Paper to be presented at the DRUID 2012

on

June 19 to June 21

at

CBS, Copenhagen, Denmark,

THE FATEFUL TRIANGLE: COMPLEMENTARITIES BETWEEN PRODUCT, PROCESS AND ORGANIZATIONAL INNOVATION IN THE UK AND FRANCE

Fabrice GALIA
Burgundy School of Business - Groupe ESC Dijon Bourgogne - Dijon Paris
Department of Organisation Management and Entrepreneurship
fabrice.galia@escdijon.eu

Gérard BALLOT
Université Paris II-Sorbonne universités and TEPP-CNRS
ERMES (EAC CNRS 7181)
gerardballot@wanadoo.fr

Fathi FAKHFAKH
Université Paris II-Sorbonne universités and TEPP-CNRS
ERMES (EAC CNRS 7181)
fathi.fakhfakh@u-paris2.fr

Ammon SALTER
Imperial College Business School London

a.salter@imperial.ac.uk

Abstract
This paper explores the triangle of relationships among product, process and organizational innovation, examining the

complementarities and substitutions between these forms of innovation. Drawing upon two large samples of French and UK manufacturing firms, its major objective is to investigate if firms can find a beneficial interplay between forms of innovation. A first analysis explores the complementarities-in-use through a trivariate probit and the correlation of its residuals. This methodology is subject to unobserved variables bias and does not bring light on the performance of strategies of joint innovation forms, although the probit provides new results on the differences between the determinants of the three forms of innovation. Then a second analysis estimates a performance equation to study the complementarities-in-performance, using supermodularity theory. The results of the tests of unconditional complementarities in pairwise relations between forms do not generally provide conclusive results. We then implement a new testing procedure based on conditional tests ? a pairwise relation conditional on the presence/absence of the third form ? which shows that the efficient strategies of innovation combinations are not the same for all the firms. They depend on the national context as well as on the firm size and the firm capabilities, and give credit to the contingency hypothesis. The main combinations are the ?technological strategy? (product-process innovations) and the ?structure oriented strategy? (organization-product), and in no case the combination of the three strategies at the same time, which is presumably too costly or difficult.

Jelcodes:O31,L25

THE FATEFUL TRIANGLE

COMPLEMENTARITIES-IN-PERFORMANCE BETWEEN PRODUCT, PROCESS AND ORGANIZATIONAL INNOVATION IN THE UK AND FRANCE*

Paper submitted to the DRUID Society Conference 2012
INNOVATION and COMPETITIVENESS
Dynamics of Organizations, Industries, Systems and Regions
Copenhagen Business School, Denmark, June 19 - June 21 2012

This version February 29, 2012
Comments welcome

Abstract:

This paper explores the triangle of relationships among product, process and organizational innovation, examining the complementarities and substitutions between these forms of innovation. Drawing upon two large samples of French and UK manufacturing firms, its major objective is to investigate if firms can find a beneficial interplay between forms of innovation. We estimate a performance equation to study the *complementarities-in-performance*, using supermodularity theory. The results of the tests of unconditional complementarities in pairwise relations between forms do not generally provide conclusive results. We then implement a new testing procedure based on conditional tests – a pairwise relation conditional on the presence/absence of the third form – which shows that the efficient strategies of innovation combinations are not the same for all the firms. They depend on the national context as well as on the firm size and the firm capabilities, and give credit to the contingency hypothesis. The main combinations are the "technological strategy" (product-process innovations) and the "structure oriented strategy" (organization-product), and in no case the combination of the three strategies at the same time, which is presumably too costly or difficult

Keywords: Innovation, Organization, Complementarities, Complementarity-in-performance, Supermodularity, UK, France

JEL codes: C12, D24, L25, O31

***** We are grateful to P. Mohnen for giving us the Gauss codes for Kodde & Palm test and M. Ingham, for their helpful comments and suggestions. The usual disclaimer applies.

1. **Introduction**

This paper explores the relationship between product, process and organizational innovation in order to better understand the complementarities between different forms of innovation. Since Milgrom and Roberts's (1990, 1995) seminal contributions, there has been a surge of research interest in complementarities in economics and management. This literature explores when sum is more than its parts, examining the beneficial interplay between different parts of a system (Athey & Stern, 1998). The complementarities perspective is not itself a theory of organizational design or performance, but rather an approach to help researchers to understand relational phenomena and how the relationships between parts of system create more value than individual elements of the system (Ennen & Richter, 2010). This approach helps to enrich understanding of how different practices and strategies are combined and recombined, and how such combinations shape subsequent performance.

The growth in complementarities research has been reflected in the study of innovation, where there has been a range of studies of complementarities between different forms of innovation and the managerial practices associated with innovation (Laursen & Foss, 2003; Leiponen, 2005; Martínez-Ros & Labeaga, 2009; Mohnen & Roller, 2005; Roper, Du, & Love, 2008). This work has demonstrated strong links between the forms of innovation as well as the relationship between internal and external knowledge in the innovation process (Arora & Gambardella, 1990; Cassiman & Veugelers, 2006; Mowery, 1983). Complementarities research has followed two broad approaches in its attempt to measure and understand complementarities, which we term, *complementarities-in-use* and *complementarities-in-performance*. The first – *complementarities-in-use* - may arise from the fact that two sets of activities are linked, in that the use of one practice often requires the use of other practices. In this case, there is a strong fit between practices, suggesting a mutual and beneficial interaction between different practices. In this approach, researchers have sought to identify the relatedness in the use of different practices, finding evidence that some practices are usually combined with others (see for example Ballot *et al.*, 2011, Colombo, Grilli, & Piva, 2006; Galia & Legros 2004). The second approach - *complementarities-in-performance* - explores the performance effects of the use of different practices in combination with one another. These studies offer a direct test of the economic value to the firm in fitting together different activities or practices and how the mutual product of the joint use of these practices produce economic benefits that are greater than the individual parts.

The paper is based on an analysis of the UK and French Innovation Surveys for 2005. We are able to explore how the complementarities vary across countries. In doing so, we can determine what relationships are specific to national contexts. Using a Heckman selection procedure on innovative firms, we explore the effects on labour productivity of the presence of different combinations of three forms of innovation, applying direct sets of strict complementarity. We explore the results of these regressions for France and UK, and for sub-samples based on size and on capabilities of firms.

2. Complementarities in economics and management literatures and innovation

2.1. Complementarities among practices

R&D has been for a long time considered as the driving factor of innovation (Mairesse & Mohnen, 2005). However the literature on firm production and performance as well as on innovation has started introducing intangible factors such as human capital. But this extension of independent production factors is not enough. The Japanese success story appears as a mystery if one looks just for the addition of independent factors. Clearly the organisation of the firms and perhaps the organisation of the economic and social system are key factors. The idea is that the sum is more than the parts, and that factors are complementary. Factors are Edgeworth complements if doing more of any one of them increases the returns to doing more of the others.

This idea has received a wide audience since Milgrom and Roberts (1990) proposed to use mathematical tools new in economics to develop models of this Edgeworth complementarity, and applied them to the explanation of some major phenomena. Milgrom and Roberts (1995) propose a simple model to explain the move from the fordist (mass production) firm to the “modern” lean, flexible firm. Complementary factors mean that a very different set of values in the main characteristics (for instance high pay replacing low pay) or often a discrete change in many characteristics (for instance the introduction of a new pay system) are necessary for the efficiency of the modern firm. Organizational coherence is at the heart of the benefits of complementarity, but it is also important to stress the source of lasting competitive advantage that a more complex strategy gives to a firm since it acts as a barrier to organizational imitation, as proved theoretically by Rivkin (2000).

A major problem with the analysis of complementarities in a performance function for empirical analysis was the need for the divisibility of the choice variables and the smoothness of the objective function (Ennen & Richter, 2010). This was a major obstacle for considering changes in organisation, which are often discrete. An example is the use of fixed salary versus a flexible pay based on performance. Milgrom and Roberts show that the use of lattice theory (Topkis, 1978; 1998) requires only the possibility of ordering: doing more than one thing increases the returns to doing more of another. Smoothness and concavity 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 conditions on the objective function $f(x, y)$:

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

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

This framework is now applied to find complementarities in the range of different settings, including human resource management, strategy, resources, knowledge management, advanced manufacturing technology (see Ennen & Richter, 2010 for a summary of this literature). Choosing the set of practices to be investigated is a significant challenge as an omitted practice from a study may lead to misleading conclusions about the efficacy of a combination as the benefits of that combination may only be realized when they are combined with a third or even fourth unmeasured element. This indicates that an important part of the research agenda for understanding complementarities should be to look at *multiple* elements rather simple interactions, allowing researchers to understand beneficial interplay arising from systems of relationships.

In summary, both case of knowledge management and lean production suggest that *complementarities-in-use* are common place and that a set of mutually reinforcing requirements and managerial practices may led to sets of activities to be undertaken concurrently in order to realize the benefits of one activity with another.

2.2. Complementarities among forms of innovation

Since Schumpeter, it has been widely acknowledged that there are strong complementarities between forms of innovation. Indeed, innovation scholars often commented that radical innovations often led to changes in product markets as well as processes of production (Freeman & Soete, 1997; Utterback, 1994). Moreover, such innovations may also beget changes in marketing, delivery and geographic scope of a set of production or service activities. This broad character of innovation suggests that studies that focus on single forms of innovation – product, process or organization – may miss out important relationships between these different forms of innovation. Indeed, it may be that to gain from an innovation, it is necessary to transform other parts of the firm's innovation efforts, including changing the system of production or delivery and organizational structure that supports the innovation. The importance of different forms of innovation is also reflected in Teece's (1986) profiting from innovation framework, which emphasizes the returns to innovation usually go to those organizations that hold valuable and rare complementary assets.

In the literature on innovation, particular attention has been placed on the potential complementarity on the relationship between internal R&D and external knowledge. When examining the rise of industrial R&D and R&D services in the US in the early 20th century, Mowery (1983) found there was a strong complementarities relationship between internal and external R&D investments. Arora and Gambardella (1990) also found evidence for the existence of complementarity between internal and external R&D investments, when studying the large firms in biotechnology. Along these lines, Cassiman and Veugelers (2006) test the complementarity between two factors, internal R&D and external knowledge acquisition, on a sample of 269 Belgian firms. They find complementarity, but push the analysis further to show that this complementarity has a stronger effect on performance when the sample is reduced to firms having a higher basic R&D reliance, i.e. getting more information from research institutes and universities than on suppliers and customers. Belderbos, Carree and Lokshin (2006) study the performance effects of simultaneous engagement in R&D cooperation with different partners (competitors, clients, suppliers, and universities). The results suggest that the joint adoption of different R&D cooperation types can have inverse effects, depending on the specific strategy combinations and on firm size; Small firms may face diseconomies of scale when pursuing many strategies, which are costly to manage.

One of the most commonly documented complementarities in the study of innovation has been the link between product and process innovation. A range of studies have found *complementarities-in-use* between product and process innovation (Martínez-Ros & Labeaga, 2009). These studies demonstrate that new products may require changes in processes in production and vice-versa. Looking at 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. Along these lines, Miravete and Pernias (2006) tested the existence of complementarity between product, process innovation and the scale of production (measured by output) on a Spanish set of 432 firms in the ceramic tile industry. Their conclusion is that the significant association between product and process innovation is mostly due to unobserved heterogeneity.

Corrazin and Percival (2006) are among the first to study the complementarities between the organizational strategies and innovation with the supermodularity methods. Complete supermodularity does not occur, but pair-wise complementarities are frequent, yet concern factors that are different among industries. Percival and Corrazin (2008) extended this analysis, distinguishing between three levels of innovation intensity, firm level, Canada level, and world level, and partition the sample by industry. Then they compute the proportion of pair wise complements and substitutes and compare them between the different intensities of innovation and industries.

Most studies of complementarities have focused on single countries and this is a significant limitation. However, Mohnen and Röller (2005) study attempts to examine the factors that affect innovation for four countries, with data from CIS1 for 1992 at firm level. They consider four obstacles to innovation, factors relating to risk and finance, factors relating to knowledge-skill within the enterprise, factors measuring the knowledge-skill outside the enterprise, and regulation. The results suggest a number of complementarities between pairs of obstacles with the probability of becoming an innovator as the objective function, while there is more substitutability when the objective function is the intensity of innovation.

The role of skills as complement to innovation and R&D collaboration in a profit margin objective function has been investigated by Leiponen (2005), using a panel of 159 Finnish firms. The results give support to strict supermodularity between skills and R&D collaboration.

Schmidt and Rammer (2007) use the German CIS4 survey to look at 'non-technological innovation'. This version of CIS contains information on profit margins. They do not test for supermodularity, but in a first part of their study use bivariate probits to compare the determinants of technological and non-technological innovations and find them similar. They also show that the two forms of innovations are linked to each other, although not systematically. In a second part of their analysis, they demonstrate, using ordered Probit and Tobit techniques, that sales are higher for firms which combine product and process innovation with both marketing and organisational innovation. The profit margin is higher for the sole combination of organisational and product innovation.

Building on this approach, Mol and Birkinshaw (2009) is one the rare papers to investigate management innovation or 'non-technological' innovation directly. Using CIS3 for UK, they explain the firm performance, measured by productivity growth, by the introduction of new management practices and find it highly significant. The dummies for product and process innovation are not significant. Finally, Polder, Leeuwen, Mohnen and Raymond (2010) go further with a three-step model in the CDM framework. They first explain R&D and ICT then use a trivariate probit to explain product, process and organizational innovation by R&D and ICT. These three innovations feed in the production function, which corresponds to Total Factor Productivity. The model is estimated on Dutch firms' data and one of the most important results is that only organizational innovation alone leads to higher TFP level, while product and process innovation only lead to a higher TFP when performed together with an organisational innovation.

Drawing on this emerging research stream, we explore the triangle of relationships among product, process and organizational innovations. In doing so, we are able to look at how multiple elements of innovation may jointly shape economic outcomes. In addition, unlike past most studies of complementarities in innovation, we focus on two different countries: the UK and France.

3. Data, variables description and econometric methodology

3.1. Data and variables description

For this study, we combine information from the 4th Community Innovation Survey (CIS) for France and the UK. CIS data is based on firm-level surveys that ask organizations to provide on their level and form of innovative efforts. Although definitions of innovation and examples are provided to respondents, all the information relies on self-reported information by managers within these organizations and therefore it has a strong subjective element (OECD, 2005). The data has the advantage of being *comprehensive,* as it covers all sectors of the private economy and *detailed*, as it captures information on many different aspects of firm's innovative efforts. Overtime, it has become a central tool for researchers working on understanding the innovation process, and there have been over 100 papers publishing academic journals using the data, including leading economic and management journals (see Smith, 2005; Griffith, Heurgo, Mairesse, & Peters, 2006; Lööf & Heshmati, 2003; Mohnen & Roller, 2005).

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

The 4th Community Innovation Survey in France was carried out by SESSI (Ministry of Economics, Finances and Industry) in 2005, covering the 2002-2004 period. Like UK survey, it focuses on firms with over 10 employees, a stratified sample of firms under 250 employees and census of large firms. The survey population included 25,000 firms, drawn manufacturing, services and construction sectors. Unlike in the UK, it was a mandatory survey and it received a response rate of 86 percent, including 8,438 firms from manufacturing sector. As expected with such high a response rate, the sample closely mirrored the original population.

Merging the two datasets, we are left with 9318 firms, with 3627 for the UK and 5691 for France. However, since our attention is focused on individual firms and performance consequences of different forms of innovation, we do not attempt to explore the reasons for these national differences.

We will focus on three forms of innovation: product, process and organizational innovation (see Table 1 for definition of variables). Product innovation was taken from a question on both surveys to whether the firm had developed a product that was new for their market. Following the UK survey, process innovation was defined as the use of new or significantly improved methods for the production or supply of goods or services. To measure organizational innovation, our approach builds on the techniques used by Schimdt and Rammer (2007) and Mol and Birkinshaw (2009). Organizational innovation was measured by using questions on the French and UK CIS about 'wider innovation' (UK) and 'organizational and marketing innovations' (France).

Our measure of firm performance is based on the sales per employee in 2004, the last year covered by the survey. Although highly imperfect as a measure of performance, it has been used in many other studies of the performance effects of innovation using CIS data (Crépon, Duguet, & Mairesse, 1998; Griffith et al., 2006; Roper et al., 2008). However, to enable a direct test of the effects of complementarities, it is requirement to have a clear performance variable and therefore we have used this measure to allow us to explore this question.

3.2. Econometric Approach: testing complementarity-in-performance

Our approach to investigate complementarities among the forms of innovation is based on *complementarity-in-performance* approach[1]. We will 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) are introduced; to (1, 1, 1) where all the three forms of innovation are introduced together. The estimated coefficients of these combinations will be used to perform the complementarity (substitutability) tests. We will 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. 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 or giving up trying) versus firms that are not active in technological innovation. We use sales per employees in 2004 as our measure of performance because it has been widely applied in past studies of the performance effects of innovation. It is readily available for both UK and French firms in the pooled sample (for a similar approach see Griffith et al., 2006).

Selection bias may occur because we are doing our subsequent estimations on the sub-sample of innovating firms (in product and/or process) and firms trying to innovate, and because the decision to be engaged in technological innovation cannot be considered as an exogenous phenomenon. The choice of this sub-sample comes from the absence of information on key explanatory variables for the firms who did not innovate nor tried to innovate in product or process. This may of course lead to some bias in our results. To control for such a selection bias, we will use a Heckman selection procedure when we estimate a performance equation.

The selection equation includes group membership (group), selling in 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 test (LR test) rejects the absence of selection problem. This justifies the use of the Heckman selection procedure.

We also perform an endogeneity test of the combination 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 ratio. The residuals, associated to each combination, are added to the performance equation using a Mill ratio. We test for the joint significance of these residuals and we find no endogeneity. However, if we do not control for the selection, we find endogeneity. This apparently surprising result of no endogeneity is mainly

[1] See Ballot *at al.* (2011) for an approach of *complementairy-in-use* investigating this fateful triangle using a trivariate probit and a multinomial logit. This last model permits to test for endogeneity of the combinations. In this paper, main determinants of the different forms of innovation and of each exclusive combination of forms of innovation are studied. This last model permits to test for endogeneity of the combinations.

due to the fact that we already control for the participation in the technological innovation activity process.

The model we estimate is a linear one in which the dependant variable is a proxy for the firm performance. We have a common measure for sales per employee (in log) in France and in the UK. This performance specification will then allow us to test for the complementarity between the three forms of innovation using the supermodularity approach.

We first test for *unconditional complementarity* for each pair of innovation forms *i.e.* whatever the status of the third form of innovation (presence or absence). Second, we will also implement a new approach by testing for *conditional complementarity* for each pair of innovation forms *i.e.* distinguishing between the presence and the absence of the third form of innovation. For these two types of tests, we also test for substituablity for each pair of innovation forms.

Unconditional complementarity

To test for the supermodularity in each pair of innovations *i.e.* [product and process], [product and organization] and [process and organization], one needs to test for a pair of inequality restrictions. For example, if we want to test for the complementarity between product and process innovation, we have to test the two following restrictions constraints simultaneously (*C1* when organizational innovation is absent and *C2* when organizational innovation is present):

H0:
W110+W000-W010-W100 > 0 (a) C1 (absence of organizational innovation)
W111+W001-W011-W101 > 0 (b) C2 (presence of organizational innovation)

H1:
W110+W000-W010-W100 ≤ 0 (absence of organizational innovation)
W111+W001-W011-W101 ≤ 0 (presence of organizational innovation)

If these first two restrictions are simultaneously accepted, the performance is supermodular in product and process. For reasons to be given below, we will in this paper use slightly different words, saying 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 pairwise of innovations forms [product and organization] and [process and organization].

Testing for *unconditional substitutability* between product and process innovation, we have to test the same restrictions constraints as above where in H0 we have to replace '>*'* by *'<'*.

In order to test this set of two inequality conditions for *unconditional complementarity* and for *unconditional substitutability*, we apply the distance or Wald test. Like Mohnen and Roller (2005), we follow Kodde and Palm (1986) who have computed lower and upper bound critical values for this test. As indicated in Appendix 1, critical values for two constraints are the following: at 5% level, lower bound (df=1) = 2.706 and upper bound (df=2) = 5.138; and 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.

To be able to conclude for complementarity or substituability we have to consider together the tests for supermodularity and for submodularity and then to combine the outcome of these two tests. Considering the seven possible cases detailed in Appendix 1, these tests lead in three cases to inconclusive interpretation.

Conditional complementarity

In order to overcome the inconclusive interpretation of *unconditional* tests in many of our samples, we will use a novel and more detailed approach to complementarity, the *conditional complementarity* which we define as complementarity between two forms of innovation conditional to the introduction or not of the third form of innovation.

For example, testing *conditional complementarity* between product and process implies to test the complementarity conditional on the absence and then on the presence of organizational innovation.

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

H0:
W110+W000-W010-W100 > 0 (a) *C1 (absence of organization innovation)*
H1:
W110+W000-W010-W100 ≤ 0 (absence of organization innovation)

H0:
W111+W001-W011-W101 > 0 (b) *C2 (presence of organization innovation)*
H1:
W111+W001-W011-W101≤ 0 (presence of organization innovation)

As we have also to test complementarities for each other pair of innovations forms, we have to test conditional complementarity between product and organizational innovation conditionally on the absence or presence of process innovation. The same holds between process and organizational innovation.

Similar tests are done in order to test for *conditional substitutability*.

After all these tests of *conditional complementarity* and *conditional substitutability*, we are able to explore the following fateful triangle (Fig. 1):

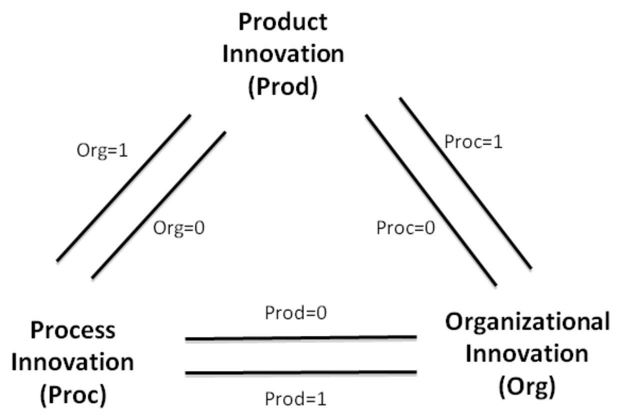


Fig. 1: Exploring the Fateful Triangle:

Testing *conditional complementarity* and *conditional substitutability*

4. Results

After a brief comparison of the French and UK samples (section 4.1), we turn sequentially to the main analysis of this paper: *complementarity-in-performance*.

In section 4.2, we will estimate a performance equation including the eight exclusive combinations of forms of innovation. The coefficients associated to these dummies as well as their variance-covariance matrix will be used to implement *unconditional* and *conditional* tests of complementarity (substituablity).

4.1. Descriptive statistics

(Insert Table 1)

Table 1 shows that French firms are slightly more productive, are larger and are investing more in R&D. Cooperation is more in use in France, and financial obstacles are more frequent too. Finally, French firms are more present in the international market and they more often belong to a group.

However, UK firms are more engaged in training, they have access to more sources of innovation and they tend to protect more their innovations.

(Insert Table 2)

Describing the three forms of innovation (Table 2), process innovation is broadly used by firms in the pooled sample as 68% of firms innovate in process. 64% of firms introduce organizational innovation whereas half of them (51%) introduce product innovation. We have found some differences between France and UK. Especially, French firms are more prone to introduce process innovation than UK firms. Three out of four French firms introduced process innovation whereas half of UK firms in the same period did so. Concerning organizational innovation, 61% of UK firms and 66% of French firms respectively introduce this form of innovation.

Concerning the combinations of innovation forms, among firms with technological activities the most frequent is the use of all the three forms of innovation *i.e.* product, process and organization at the same time, and this suggests that there is some value in the complementarity theory. This situation represents 26% of firms for the pooled sample, 21% for UK and 30% for France. The second most frequent combination concerns firms using at the same time process and organizational innovation without introducing product innovation respectively 21%, 16% and 24% for pooled, UK and French samples. Introducing no innovations represents in the pooled sample 8.5%, 11% of UK firms and 6.5% of French firms. Introducing only one form of innovation is around 5% to 12%. The most frequent innovation form used alone is process innovation.

4.2. Complementarities-in-performance between forms of innovations

The results of the performance equation in Table 3 first show that all the exclusive combinations of forms of innovation have a positive and significant effect on performance. The mere attempt to innovate technologically without any innovation success (W000) has a positive effect, but doing all the forms of innovation at the same time (W111) has a higher effect for each country. The results do not show a regular increase in the performance as more forms of innovation are added. While size has no influence, R&D has the expected positive effect on performance. Since innovation activity is controlled for, this direct effect on performance gives credit to the absorption capacity role of R&D. It increases the understanding and efficiency of existing technologies, as well as the introduction of product innovation new to the firm but not to the market (which we do not include in product innovation). The financial and knowledge obstacles have the right negative sign but are not always significant, while the market obstacles are always significant and have a negative effect. Appropriability methods have no effect on performance (the effect is taken into account in the dummies for the exclusive combination forms).

(Insert Table 3)

Let us now turn to the tests of the *complementarities-in-performance* (Table 4), which are based on the estimated coefficients w_{ijk}. We first present the *unconditional* tests, and as they are mostly inconclusive, we naturally turn to and concentrate on the *conditional* tests.

We first use the traditional *unconditional* Kodde-Palm LR tests (see Appendix 2-1 and 2-2). Considering the French and UK full samples, the tests are inconclusive. When we look at the sample splits (large / small and medium firms; and low R&D / high R&D firms), we only find two conclusive tests. First, strict complementarity is found between process and organizational innovations in UK for the small and medium firms (Appendix 2-2). Second, we find weak substitution between the process and organizational innovation for large firms in UK (Appendix 2-2). We do not find the classic complementarity between product and process innovation

These mostly inconclusive results for pairwise relations have allowed us not to test the *unconditional* complementarity and substitutability between the three types of innovation simultaneously, *i.e.* to do the test of a global supermodularity or submodularity. Anyhow a significant result with more than two factors is usually not found in the literature. These results suggest investigating *conditional* tests. We then find a number of conditional complementarities and three cases of conditional substitutability.

(Insert Table 4)

Using a triangle between product, process and organization, the results can be summarized in the following figure Fig. 2 and are detailed in table 4:

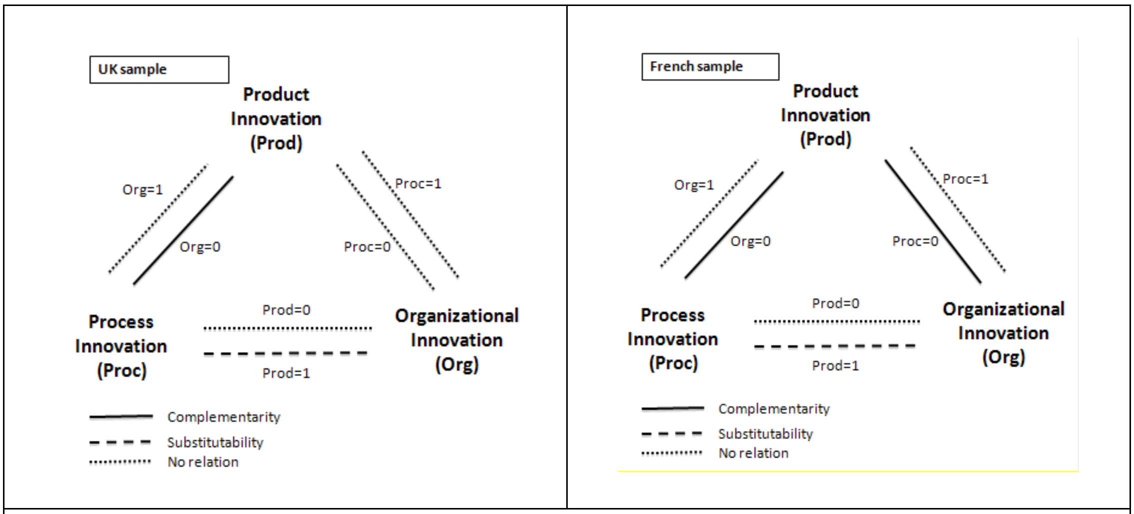


Fig. 2: Exploring the Fateful Triangle: Testing conditional *complementarities-in-performance* between forms of innovations

Looking first at the UK case, we observe the three sides of the triangle in turn and find three results. First product and process innovation are found to be conditional complements when (and only when) organizational innovation is not introduced. This result is in line with previous research dealing with complementarity between product and process. It can be interpreted as a technical necessity in many cases to make a process innovation in order to make a product new to the market. However, it appears that a simultaneous organizational change - which has a cost - is not required in many cases. We will name this strategy of product-process innovation the “technological strategy”.

Secondly no relation occurs between product and organizational innovation. Thirdly a substitution effect exists between process and organizational innovation when firms introduce product innovation. This suggests that rather than doing the three types of innovation at the same time, a costly strategy, a representative UK firm should innovate simultaneously in product and process.

We then turn to France. First we find similar results concerning *conditional complementarities* between product and process innovation when organizational innovation is absent. Secondly no relation occurs between product and organizational innovations. Thirdly, now product and organizational innovations are conditional complements when firms do not introduce process innovation. This can be termed a “structure oriented strategy” in the line of Chandler (1962)[2].

Hence French firms can choose between two alternative strategies: the technological strategy and the structure oriented strategy. A test shows that no strategy dominates the other.

The variability of the high performance strategies between countries as well as between firms within a country is not a problematic result. This is on the contrary an

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

interesting empirical confirmation of a well established theory in the management literature. Termed the “contingency theory”, it 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 theoretical and empirical reasons to find a unique best complementarity strategy for all the firms in our sample (Milgrom and Roberts, 1995). We would like to understand why the French firms have a choice of complementarity strategies which the British firms do not have. However the CIS4 data do not appear to contain information to go further[3].

One possibility to explore in more depth these somewhat different results for the two countries is to consider more detailed sample splits: by size, and by R&D intensity.

Sample splits: size and R&D

We conduct an additional analysis to determine how the complementarities among product, process and organizational innovations are shaped by the resources and capabilities of the firm. We use firm size and relative R&D expenditures as proxies for resource and capabilities respectively. In the case of size, we use the common distinction between small and medium sized firms with less than 250 employees and large firms with more than 250 employees. The triangles in Fig. 3 show that the complementarities-in-performance between the forms of innovation differ. To make a concise comparison let us count the number of each type of conditional relation for the set of the two samples (UK, France). For *small and medium* firms, we find 3 complementarities, 6 non relations and 3 substitutions. For *large* firms, we find 1 complementarity, 11 non relations and no substitutions.

The patterns of strategies are statistically quite different according to the size of the firms. The substitutions occur only for small and medium firms. They are between process and organizational innovation and 2 out of 3 take place when product innovation is present. This can be explained in terms of the costs of a triple innovation strategy for small and medium firms. The small and medium firms should use the technological strategy in UK, and this strategy or the structure oriented strategy in France.

The corresponding conditional strategies for the large firms show different relations, namely process-organization complementarity for the UK, and no relation for the French sample. These large UK firms have a third strategy not found in the full sample, a strategy which combines organizational change and process innovation. This strategy is efficient when product innovation is present. It is likely to be financially allowed by the economies of scale that large firms have, at least the UK firms as a group.

The size split finally shows that the small and medium firms can be responsible for the results of the full sample which displays only two alternative strategies, “technological”, and “structure oriented”.

(Insert Fig. 3)

[3] A look at the European Innovation Scoreboard (European Commission, 2007) which collects data corresponding approximately to the period covered by CIS4 does not reveal high differences in terms of 26 “innovation performance measures”. UK and France are quite close among the 27 EU countries.

Let us look now at the role of capabilities in shaping innovation strategies. Capabilities were captured by whether the firm had greater (or lower) levels of R&D expenditures per employee than their industry average using a 10 industry classification index (Fig. 4). For the high R&D firms, we find 2 conditional complementarities, 10 non relations, and no substitutions. For the low R&D firms we find 1 conditional complementarity, 8 non relations, and 3 substitutions.

(Insert Fig. 4)

The differences in strategies in statistical terms show no *substitutability-in-performance* for firms which spend more than average R&D while firms which spend less than average display some substitutability. This is a coherent result since these high R&D firms probably undergo a higher competition on their segment of the market and need a more sophisticated innovation strategy. The choice of the complements is however different in France and UK, pointing out to national differences in the environment. The high R&D UK firms use the technological complementarity while the French firms use the structure oriented strategy. The low R&D UK firms display no complementarity while the low R&D French firms use the structure oriented strategy.

5. Conclusions

The first and important regularity which runs across the results of this paper is the diversity among firms in terms of simultaneous use of the three forms of innovation and in terms of their effects on performance. This means that, if firms are rational, their strategies are dependant on the context and possibly their characteristics, Country, size, capabilities.

A first approach of the diversity comes from the observation of the rough statistics. We have shown that a majority of firms in the sample innovate in one form or another. 26% of firms in the sample introduce the three forms of innovation during the period covered (3 years). This is the largest group but not overwhelming in contrast to what the standard theory of supermodularity would suggest. The second and third combinations of innovations are process-organization and process only and the no innovation case is much less frequent. These results question the basic version of the theory which suggests a polarization on the two extreme strategies, the complete supermodularity if costs are not high, no innovation if they are.

The second approach aims to assess the *complementarities-in-performance.* We have estimated a performance equation using a Heckman OLS, and proceeded to three steps in the analysis. First the equation shows that firm performance is enhanced by any innovation activity or combination of innovation forms, but more by the combination of all forms of innovation. Even an attempt to innovate not followed by success has a positive effect. R&D has a positive effect, and since innovation activities are controlled for, this direct effect on performance gives credit to the absorption capacity role of R&D. The following steps of the analysis correspond to the tests of supermodularity and submodularity. In a second step we show that *unconditional pairwise complementarities* in performance do not appear in the national samples, but only between process and organizational innovations in the small and medium UK firms. *Unconditional pairwise substitutions* are nonexistent except a weak substitution in the large UK firms. Global supermodularity which is suggested by the supermodularity theory then cannot exist. Presumably the associated cost is too high compared to its benefits. The results are mostly inconclusive, an outcome which is not so different from the other studies, and has lead us to a third step.

We turn to a novel analysis which looks at the *conditional pairwise* complementarities and substitutions in performance. These are summarized by the (double) triangles of pairwise relations. The first result from these tests is that no unique strategy of complementarity/substitution is always the most productive. However substitutions are a less common occurrence than complementarities, keeping the credit of the economic theory of complementarity strategies once amended as follows. The second important result, based on the study of sub-samples, is that both the external context, here measured by the Country, and the characteristics of the firm, here proxied by the size and the capabilities (R&D relative to the mean of the sector) influence the strategy[4]. The contingency theory of optimal practices of the firm is given credit. Moreover complementarities between two forms of innovation are usely conditional on the presence/absence of the third form. The third result concerns the strategies selected. Among the set of possible conditional strategies, two strategies are privileged, namely a "technological" strategy based on process-product innovation, and a strategy which we term "structure oriented" since it combines product and organizational innovation. Firms should choose between these two strategies after evaluating statistically their relative performance. This choice is available to French firms only. UK firms should only choose the technological strategy. However we also observe a third strategy used by large firms in UK which combines process and organizational innovation, hinting to the role of economies of scale in process and organizational innovation.

When looking at all the sub-samples, complementarities statistically dominate substitutions. One more result appears concerning the sample split according to R&D relative intensity. High R&D UK firms appear to obtain more benefit from complementarity strategies than low R&D firms, which is in accord with the idea that they need more sophisticated innovation strategies since they are on the upper segment of the market, and more actively define such a sophisticated strategy. This difference is not significant however for French firms. Finally the results point to complementarities-in-performance which can differ from the complementarities-in-use, pointing out to the necessity and fruitfulness of the former analysis.

[4] The high intensity of R&D could also be viewed as imposed by the characteristics of the segment of the market on which the firm competes and an element of the external context.

References

Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. 2005. Competition and Innovation: An Inverted U Relationship, ***Quarterly Journal of Economics***, 120(2): 701-728.

Ahuja, G. 2000. Collaboration networks, structural holes and innovation: a longitudinal study. ***Administrative Science Quarterly***, 45: 425-455.

Argote, L., McEvily, B., & Reagans, R. 2003. Managing Knowledge in Organizations: An Integrative Framework and Review of Emerging Themes. ***Management Science***, 49(4): 571-582.

Arora, A., & Gambardella, A. 1990. Complementarity and external linkages: the strategies of the large firms in biotechnology. ***The Journal of Industrial Economics***, 38: 361-379.

Athey, S., & Stern, S. 1998. An empirical framework for testing theories about complementarity in organizational design, ***Working Paper***. Cambridge, MA.: NBER.

Ballot, G., Fakhfakh, F., Galia, F., & Salter, A. 2011. The Fateful Triangle: Complementarities between Product, Process and Organizational Innovation in the UK and France. *Working Paper ERMES*, No. 11-05.

Belderbos, R., Carree, M., & Lokshin, B. 2006. Complementarity in R&D Cooperation Strategies. ***Review of Industrial Organization***, 28: 401-426.

Burns, T. & Stalker, G.M. 1961. **The management of innovation**. London:Tavistock.

Cassiman, B., & Veugelers, R. 2006. In Search of Complementarity in Innovation Strategy. ***Management Science***, 52(1): 68-82.

Chandler, A. D.1962. Strategy and Structure: Chapters in the History of the American Idustrial Enterprise.Cambridge MA: MIT Press.

Cohen, W. M. 1995. Empirical Studies of Innovative Activities. In P. Stoneman (Ed.), ***Handbook of the Economics of Innovation and Technological Change***. Oxford: Basil Blackwell.

Cohen, W. M., & Levinthal, D. A. 1990. Absorptive capacity: A new perspective of learning and innovation. ***Administrative Science Quarterly***, 35(1): 128-152.

Colombo, M. G., Grilli, L., & Piva, E. 2006. In search of complementary assets: The determinants of alliance formation of high-tech start-ups. ***Research Policy***, 35: 1166-1199.

Cozzarin, B. P., & Percival, J. C. 2006. Complementarities between organisational strategies and innovation. ***Economics of Innovation and New Technology***, 15(3): 195-217.

Crépon, B., Duguet, E., & Mairesse, J. 1998. Research Innovation and Productivity: An Econometric Analysis at the Firm Level. ***Economic of INnovation and New Technologies***, 7: 115-158.

Edgerton, D. 1999. From Innovation to Use: ten (eclectic) theses on the history of technology. ***History and Technology***, 16: 1-26.

Ennen, E., & Richter, A. 2010. The Whole Is More Than The Sum of Its Parts - Or Is It? A Review of the Empirical Literature on Complementarities in Organizations. ***Journal of Management***, 36(1): 207-233.

European Commission.2007. **Innovation Scoreboard 2007**.

Evangelista, R., & Vezzani, A., 2010 The economic impact of technological and organizational innovations. A firm-level analysis. ***Research Policy,*** 39: 1253-1263.

Freeman, C., & Soete, L. L. G. 1997. ***The Economics of Industrial Innovation***. London: Pinter.

Galia, F. & Legros, D. 2004. Complementarities between Obstacles to Innovation: Evidence from France, ***Research Policy***, 33(8).

Gault, F., & Foray, D. 2003. Measuring Knowledge Management in the Business Sector: First Steps. Paris: OECD.

Griffith, R., Heurgo, E., Mairesse, J., & Peters, B. 2006. Innovation and productivity across four European countries. ***Oxford Review of Economic Policy***, 22(4).

Koode, D., & Palm, F., 1986. Wald criteria for jointly testing equality and inequality restrictions. ***Econometrica***, 54(5): 1243-48.

Kraft, K. 1990. Are product- and process-innovations independent of each other? ***Applied Economics***, 22: 1029-1038.

Lam, A. 2010. Innovative Organizations: Structure, Learning and Adaptation, in ***Innovation Perpective for the 21th century***, Madrid: BBVA, 163-175.

Laursen, K., & Foss, N. J. 2003. New HRM Practices, Complementarities and the Impact on Innovative Performance. ***Cambridge Journal of Economics***, 27(2): 243-263.

Laursen, K., & Salter, A. 2006. Open for innovation: The role of openness in explaining innovation performance among UK manufacturing firms. ***Strategic Management Journal***, 27(2): 131-150.

Leiponen, A. 2005. Skills and innovation. ***International Journal of Industrial Organization***, 23: 303-323.

Levin R., Klevorik A., Nelson R., Winter S. 1987, Appropriating the Returns from Industrial R&D, ***Brookings Papers on Economic Activity****, 3: 783-820*

Lippman, S., & Rumelt, R. 1982. Uncertain Imitability: An Analysis of Interfirm Differences in Efficiency under Competition. ***The Bell Journal of Economics***, 13(2): 418-438.

Lööf, H., & Heshmati, A. 2003. The Link Between Firm-Level Innovation and Aggregate Productivity Growth: A Cross-Country Examination. ***Research Evaluation***, 12: 131-147.

MacGarvie, M. 2006. Do Firms Learn from International Trade? ***Review of Economics and Statistics***, 88(1): 46-60.

Mairesse, J., & Mohnen, P. 2005. The importance of R&D for innovation: a reassessment using French survey data. ***Journal of Technology Transfer***, 30(1/2): 183-197.

March, J. G. 1991. Exploration and Exploitation in Organization Learning. ***Organization Science***, 2(1): 71-87.

Martinez-Ros, E. 2000. Explaining the decisions to carry out product and process innovations: the Spanish case. ***Journal of High Technology Management Research***, 10(2): 223-242.

Martínez-Ros, E., & Labeaga, J. 2009. Product and process innovation: Persistence and complementarities. ***European Management Review***, 6(1): 64-75.

Milgrom, P. R., & Roberts, B. M. 1990. The Economics of Modern Manufacturing Technology, Strategy and Organization. ***American Economic Review***, 80: 511-528.

Milgrom, P. R., & Roberts, B. M. 1995. Complementarities and Fit: Strategy, Structure and Organizational Change in Manufacturing. ***Journal of Accounting and Economics***, 19: 179-208.

Mintzberg, H. 1981. Organization design: fashion or fit?, **Harvard Business Review**, 103-116.

Miravete, E., & Pernias, J. 2006. Innovation complementarity and scale of production. ***Journal of Industrial Economics***, LIV(1): 1-29.

Mohnen, P., & Roller, L. 2005. Complementarities in innovation policy. ***European Economic Review***, 49(6): 1431-1450.

Mol, M., & Birkinshaw, J. 2009. The sources of management innovation: When firms introduce new management practices. ***Journal of Business Research***, 62: 1269-1280.

Mowery, D. C. 1983. The relationship between intrafirm and contractual forms of industrial research in American manufacturing, 1900-1940. ***Explorations in economic history***(20): 351-374.

Nelson, R., & Winter, S. 1982. ***An Evolutionary Theory of Economic Change***. Cambridge, MA: Harvard University Press.

Ocassio, W. 1997. Towards an attension-based view of the firm. ***Strategic Management Joural***, 19 (Summer Special Issue): 187-206.

OECD. 1997. **Proposed guidelines for collecting and interpreting technological innovation data: the 'Oslo Manual'**. Paris: Organisation for Economic Development and Co-operation.

OECD. 2005. **Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data**. Paris: Organisation for Economic Co-operation and Development.

Ordonez, L., Schweitzer, M. E., Galinsky, A., & Bazerman, M. 2009. Goals gone wild: How goals systematically harm individuals and organizations. ***Academy of Management Perspectives***, 23(1).

Percival, J. C., & Cozzarin, B. P. 2008. Complementarities Affecting the Returns to Innovation. ***Industry and Innovation***, 15(4): 371-392.

Polder, M.,van Leeuwen, G., Mohnen, P.& Raymond, W. 2010. product, process and organizational innovation: drivers, complementarity and productivity effects. **UNU-MERIT working paper.**

Reichstein, T., & Salter, A. 2006. Investigating the sources of process innovation among UK manufacturing firms. ***Industrial and Corporate Change***, 15(4): 653 - 682.

Rivkin, J. W. 2000. Imitation of Complex Strategies. ***Management Science***, 46(6): 824-844.

Roper, S., Du, J., & Love, J. 2008. Modelling the innovation value chain. ***Research Policy***, 37: 961-977.

Schmidt, T., & Rammer, C. 2007. Non-technological and Technological Innovation. In ZEW (Ed.), ***Discussion Paper***: Centre for European Economic Research

Smith, K. 2005. Measuring Innovation. In J. Fagerberg, D. C. Mowery, & R. R. Nelson (Eds.), ***The Oxford Handbook of Innovation***: 148-179. Oxford: Oxford University Press.

Teece, D. J. 1986. Profiting from technological innovation: Implications for integration collaboration, licensing and public policy. ***Research Policy***, 15: 285-305.

Tether, B. S. 2002. Who co-operates for innovation, and why: An empirical analysis. ***Research Policy***, 31(6): 947-967.

Topkis, D.M. 1978. Minimizing a Supermodular Function on a Lattice. ***Operations Research***. 26(2): 305-321.

Topkis, D.M. 1998. ***Supermodularity and Complementarity***, Princeton University Press, Princeton, NJ.

Tushman, M., & O'Reilly, C. 1997. ***Winning through Innovation: A practical guide to leading organizational change and renewal***. Boston, Mass: Harvard Business School Press.

Utterback, J. M. 1994. ***Mastering the Dynamics of Innovation***. Boston: Harvard Business School Press.

Van Reenen, J., & Bloom, N. 2007. Measuring and explaining management practices across firms and countries. ***Quarterly Journal of Economics***, 122(4): 1351-1408.

Wooldridge, J., 2022, **Econometric Aanalysis of Cross section and Panel Data**, MIT Press.

Womack, J., & Jones, D. 2005. ***Lean Solutions: How Companies and Customers Can Create Value and Wealth Together***. New York: Free Press.

Womack, J., Jones, D., & Roos, D. 1991. ***The Machine That Changed The World: The Story of Lean Production***. New York: Harper.

Womack, J. P., & Jones, D. T. 1996. ***Lean Thinking***. London: Simon & Schuster.

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 one of the following: new or significant improved organizational structure, system for managing knowledge, or marketing activities (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 appro-priability	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 appro-priability	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%)*		

[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.

Sources: CIS 4 (UK and France)

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: *(a)* C1=0 & *(b)* C2=0**	1.83	0.601	3.21	0.799
	Organizational innovation = 0: **H0: *(a)*** C1=W110+W000-W010-W100 >/< 0 ? Complements (C1>0) / Substitutes (C1<0)	**COMPL.**	**0.911**	**COMPL.**	**0.915**
	Organizational innovation = 1: **H0: *(b)*** C2=W111+W001-W011-W101 >/< 0 ? Complements (C2>0) / Substitutes (C2<0)	NONE		NONE	
Product / Organization	**H0: *(a)* C1=0 & *(b)* C2=0**	1.29	0.475	4.55**	0.897
	Process innovation = 0: **H0: *(a)*** C1=W101+W000-W100-W001 >/< 0 ? Complements (C1>0) / Substitutes (C1<0)	NONE	0.849	**COMPL.**	**0.983**
	Process innovation = 1: **H0: *(b)*** C2=W111+W010-W110-W011 >/< 0 ? Complements (C2>0) / Substitutes (C2<0)	NONE		NONE	
Process / Organization	**H0: *(a)* C1=0 & *(b)* C2=0**	3.56	0.831	3.54	0.830
	Product innovation = 0: **H0: *(a)*** C1=W011+W000-W010-W001 >/< 0 ? Complements (C1>0) / Substitutes (C1<0)	NONE		NONE	
	Product innovation = 1: **H0: *(b)*** 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.)

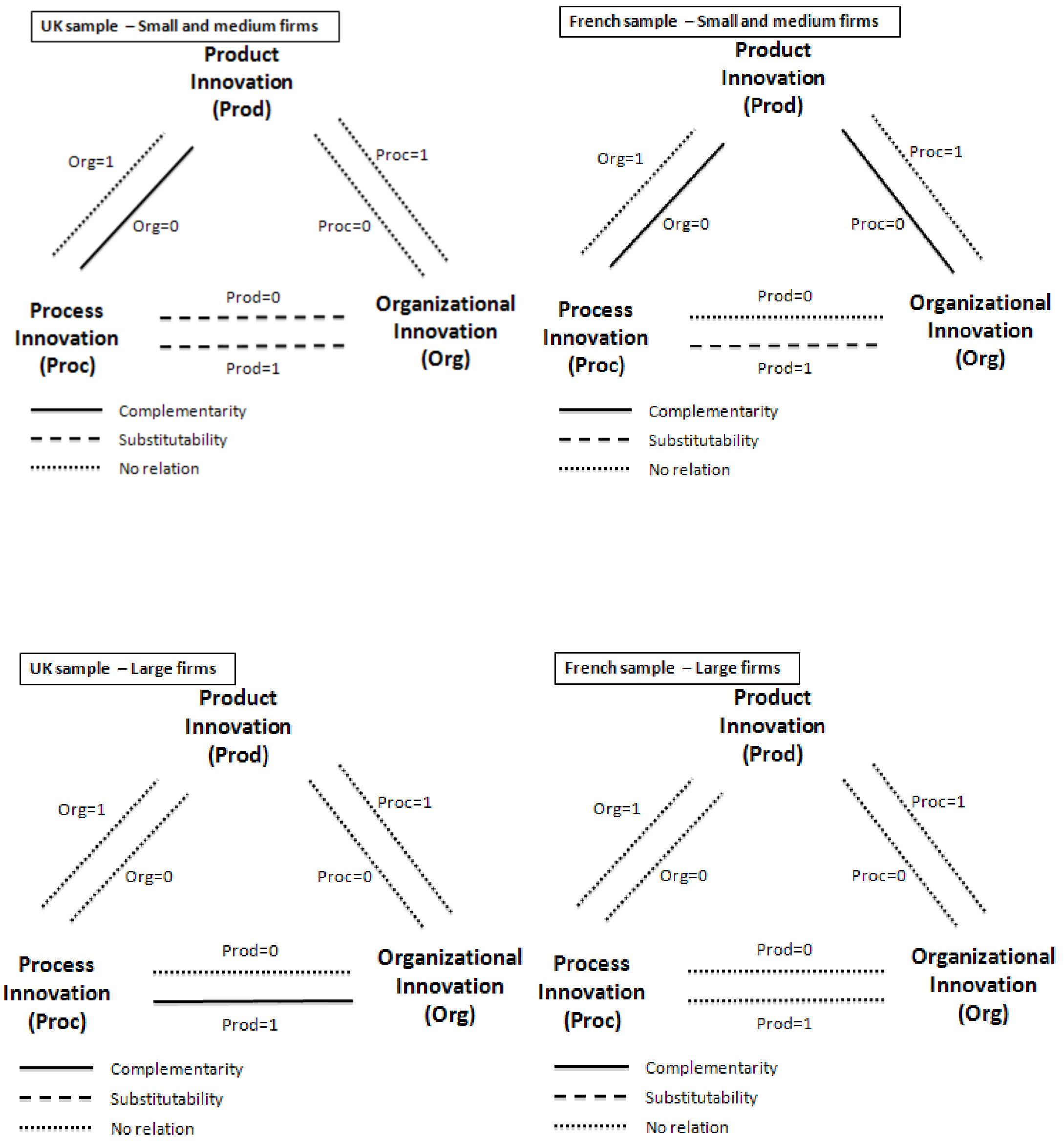
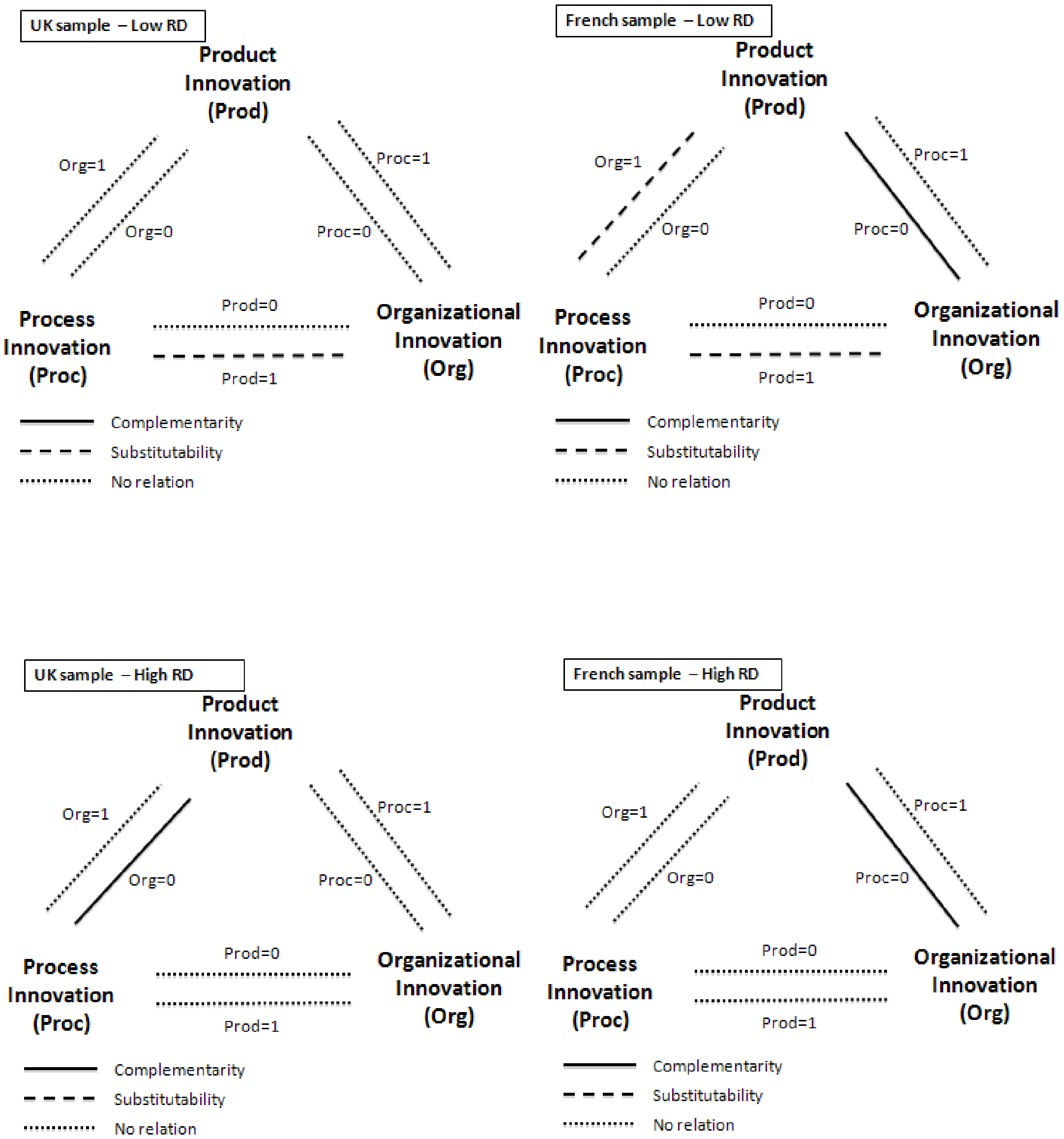
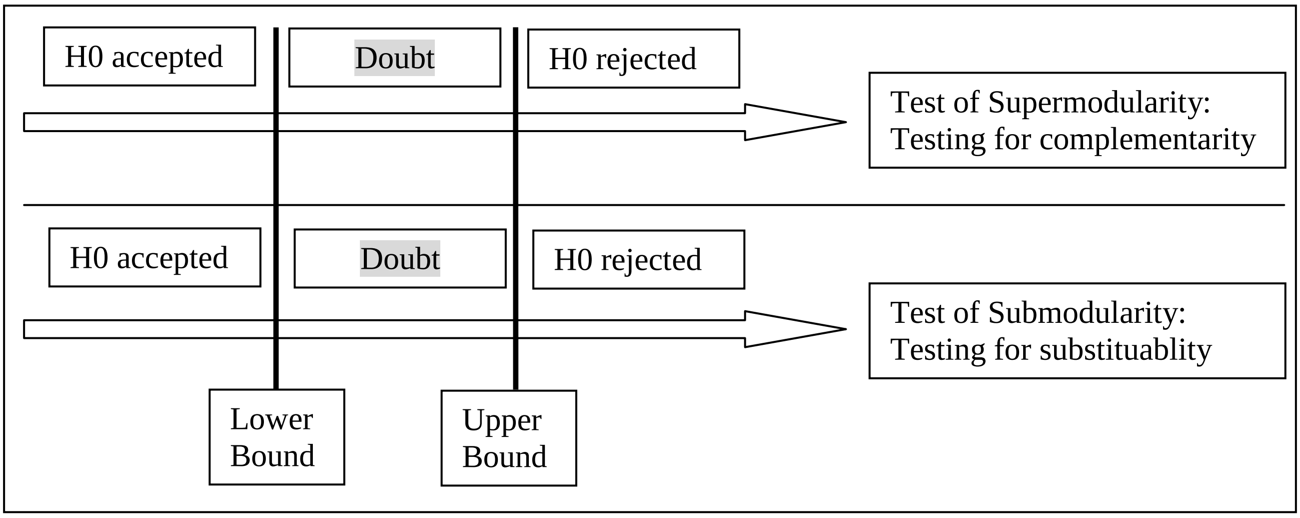


Fig. 4: Testing *conditional complementarities-in-performance* between forms of innovations for low and high R&D firms



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: C1=W110+W000-W010-W100>0	1.108***	0.977***
	C2=W111+W001-W011-W101>0	H0 accepted	H0 accepted
	Submodularity:		
	H0: C1=W110+W000-W010-W100<0	0.008***	0.610***
	C2=W111+W001-W011-W101<0	H0 accepted	H0 accepted
		Inconclusive	**Inconclusive**
Product / Organization	**Supermodularity:**		
	H0: C1=W101+W000-W100-W001>0	0.622***	1.873***
	C2=W111+W010-W110-W011>0	H0 accepted	H0 accepted
	Submodularity:		
	H0: C1=W101+W000-W100-W001<0	0.145***	0.000***
	C2=W111+W010-W110-W011<0	H0 accepted	H0 accepted
		Inconclusive	**Inconclusive**
Process / Organization	**Supermodularity:**		
	H0: C1=W011+W000-W010-W001>0	0.000***	0.222***
	C2=W111+W100-W110-W101>0	H0 accepted	H0 accepted
	Submodularity:		
	H0: C1=W011+W000-W010-W001<0	2.251***	1.622***
	C2=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 rejected	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted	H0 accepted
	Strict COMPL.	**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%