outside the firm is 'very important' or 'important' (0,1)	50.64 % *(44.61 %)*	34.61 % *(31.07 %)*	60.73 % *(53.24 %)*
Knowledge obstacles	If lack of qualified personnel, lack of information on technology or lack of information on market are 'very important' or 'important' (0,1)	55.22 % *(46.94 %)*	52.73 % *(43.75 %)*	56.79 % *(48.97 %)*
Market obstacles	If market dominated by established enterprises or uncertain demand for innovative good or services are 'very important' or 'important' (0,1)	58.66 % *(51.94 %)*	57.89 % *(49.79 %)*	59.14 % *(53.31 %)*
Formal appropriability	Number of formal methods for protection for innovation, including registration of designs, trademarks, patents and copyrights (0-4)	1.57 *(1.15)*	2.01 *(1.53)*	1.29 *(0.91)*
Informal appropriability	Number of informal methods of protection for innovation, including secrecy, complexity of design or lead-time advantage on competitors (0-3)	1.54 *(1.10)*	2.24 *(1.72)*	1.09 *(0.71)*
International market	Dummy for firms operating in 'European' or 'International' markets (0,1)	79.48 % *(66.84 %)*	73.53 % *(61.79 %)*	83.22 % *(70.07 %)*
Group	Dummy for firms belonging to a group (0,1)	62.20 % *(52.74 %)*	48.31 % *(41.36 %)*	70.94 % *(59.99 %)*
Industry	Dummies for: Textile, Paper, Chemical, Plastics and rubber, Basic metals, Fabricated metal, Machinery, Electric equipments, Transport equipment and other for the remaining firms.			
French	Dummy for French firms (0,1)	61.38% *(61.08%)*		

Sources: CIS 4 (UK and France)

[1] Figures in brackets and italics concern all firms in the sample (9318 firms). Other figures concern the sample of firms with technological innovating activities (Product, Process or Project).

[2] Figures are not available.

Table 2: Descriptive statistics of forms of innovations and the eight exclusive associated combinations

	Pooled	*UK*	*France*
Product innovation	2646 (50.74%)	994 (49.35%)	1652 (51.61%)
Process innovation	3530 (67.69%)	1111 (55.16%)	2419 (75.57%)
Organizational innovation	3336 (63.97%)	1217 (60.43%)	2119 (66.20%)
Product innovation only (W100)	374 (7.17%)	192 (9.53%)	182 (5.69%)
Process innovation only (W010)	637 (12.21%)	229 (11.37%)	408 (12.75%)
Organizational innovation only (W001)	395 (7.57%)	229 (11.37%)	166 (5.19%)
Product and process innovation (W110)	423 (8.11%)	137 (6.80%)	286 (8.93%)
Product and organizational innovation (W101)	471 (9.03%)	243 (12.07%)	228 (7.12%)
Process and organizational innovation (W011)	1092 (20.94%)	323 (16.04%)	769 (24.02%)
All forms of innovations (W111)	1378 (26.42%)	422 (20.95%)	956 (29.87%)
None (W000)	445 (8.53%)	239 (11.86%)	206 (6.44%)
Nb of firms with technological innovating activities (Product, Process and/or Project)	5215	2014	3201

Sources: CIS 4 (UK and France)

Table 3: Exclusive innovation combinations and performance.

Dependent variable: Log of sales per employee (2004 in Euro)

	UK		*France*	
	Coef.	z	Coef.	z
W000	0,843***	7.71	0,758***	5.35
W100	0,813***	7.45	0,723***	5.16
W010	0,876***	7.97	0,759***	5.23
W001	0,866***	7.80	0,734***	5.16
W110	0,903***	8.00	0,773***	5.33
W101	0,878***	8.00	0,789***	5.47
W011	0,880***	8.07	0,758***	5.31
W111	0,886***	7.93	0,775***	5.43
Firm performance (2002)	0,833***	32.57	0,886***	53.89
Size	0,009	1.25	-0,006	-0.78
R&D (log)	0,045***	3.79	0,011*	1.81
Training	0,020	1.25	0,005	0.52
Cooperation	-0,012	-0.74	0,004	0.42
Openness	-0,002	-0.49	-0,002	-0.56
Financial obstacles	-0,013	-0.78	-0,076***	-4.06
Knowledge obstacles	-0,010	-0.54	-0,027	-2.26
Market obstacles	-0,043***	-2.70	-0,010**	-0.97
Formal appropriability	0,003	0.52	-0,016	-1.52
Informal appropriability	-0,001	-0.19	0,003	0.59

Sources: CIS 4 (UK and France), Industry dummies are not reported.

Significance levels at *** 1%, ** 5% and * 10%.

Wijk refers to the exclusive innovation combinations: the combination of innovations forms (0/1, 0/1, 0/1) reflect whether a firm has introduced a product, process and/or organizational innovation.

All the tests reject the independence between the selection and the performance equation.

Dropping R&D from this equation performance did not change the results.

Statistics for endogeneity tests (regression based Hausman test, Wooldridge 2002) are the following: for UK F(7, 1987)=1.31, Prob>F=0.241 and for France F(7, 3174)=1.44, Prob>F=0.186.

Table 4: Testing *conditional complementarities-in-performance* between forms of innovations

		UK		*France*	
		Chi2	P-value	Chi2	P-value
Product / Process	**H0: C1=0 & C2=0**	1.83	0.601	3.21	0.799
	Organizational innovation = 0: **H0:** C1=W110+W000-W010-W100 >/< 0 ? Complements (C1>0) / Substitutes (C1<0)	**COMPL.**	**0.911**	**COMPL.**	**0.915**
	Organizational innovation = 1: **H0:** C2=W111+W001-W011-W101 >/< 0 ? Complements (C2>0) / Substitutes (C2<0)	NONE		NONE	
Product / Organization	**H0: C1=0 & C2=0**	1.29	0.475	4.55**	0.897
	Process innovation = 0: **H0:** C1=W101+W000-W100-W001 >/< 0 ? Complements (C1>0) / Substitutes (C1<0)	NONE	0.849	**COMPL.**	**0.983**
	Process innovation = 1: **H0:** C2=W111+W010-W110-W011 >/< 0 ? Complements (C2>0) / Substitutes (C2<0)	NONE		NONE	
Process / Organization	**H0: C1=0 & C2=0**	3.56	0.831	3.54	0.830
	Product innovation = 0: **H0:** C1=W011+W000-W010-W001 >/< 0 ? Complements (C1>0) / Substitutes (C1<0)	NONE		NONE	
	Product innovation = 1: **H0:** C2=W111+W100-W110-W101 >/< 0 ? Complements (C2>0) / Substitutes (C2<0)	**SUBST.**	**0.964**	**SUBST.**	**0.959**
	Nb of observations	3627		5691	
	Nb of uncensored obs.	2014		3201	

Sources: CIS 4 (UK and France)

Significance levels at *** 1%, ** 5% and * 10%

Wijk refers to the exclusive innovation combinations: the combination of innovations forms (0/1, 0/1, 0/1) reflect whether a firm has introduced a product, process and/or organizational innovation.

All the tests reject the independence between the selection and the performance equation.

Fig. 3: Testing *conditional complementarities-in-performance* between forms of innovations for small and medium firms (less than 250 empl.) and large firms (more than 250 empl.)

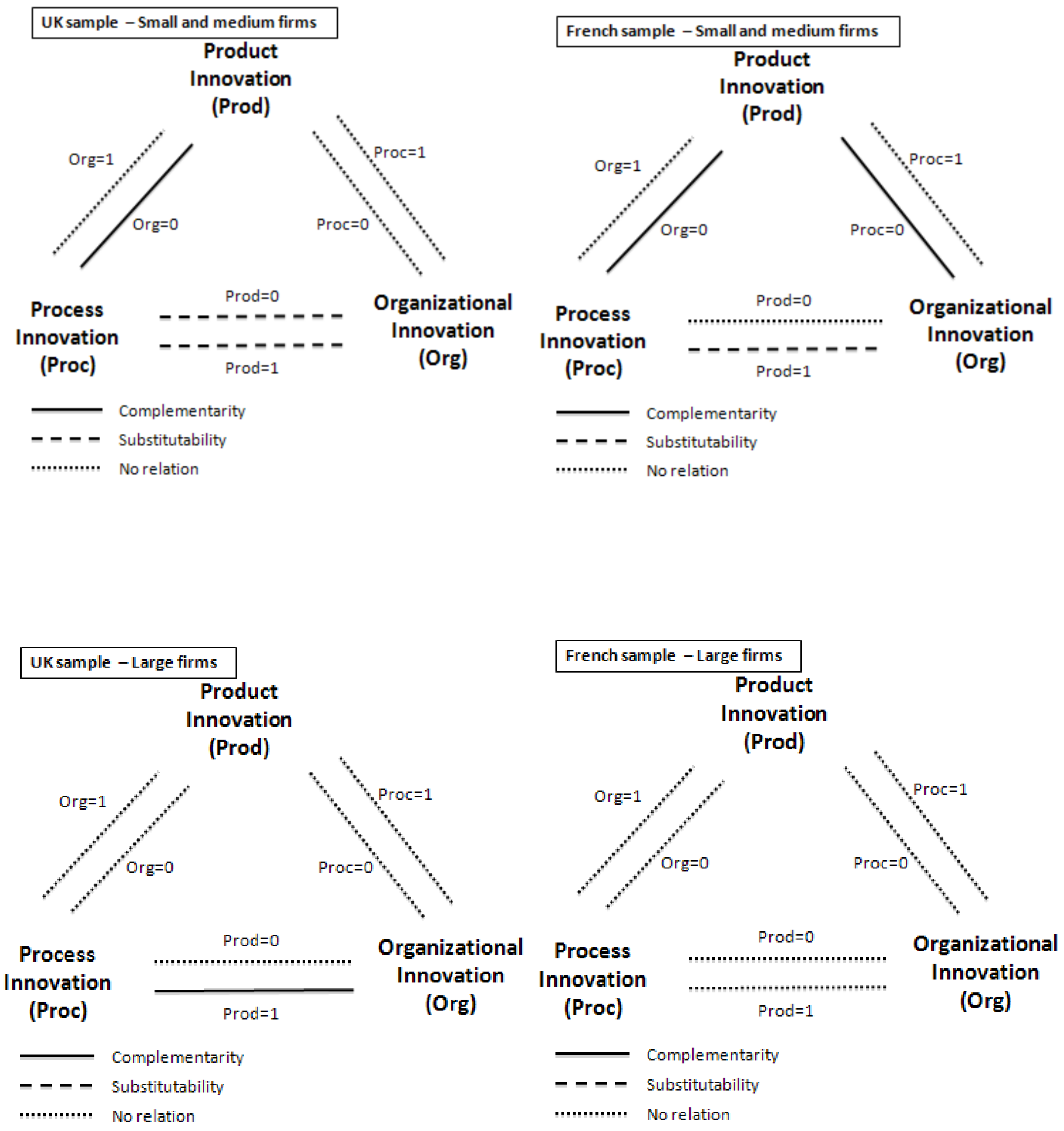
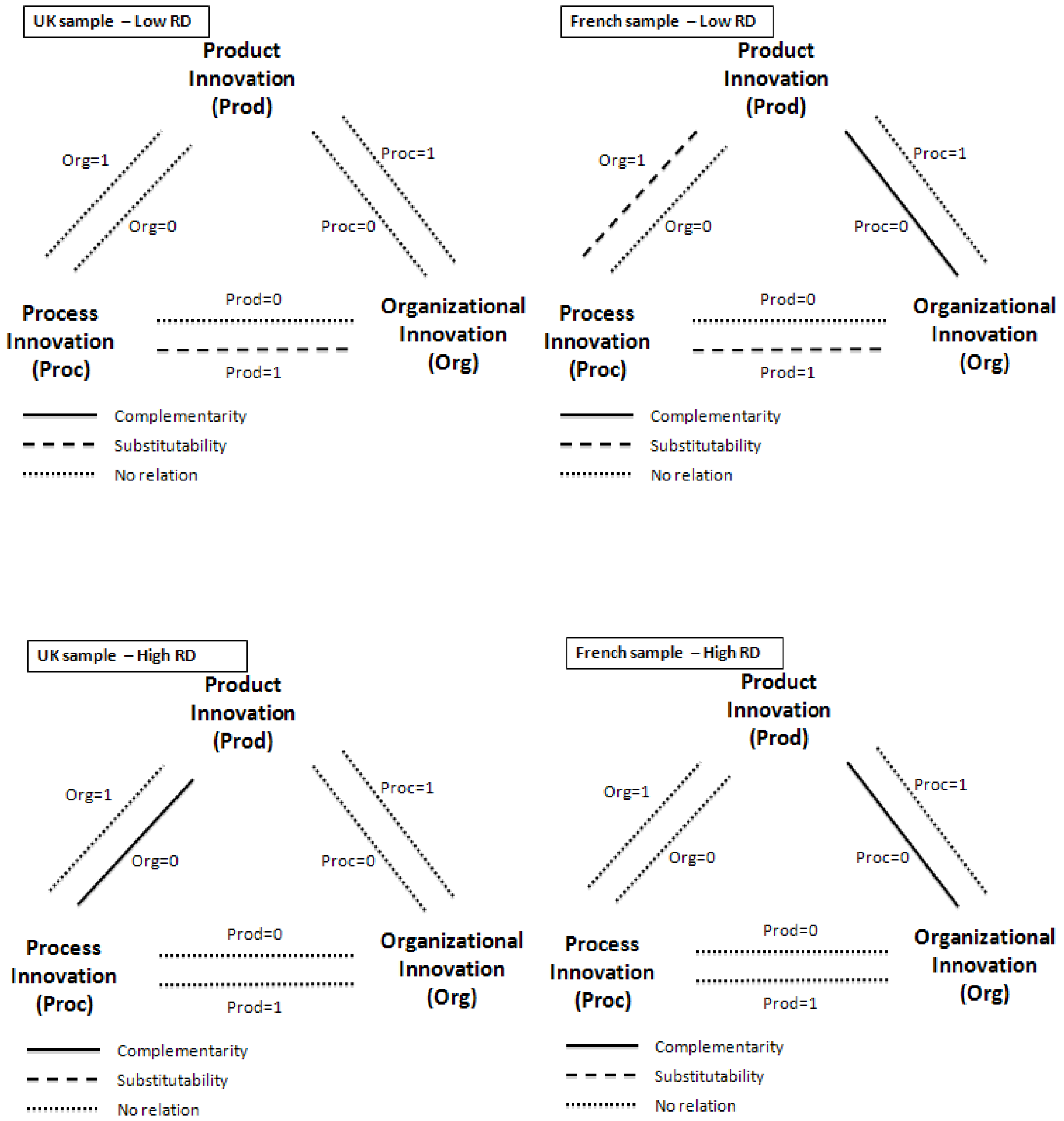
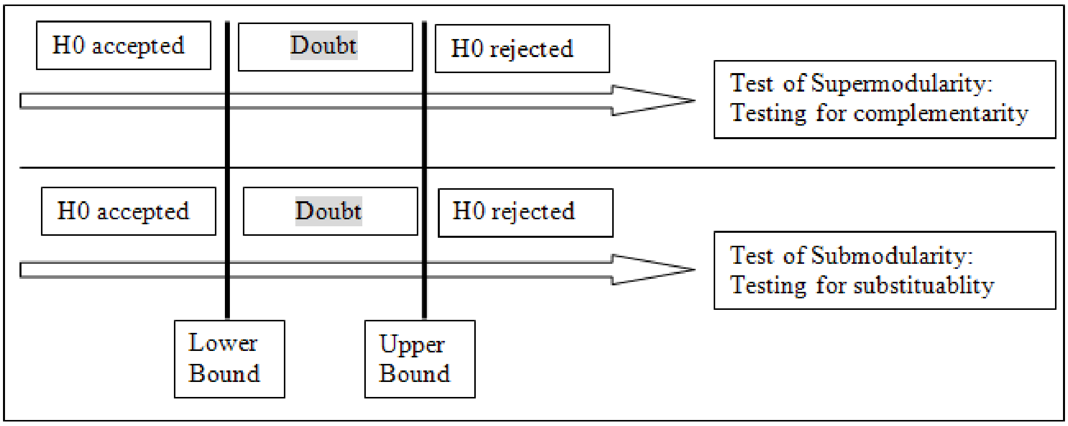


Fig. 4: Testing *conditional complementarities-in-performance* between forms of innovations for low and high R&D firms



Appendix 1: Testing complementarity and substituability of the 7 possible cases of interpretation (Kodde-Palm LR tests)



Critical values for two constraints:

at 5% level: lower bound (df=1) = 2.706 and upper bound (df=2) = 5.138

at 1% level: lower bound (df=1) = 5.412 and upper bound (df=2) = 8.273

We accept H0 if LR statistic is smaller than the lower bound. We reject H0 if this LR statistic is larger than the upper bound. If this statistic is between the bounds, the outcome is within the doubt region.

	Test of Supermodularity: Testing for complementarity	**Test of Submodularity: Testing for substituablity**	**Interpretation**
Case 1	H0 accepted	H0 rejected	Strict complementarity (Strict COMPL.)
Case 2	H0 rejected	H0 accepted	Strict substituability (Strict SUBST.)
Case 3	H0 accepted	Doubt	Weak complementarity (Weak COMPL.)
Case 4	Doubt	H0 accepted	Weak substituability (Weak SUBST.)
Case 5	H0 accepted	H0 accepted	Inconclusive
Case 6	H0 rejected	H0 rejected	Inconclusive
Case 7	Doubt	Doubt	Inconclusive

Appendix 2-1: Testing *unconditional complementarities-in-performance* between forms of innovations (Kodde-Palm LR tests)

		UK	France
Product / Process	**Supermodularity:**		
	H0: R1=W110+W000-W010-W100>0	1.108***	0.977***
	R2=W111+W001-W011-W101>0	H0 accepted	H0 accepted
	Submodularity:		
	H0: R1=W110+W000-W010-W100<0	0.008***	0.610***
	R2=W111+W001-W011-W101<0	H0 accepted	H0 accepted
		Inconclusive	**Inconclusive**
Product / Organization	**Supermodularity:**		
	H0: R1=W101+W000-W100-W001>0	0.622***	1.873***
	R2=W111+W010-W110-W011>0	H0 accepted	H0 accepted
	Submodularity:		
	H0: R1=W101+W000-W100-W001<0	0.145***	0.000***
	R2=W111+W010-W110-W011<0	H0 accepted	H0 accepted
		Inconclusive	**Inconclusive**
Process / Organization	**Supermodularity:**		
	H0: R1=W011+W000-W010-W001>0	0.000***	0.222***
	R2=W111+W100-W110-W101>0	H0 accepted	H0 accepted
	Submodularity:		
	H0: R1=W011+W000-W010-W001<0	2.251***	1.622***
	R2=W111+W100-W110-W101<0	H0 accepted	H0 accepted
		Inconclusive	**Inconclusive**
	Critical values for two constraints[a]		
	at 5% level: lower bound (df=1) = 2.706 and upper bound (df=2) = 5.138		
	at 1% level: lower bound (df=1) = 5.412 and upper bound (df=2) = 8.273		
	Nb of observations	3627	5691
	Nb of uncensored obs.	2014	3201

Sources: CIS 4 (UK and France)

[a] We accept H0 if LR statistic is smaller than the lower bound. We reject H0 if this LR statistic is larger than the upper bound. If this statistic is between the bounds, the outcome is within the doubt region.

Significance levels at *** 1%, ** 5% and * 10%

Appendix 2-2: Testing *unconditional complementarities-in-performance* between forms of innovations (Kodde-Palm LR tests) for small and medium firms, large firms, low R&D firms and high R&D firms

	UK *Small and medium firms*	*France* *Small and medium firms*	*UK* *Large firms*	*France* *Large firms*	*UK* *Low R&D firms*	*France* *Low R&D firms*	*UK* *High R&D firms*	*France* *High R&D firms*
Product / Process								
Supermodularity:	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted
Submodularity:	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted
	Inconclusive	**Inconclusive**	**Inconclusive**	**Inconclusive**	**Inconclusive**	**Inconclusive**	**Inconclusive**	**Inconclusive**
Product / Organization								
Supermodularity:	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted
Submodularity:	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted
	Inconclusive	**Inconclusive**	**Inconclusive**	**Inconclusive**	**Inconclusive**	**Inconclusive**	**Inconclusive**	**Inconclusive**
Process / Organization								
Supermodularity:	H0 accepted	H0 accepted	Doubt	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted
Submodularity:	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted
	Inconclusive	**Inconclusive**	**Weak SUBST.**	**Inconclusive**	**Inconclusive**	**Inconclusive**	**Inconclusive**	**Inconclusive**
Critical values for two constraints[a]								
at 5% level: lower bound (df=1) = 2.706 and upper bound (df=2) = 5.138								
at 1% level: lower bound (df=1) = 5.412 and upper bound (df=2) = 8.273								
Nb of observations	2938	4285	689	1406	3057	4561	570	1130
Nb of uncensored obs.	1509	2058	505	1143	1506	2071	508	1130

Sources: CIS 4 (UK and France)

[a] We accept H0 if LR statistic is smaller than the lower bound. We reject H0 if this LR statistic is larger than the upper bound. If this statistic is between the bounds, the outcome is within the doubt region.

Significance levels at *** 1%, ** 5% and * 10%