J Technol Transf (2017) 42:441–459
DOI 10.1007/s10961-015-9435-6

Product–process matrix and complementarity approach

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Published online: 8 September 2015

Abstract The relationship between different types of innovation is analysed from three different approaches. On the one hand, the distinctive view assumes that the determinants of each type of innovation are different and therefore there is no relationship between them. On the other hand, the integrative view considers that the different types of innovation are complementary. Finally, the product–process matrix framework suggests that the relationship between product innovation and process innovation is substitutive. Using data from Spain belonging to the Technological Innovation Panel (PITEC) for the years 2008, 2009, 2010, 2011 and 2012, we tested which of the three approaches is predominant. To perform the hypothesis test, we used the so-called complementarity approach. We find that there is no unique relation. The nature of the relationship depends on the types of innovation that interact. Our most significant finding is that the relationship between product innovation and process innovation is complementary. This finding contradicts the proposal of the product–process matrix framework. Consequently, the joint implementation of both types of innovation generates a greater impact on the performance of a company than the sum of their separate implementations.

Keywords Product innovation · Process innovation · Organizational innovation · Product–process matrix · Complementarity approach

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JEL Classification O31 · O32

1 Introduction

The relationship between product innovation and process innovation has been discussed in the literature from three different approaches. The distinctive view assumes that the determinants of each type of innovation are different (Baldwin et al. 2002; Fritsch and Meschede 2001), and their impact on the innovation performance of firms is also different (Damanpour et al. 1989). Therefore, from the distinctive view, there is no interaction between the two types of innovation. However, from the integrative view, product innovation and process innovation are interdependent (Damanpour and Gopalakrishnan 2001; Pisano and Wheelwright 1995; Roberts and Amit 2003), and their simultaneous implementation generates a synergistic effect (complementary) on performance company (e.g. Battisti and Stoneman 2010; Damanpour et al. 2009; Damanpour and Evan 1984; Schmidt and Rammer 2007; Walker 2004).

Another approach to the relationship between product innovation and process innovation is the product–process matrix (PPM), proposed by Hayes and Wheelwright (1979a, b). The PPM extends and complements the previous contributions of Abernathy and Townsend (1975) and Utterback and Abernathy (1975). The PPM offers a direct link between the product life cycle stages (horizontal axis) and the process life cycle stages (vertical axis). The PPM points out that the enterprises should move along or close to the diagonal from top left to bottom right. As you go down the diagonal, the production flexibility, the cost and the role of product innovation will reduce gradually (Tiantian et al. 2013). The PPM framework suggests that there is a direct trade-off between product innovation and process innovation. That is, the PPM framework proposes that both types of innovation are substitutes.

Therefore, the proposals of the three approaches can be summarised as follows: the distinctive view suggests that there is no definite pattern in the relationship between product innovation and process innovation, or that in some cases this relationship can be substitutive; the integrative view defends the existence a complementary relationship; and the framework PPM proposes the existence of a substitutive relationship.

Moreover, it should be mentioned that the literature on innovation suggests that organisational innovation can reinforce or undermine the basic proposals made by the three approaches described above. Thus, in the context of the integrative view, many authors note that companies that simultaneously introduce technological and organisational innovations enjoy greater competitive advantages and reinforce the existing complementary nature between product innovation and process innovation (Lokshin et al. 2008; Evangelista and Vezzani 2010; Gunday et al. 2011; Le Bas et al. 2015). Also, in the context of the PPM framework, authors like Dean and Snell (1996) and Boyer et al. (1997) note that the use of innovative management can eliminate or at least minimise some of the trade-offs suggested in the PPM framework, i.e. convert substitutability relationships between product innovation and process innovation in independent relationships or even complementary. On this issue, McDermott et al. (1997) argue that the PPM framework has lost its relevance in today's complex manufacturing environment, and Lam (2005) emphasises that the organisational innovation is a supporting factor for product and process innovations.

Based on the above arguments, it is clear that the analysis of the relationship between product innovation and process innovation must take into account organisational innovation.

Following the research of the three aforementioned approaches, clearly the relationship between different types of innovation is not an exhausted subject. Therefore, the aim of our study is to examine further the relationship between product innovation and process innovation, exploring such relationships within the context of organisational innovation. On this matter, it should be stressed that the empirical research on the relationship between different innovation types remains scarce.

This paper contributes in three important ways to the analysis of the relationship between product innovation, process innovation and organisational innovation. First, this study analyses for the first time, simultaneously, the validity of the product–process matrix, the distinctive view and the integrative view on a large database of industrial Spanish companies. The previous empirical studies tested the distinctive view, the integrative view, the distinctive view versus the integrative view or only the validity of the product–process matrix. However, the partial exploration of a three-dimensional reality in the relation between different types of innovation (no relation/complementarity/substitutability) can produce significant biases in the results. Second, to perform the validity test, we utilise the complementarity approach (Topkis 1978; Milgrom and Roberts 1990). The output provided by this approach is appropriate to the objectives we pursue. The use of causality (e.g. Kraft 1990; Gunday et al. 2011) as research methodology does not allow simultaneous exploration of the three approaches and the use of correlation coefficients (e.g. Damanpour and Gopalakrishnan 2001; Ahmad and Schroeder 2002) can lead to biased results, since a positive/negative correlation is neither necessary nor sufficient for complementarity/substitutability (Athey and Stern 1998). Third, our study tries to overcome the classic problems of unobserved heterogeneity between different observations as a result of using cross-sectional data. In this study, we use panel data, totalling 18,524 observations pertaining to the period 2008–2012.

Our study contributes to extend the empirical investigation of the three aforementioned approaches, using the complementarity approach as a research tool (for a review of the use of complementarity approach, see Ennen and Richter 2010 and Carree et al. 2011).

In the next section, we present the theoretical background and formulate our hypotheses. Section 3 describes the data set, the econometric methodologies used to estimate the coefficients and to test complementarities. We also define the variables used. In Sect. 4 the results are presented and discussed. Finally, conclusions are presented in Sect. 5.

2 Theoretical background and hypotheses

At present, the recognition of innovation as a cornerstone of economic and social development is unanimous. The ability to innovate in companies has become a crucial factor for increasing its market share, access to new markets and obtaining and sustaining competitive advantages over time (Hitt et al. 2001; Hult et al. 2003; Gunday et al. 2011). Consequently, innovation has come to play a key role within the business strategy (Audretsch et al. 2002) since it provides companies a strategic orientation to deal with the uncertainty that increased competitive pressure entails (Kuratko et al. 2005).

However, we must also bear in mind that there are different types of innovation. In the literature, there is intense debate about the relationship between product innovation and

process innovation. The distinctive view argues that the determinants of both types of innovation are different, and that there is no definite pattern in the relationship between both types of innovation. However, in the PPM framework, it is argued that the relationship between product innovation and process innovation is substitutive. Finally, the integrative view considers that the joint and simultaneous adoption of both types of innovation produce complementary effects on the performance of companies.

The distinctive view rests on the principles of analytical thinking, assuming that the understanding of a phenomenon can be achieved through understanding the behavior of different parts in which this phenomenon is divided (Ackoff 1999). The result of this view has resulted in a course of action present in multiple analyzes on innovation. In them we see that different types of innovation (such as product and process innovation) are studied as if they were phenomena that contribute differently to the competitiveness of companies and to their growth, and assuming that the determinants of each type of innovation are also different (Damanpour 2010).

Examples of this kind of propositions are found in many works, such as those which consider that product and process innovation lead, respectively, to cost leadership and differentiation (Schilling 2005). Those advantages, on the other hand, have been considered as mutually exclusive (Porter 1985). But, as we have previously reflected not only the effects of each type of innovation are considered different, but it is presumed that its determinants are not the same. Thus, it is common, for example, consider the competitive intensity as a determinant that drives product innovation to a greater extent than process innovation, while the size of firms is identified as a factor that affects more than any other to process innovation (Baldwin et al. 2002; Cohen and Klepper 1996; Fritsch and Meschede 2001; Kraft 1990).

The above examples are a sample of the logic that is used by these postulates to exclude any type of interaction between different kinds of innovation. That is why the studies that make up the so-called distinctive view, have separately addressed the study of the determinants of each type of innovation and its corresponding impact on firm performance. On this, there are numerous examples at the level of product innovation (e.g. Atuahene-Gima 1996; Han et al. 1998; Li and Atuahene-Gima 2001), process innovation (e.g. Marcus 1988; Ittner and Larcker 1997; Whittington et al. 1999; Knott 2001; Baer and Frese 2003) and organizational innovation (e.g. Damanpour 1991; Sapprasert and Clausen 2012).

Of the three approaches discussed in this paper, the distinctive view is the oldest, and also the one that has generated more empirical research. However, in the field of Operations Management (OM), in the late 1970s, a new approach emerged suggesting that the relationship between product innovation and process innovation is substitutive. The first contribution of this approach (Hayes and Wheelwright 1979a) discusses the static aspects of this relationship, while the second (Hayes and Wheelwright 1979b) discusses the dynamic ones. The PPM framework stresses that companies combine product innovation and process innovation, and when the firm's mix of product innovation and process innovation changes, customisation (variety) and efficiency mix also change. The higher the weight of the process innovation, the greater will be the efficiency and the lower the product range (less variety of products manufactured). The higher the weight of product innovation, the greater will be the capacity to manufacture different products and the lower the production efficiency (Ahmad and Schroeder 2002). Therefore, the PPM framework proposes the existence of a substitutive relationship between product innovation and process innovation, since along the diagonal of the matrix PPM the presence of product innovation increases at the expense of the presence of process innovation, and vice versa.

Empirical research to test the validity of the PPM framework has been limited, and yielded conflicting results. For example, Safizadeh et al. (1996) verified that the enterprises located on or close to the diagonal always have better performance than those far from the diagonal. However, McDermott et al. (1997) did not entirely validate the propositions of the PPM framework. In fact, a growing number of researchers (Corbett and Van Wassenhove 1993; Dean and Snell 1996; Boyer et al. 1997; Ahmad and Schroeder 2002; Ariss and Zhang 2002) stress that the increasing use of new processing technologies (e.g. computer integrated technology), new product designs (e.g. computer aided design) and new managerial practices (e.g. just-in-time) can eliminate or at least minimise the trade-off between customisation and efficiency. Some of these researchers have found combinations of product innovation and process innovation with high levels of customisation and high levels of efficiency. That is, they found complementary combinations of product innovation and process innovation, away from the diagonal of the product–process matrix.

Also, the so-called integrative view has grown in popularity in recent times in the literature on innovation. This view relies on synthetic thinking, according to which the behaviour of a phenomenon can be understood in terms of its interdependence with other parts that are included within a larger phenomenon that encompasses them (Ackoff 1999). That is why this view, far from considering the different types of innovation as separate elements, presumes complementarity between them (Damanpour 2010). Such an assumption highlights the enormous potential of performing different types of innovation simultaneously (Pisano and Wheelwright 1995), because the aforementioned interdependence can result in gaining a sustainable competitive advantage over time, given that a more complex business strategy will involve a barrier to imitation for competitors (Rivkin 2000).

With regard to its empirical analysis, the relationship between different types of innovation has been scrutinized in various ways: comparing the behaviour of the determinants of each type of innovation through the causal relationships between them and studying their coexistence through the correlation coefficients.

The analysis of the causal relationships between different types of innovation has also proven to be a common practice in the literature. Studies that have addressed this task are based upon certain assumptions, such as the possibility that the process innovation is needed after a product innovation (Fritsch and Meschede 2001) or that process innovation requires subsequent organizational innovations (e.g. Womack et al. 1991). There are many examples of the use of this approach in different empirical analyses. Papers like those by Fritsch and Meschede (2001) and Gunday et al. (2011) have made use of it, albeit with mixed results.

Another group of studies has chosen to analyse the possible interdependence between types of innovation through their correlation coefficients. In this regard, Damanpour and Gopalakrishnan (2001) and Gunday et al. (2011), among others, found a positive relationship between different types of innovation.

Finally, emphasize that, through a review of the previous literature, Damanpour (2010) analysed the possible interdependence between product innovation and process innovation. Accordingly, he considered whether the determinants of the two types of innovation are coincident, which would support the principles of the integrative view, or whether they differ from each other, which would support the tenets of the distinctive view. The results found no evidence to support the different impacts of the determinants analysed (firm size and competitive intensity) on both types of innovation, so the results are consistent with the integrative view.

Thus, the latest contributions stress that the relationship between product innovation and process innovation is complementary in nature. In order to test this complementarity, we use the complementarity approach in the present study (Topkis 1978; Milgrom and Roberts 1990). In this approach, the relationship between variables is tested by pairwise. As we explore the relationship between product innovation and process innovation in the context of three possible variables (product innovation, process innovation and organisational innovation), the number of nontrivial inequality constraints implied by the definition of supermodularity is two (Mohnen and Röller 2005): the first nontrivial constraint inequality is tested among firms without organisational innovation; the second, among firms that perform organisational innovation. If the two inequalities give complementary results, it is said that there is unconditional complementarity. If only one of the inequalities is complementary, it is said that there is conditional complementarity.

In line with the cited literature, we propose the following hypothesis:

Hypothesis 1 The relationship between product innovation and process innovation is unconditional complementarity.

The main objective of this paper is to analyse whether the relationship between product innovation and process innovation is complementary, substitutive or independent. However, as we have introduced organisational innovation as contextual variable, it is also possible to explore the nature of the relationship between organisational innovation and product or process innovation.

In general, the literature on innovation emphasises that different types of innovation influence each other, so they should be implemented simultaneously (Walker 2004; Li et al. 2007). Most of the literature suggests that technological innovation is a driver of organisational innovation (Danneels 2002). However, although there are authors who argue that in many cases organisational innovations facilitate the emergence of technological innovations (Bharadwaj and Menon 2000; Lokshin et al. 2008), in a recent empirical study, Mothe et al. (2015) found that product innovation and process innovation are subject to different organisational management tools.

Product innovation is conducted under conditions of high uncertainty and depends heavily on the creativity of the teams. Normally, creativity does not fructify where there is an excessive order, because the order tends to reproduce itself. The companies with a vocation to innovate in products need a lean and flexible organisation, where the interaction between workers takes place both laterally and vertically, and communication is more a query than an order.[1]

Based on the data available in the database examined in this paper, we consider the impacts of three types of organisational innovation practices (OECD 2005): new organisational method (e.g. knowledge management), new workplace organisation (e.g. lean and just-in-time production) and new external relations (e.g. alliances, outsourcing and subcontracting). As previously emphasised, we intuit a positive relationship between knowledge management and product innovation, another positive relationship between new external relations and product innovation, and that the relationship between new workplace

[1] Usually, the lean and flexible organizational structures are more abundant in organizations that perform basic research, for this reason this kind of organizations also exhibit a greater propensity to innovate in product. For example, the study of Barbero et al. (2014), based on the Spanish economy, analyzes the innovative behavior of four different types of incubator (basic research, university, economic development and private). The basic research incubator is the one that generates more product innovations. Specifically, 45.9 % of companies belonging to basic research incubator have made product innovation. The type of incubator that is closest reached the figure of 22.2 %.

organisation and product innovation may be negative. Therefore, the relationship between product innovation and organisational innovation depends on which of the two opposing forces prevails. Empirical research on this relationship is inconclusive. Schmidt and Rammer (2007) found that the combination of organisational innovation and product innovation has a positive impact on a firm's return on sales. However, Gunday et al. (2011) noted that the relationship between both types of innovation was negative, although not significant.

However, the emergence of complementary/substitutive effects depends not only on the combination of potentially complementary/substitutive business policies. Thus, according to Ballot et al. (2015), the simultaneous execution of product innovation and organisational innovation does not produce the same results in France as in Britain. The specific environment of each country influences the achievement of complementarities by companies.

We use data from the Spanish economy, which is characterised as technologically a follower, with less propensity to innovate than most of the developed economies and also with lower levels of cooperation between organisations. Therefore, we believe that the antagonistic forces of three types of organisational innovation practices tend to negate each other. Also, product innovation does not always need changes at the organisational level. Furthermore, these changes have a cost, so companies often do not make the changes simultaneously. Accordingly, our basic hypothesis on the relationship between product innovation and organisational innovation is as follows:

Hypothesis 2 There is no relationship between product innovation and organisational innovation.

The relationship between organisational innovation and process innovation has been poorly studied (Cozzarin 2015). However, recent research suggests that this relationship is important. Thus, Polder et al. (2010) found evidence that the combination of process innovation and organisational innovation is complementary, while Hervas-Oliver et al. (2014) noted that process innovation is improved with the adoption of organisational innovation. On the contrary, Ballot et al. (2015) identified no relationship between the two types of innovation in the case of firms that do not conduct product innovation, and identified a substitutive relationship in the case of companies that conduct product innovation. However, as we previously mentioned, innovation is not configured for a single practice. In this paper, according to the database examined and the definition of OECD (2005), organisational innovation consists of three managerial practices. Therefore, the relationship between process innovation and organisational innovation also depends on the weight and the sign of influence of each of these practices. In this sense, Le Bas et al. (2015) found that new external relations have a strong negative and significant influence on persistently conducted process innovation, that workplace organisation has a strong positive and significant influence and that knowledge management has a negative but not significant influence. Also, Cozzarin (2015) analysed the relationship in five different productive structures (labour intensive, resource intensive, scale intensive, science and specialised), highlighting mixed results. For example, in the labour intensive—a structure with certain similarities to the Spanish productive structure—none of the three managerial practices have significant influence on the process innovation.

Therefore, the evidence indicates that there is no fixed predetermined relationship between organisational innovation and process innovation. The relationship depends largely on the existing production structure. In this sense, at present, manufacturing organisations have several options to combine process innovation and organisational innovation. Organisations that introduce processing technology (e.g. flexible process) are likely to be

obliged to perform organisational innovations simultaneously or consecutively (e.g. just-in-time and new external relations). However, it is likely that organisations that are not primarily using flexible manufacturing technologies have to face another kind of dilemma: the introduction of organisational innovations tends to replace the introduction of process innovations, i.e. in a context where the use of flexible manufacturing technologies is not widespread, organisational innovation and process innovation are substitutes.

In the Spanish manufacturing sector, only 27.5 % of companies use flexible manufacturing technologies (Arroyo-Gutiérrez and Jiménez-Partearroyo 2013). Consequently, according to the literature review conducted and the reality of the productive structure of the Spanish companies, we propose the following hypothesis:

Hypothesis 3 The relationship between process innovation and organisational innovation is unconditional substitutive.

3 Data, methodology and variables

The data used in this study come from the Technological Innovation Panel (PITEC), managed by the Spanish National Statistics Institute (INE). PITEC is a firm-level panel database on the innovative activities of Spanish firms based on Community Innovation Survey data (CIS).

We based the construction of the panel data database that we use in our study on the PITEC databases for the years 2009, 2010, 2011, and 2012. The number of companies surveyed in these databases is 12,813, 12,817, 12,821, and 12,828, respectively. From these databases, we selected manufacturing companies, because our study focuses on this kind of business. After removing observations with missing values and those that had some sort of impact on the variables of interest, we obtained a database with 4631 observations for each of the years under analysis and 18,524 observations for the whole data database. Our panel data are strongly balanced, that is, all the individual units are observed in all the time periods.

Most of the literature on innovation that has tested the complementarities between different forms of innovation or between different innovation strategies has used cross-sectional data (e.g. Cassiman and Veugelers 2006). Far fewer studies have used panel data (e.g. Martínez-Ros and Labeaga 2009). However, Miravete and Pernias (2006) stressed that the complementarity between product innovation and process innovation endorsed in many studies is largely due to the presence of unobserved heterogeneity. Therefore, given that cross-sectional analysis does not allow us to overcome the problems of unobserved heterogeneity, we inclined towards the use of panel data, which allowed us to avoid it.

Formally, a pair of innovation activities is complementary if the sum of the benefits to do just one or the other is no greater than the benefit of doing both together.

In order to implement the complementarity approach proposed by Milgrom and Roberts (1990), an objective function needs to be established. Suppose there are two innovation activities Xi and Xj, and Z is a vector of exogenous variables in an objective function F(Xi,Xj,Z). Assume that Xi and Xj are dichotomous choices that take the value 1 if they are adopted by the firm and the value 0 if they are not. The complementarity approach regresses an objective on exclusive combinations of innovation activities:

$$F(Xi, Xj, Z) = \beta_{00}(1 - Xi)(1 - Xj) + \beta_{10}Xi(1 - Xj) + \beta_{01}(1 - Xi)Xj + \beta_{11}XiXj + \beta_{z}Z + e$$

where β_{11} measures the cross-partial returns of choosing Xi and Xj jointly; β_{10} for choosing only of Xi; β_{01} for choosing only of Xj; β_{00} for choosing none of them.

Then, the objective function F(Xi,Xj,Z) is supermodular and Xi and Xj are complementary if:

$$\beta_{11} + \beta_{00} - \beta_{10} - \beta_{01} > 0$$

Obviously, the objective function F(Xi,Xj,Z) is submodular and Xi and Xj are substitutes if:

$$\beta_{11} + \beta_{00} - \beta_{10} - \beta_{01} < 0$$

According to Topkis (1978), if there are k variables, the number of non-trivial inequalities to be tested will be $2^{k-2}\sum_{i=1}^{k-1} i$. In our particular case, since there are three variables to consider, the number of restrictions to be tested will be six.

For example, if we have three variables (product innovation, process innovation and organizational innovation) and we want to test for the complementarity between product and process innovation, we have to test the two following non-trivial inequalities:

$$\beta_{110} + \beta_{000} - \beta_{100} - \beta_{010} > 0 \text{ (in absence of organizational innovation)}$$
$$\beta_{111} + \beta_{001} - \beta_{101} - \beta_{011} > 0 \text{ (in presence of organizational innovation)}$$

The econometric technique that we used to estimate the coefficients is maximum-likelihood random effects. This technique allowed us to obtain the coefficients of all the innovation profiles (which are strictly necessary to test the existence of complementarity) to the extent that the output of the regression provided a constant that could be removed to avoid the perfect multicollinearity caused by the presence in the model of all of the dummies representing the eight possible combinations of the three modes of innovation tested (product innovation, process innovation, and organizational innovation). Furthermore, this econometric technique had the added advantage of providing estimations of all the coefficients, even in the event that there were time-invariant regressors.

Another problem that we tried to overcome in this study is referred to as the alleged delay in the influence of technological innovations on the productivity gains of firms. In general, as we noted above, most of the studies on the complementarity of different types of innovation have used cross-sectional data. This involves the implicit assumption that the effect of innovation on firm performance is immediate. However, common sense tells us that, in most cases, the effect of innovations on the productivity of firms tends to appear later (Bessler and Bittelmeyer 2008): newly planted trees do not bear fruit immediately. In this regard, Belderbos et al. (2004) and Bloom and Van Reenen (2002) noted that the impact of innovation on firm productivity occurs with a certain lag. The use of panel data helped to us partially to overcome this problem, because this kind of econometric analysis considers multiple years (in our study, 4 years). However, it seemed desirable to go a little further. Therefore, in this study all the variables used in the econometric estimations belonged to the years 2009, 2010, 2011, and 2012, with the exception of the dummy variables representing the different combinations of innovation types analysed, which belonged to the years 2008, 2009 2010 and 2011. Thus, we could analyse the impact of innovations on the productivity of the firms 1 year later.

To perform the test of complementarity proposed in the seminal study by Milgrom and Roberts (1990), it is necessary to define a function of firm performance. In the strict field of innovation, the two variables most commonly used to measure performance are labour productivity and the percentage of total sales from new products. In this study, we used as the dependent variable the natural logarithm of labour productivity, since our goal was to test the complementarity of product innovation, process innovation, and organizational innovation. Therefore, we used a broad measure of performance that reflected the influences of many different sources that generate productivity. From a strictly conceptual perspective, the percentage of total sales from new products does not collect the direct impact of process innovation and organizational innovation.

Regarding the independent variables representing the three types of innovation analysed, the PITEC asked companies if during the period of analysis they conducted product innovations and process innovations (0 no, 1 yes). In relation to organizational innovations, the PITEC posed three questions (0 no, 1 yes). If the answer to at least one of the three questions was affirmative, we considered that the company made organizational innovation (Mol and Birkinshaw 2009). When estimating the coefficients of the regression model, these three forms of innovation were enlarged to eight possible combinations, of which each combination represented exclusively the interaction of the three analysed innovations (product innovation, process innovation, organizational innovation). For example, (1, 1, 0) represented that only product innovation and process innovation were present. Thus, using the corresponding regression coefficients, we estimated the contributions of combinations of innovations to the labour productivity.

Besides the mentioned combinations of innovations, we introduced into the model different independent variables from different sources of innovation and the obstacles to their development. The variables are the same as those used in other studies exploring the influence of the types of innovation on some measure of performance (e.g. Ballot et al. 2015). A precise definition of how the variables were constructed can be found in Table 1.

4 Results and discussion

Table 2 contains the results of the maximum-likelihood random effects estimation for labour productivity. The estimate of the coefficients is needed in order to perform hypothesis tests of the complementarity approach in the post-estimation phase. Therefore, as in this paper estimation of the coefficients is not an objective, but an instrument, we make no comment on its significance.

Table 3 shows the results of the tests of complementarity/substitutability that we have carried out. For each pair of variables it is checked first whether the two types of innovation analysed have a relationship between them. If at statistically significant level the test indicates that there is no relationship, then we are able to accept the distinctive view. Conversely, if the test indicates that the relationship is significant, then we have to perform a second test in order to confirm whether this relationship is complementary or substitutive. If it is a substitutive relationship, this means accepting the proposals of the PPM framework. If the relationship is complementary the propositions of integrative view are accepted, as well as those of the authors who have introduced reformulations to the PPM framework (PPMR), integrating the influence of new processing technologies, new product designs and new managerial practices on the product–process matrix (e.g. Ahmad and Schroeder 2002).

Table 1 Variable definitions and descriptive statistics

Variable name	Variable construction	Sample mean/ Standar dev.
Labour productivity (dependent variable)	Log of sales per employee	5.1974/0.3603
Product innovation	The firm introduces a new product (0,1)	0.6053/0.4887
Process innovation	The firm introduces a new process (0,1)	0.6109/0.4875
Organisational innovation	If the company makes or modifies at least one of the following practices or methods: workplace organization, new organizational method and external relations (0,1)	0.4394/0.4963
RD intensity	Relationship between internal and external R&D expenditures and total sales of the firm	0.0398/0.3047
Legal protection	Sum of the scores of the following methods for protecting inventions or innovations (1 (used) and 0 (not-used)): Patents; Registration of design; Trademarks; Copyright. Rescaled between 0 (not-used) and 1 (high)	0.0931/0.1857
Internal sources	Importance of innovation inside the company or the group for innovation process (number between 0 (not used) and 3 (high)). Rescaled between 0 (not used) and 1 (high)	0.6073/0.4293
Industrial external sources	Sum of the scores about the importance of the following information sources for the innovation process. Those sources are related to de industry (number between 0 (not used) and 3 (high)): Suppliers; Clients; Competitors; Fairs and exhibitions; Journals, and Professional associations. Rescaled between 0 (not used) and 1 (high)	0.3271/0.2803
Scientific external sources	Sum of the scores about the importance of the following information sources for the innovation process. Those sources are related to the scientific field (number between 0 (not used) and 3 (high)): Commercial laboratories; Universities; Public research centers and technological centers. Rescaled between 0 (not used) and 1 (high)	0.2175/0.2624
Cost obstacles	It is a measure of the importance of the costs as an obstacle to innovation process (number between 0 (not relevant) and 3 (high)). Rescaled between 0 (not relevant) and 1 (high)	0.6225/0.3553
Financial obstacles	The sum of the scores about the importance of the following obstacles to the innovation process (number between 0 (not relevant) and 3 (high)): lack of funds within the company or group and lack of external funding. Rescaled between 0 (not relevant) and 1 (high)	0.6153/0.3408
Knowledge obstacles	The sum of the scores about the importance of the following obstacles to the innovation process (number between 0 (not relevant) and 3 (high)): lack of qualified personnel; lack of information on technology; lack of information on market, and the difficulty of finding cooperation partners. Rescaled between 0 (not relevant) and 1 (high)	0.3960/0.2580

Table 1 continued

Variable name	Variable construction	Sample mean/ Standar dev.
Market obstacles	The sum of the scores about the importance of the following obstacles to the innovation process (number between 0 (not relevant) and 3 (high)): market dominated by established enterprises, and uncertain demand for innovative goods or services. Rescaled between 0 (not relevant) and 1 (high)	0.5317/0.3140
Group	The firm belongs to a group (0,1)	0.4036/0.4906
Cooperation	The firm cooperates with other enterprises or institutions (0,1)	0.2722/0.4451
Export intensity	Export share in total firm sales	0.2904/0.3159
Size	Log of number of employees	1.7175/0.6138

Table 2 Productivity regressions: dependent variable labour productivity

	Coef.	SE
RD intensity	−0.0593531***	0.0094768
Legal protection	0.0044375	0.0218706
Internal sources	0.1134561***	0.0114578
External sources industrial	0.0590969***	0.0209226
External sources science	0.008809	0.0206657
Cost obstacles	0.101466***	0.0133439
Financial obstacles	0.0756353***	0.015054
Knowledge obstacles	0.0376935**	0.0183013
Market obstacles	0.1126491***	0.0143824
Group	0.0152779	0.0132572
Cooperation	−0.0073481	0.0093768
Export intensity	0.1328277***	0.0147085
Size	0.6941719***	0.0202447
(0, 0, 0)	3.534184***	0.039911
(1, 0, 0)	3.369422***	0.0385783
(0, 1, 0)	3.541942***	0.0409542
(0, 0, 1)	3.519044 ***	0.0431752
(1, 1, 0)	3.457969***	0.0396033
(1, 0, 1)	3.323074***	0.0401565
(0, 1, 1)	3.489016***	0.0411989
(1, 1, 1)	3.432832 ***	0.039514
Year 2010	0.093186***	0.0065699
Year 2011	0.0368335***	0.0067309
Year 2012	0.1136998***	0.006804
Model	Wald $Chi^2(25) = 434{,}650.96$ p value = 0.0000	

Statistical significance of the coefficients: at *** 1 %, ** 5 % and * 10 %

Table 3 Complementarity tests

	Chi^2	*p* value
Product − process		
Organizational innovation = 0		
T1: $\beta_{110} + \beta_{000} - \beta_{010} - \beta_{100} = 0$	19.41	0.0000
T2: $\beta_{110} + \beta_{000} - \beta_{010} - \beta_{100} \leq 0$		0.0130
Complements/substitutes/no relation	Complements	
Organizational innovation = 1		
T1: $\beta_{111} + \beta_{001} - \beta_{011} - \beta_{101} = 0$	28.34	0.0000
T2: $\beta_{111} + \beta_{001} - \beta_{011} - \beta_{101} \leq 0$		0.0017
Complements/substitutes/no relation	Complements	
Product − organisational		
Process innovation = 0		
T1: $\beta_{101} + \beta_{000} - \beta_{100} - \beta_{001} = 0$	1.53	0.2158
T2: $\beta_{101} + \beta_{000} - \beta_{100} - \beta_{001} \leq 0$		
Complements/substitutes/no relation	No relation	
Process innovation = 1		
T1: $\beta_{111} + \beta_{010} - \beta_{110} - \beta_{011} = 0$	2.24	0.1348
T2: $\beta_{111} + \beta_{010} - \beta_{110} - \beta_{011} \leq 0$		
Complements/substitutes/no relation	No relation	
Process − organisational		
Product innovation = 0		
T1: $\beta_{011} + \beta_{000} - \beta_{010} - \beta_{001} = 0$	2.56	0.1094
T2: $\beta_{011} + \beta_{000} - \beta_{010} - \beta_{001} \leq 0$		0.9453
Complements/substitutes/no relation	Substitutes	
Product innovation = 1		
T1: $\beta_{111} + \beta_{100} - \beta_{110} - \beta_{101} = 0$	1.12	0.2891
T2: $\beta_{111} + \beta_{100} - \beta_{110} - \beta_{101} \leq 0$		
Complements/substitutes/no relation	No relation	

The hypothesis test conducted on the relationship between product innovation and process innovation indicates that this is an unconditional complementary relationship, as the two complementary tests are positive, both among companies that do not perform organisational innovation and those that do. Therefore, the results plainly support the integrative view. These results also support the proposals of the PPMR, because the relationship is complementary among the companies that have introduced organisational innovations (new managerial practices). In addition, it is also possible that the complementarity detected among the companies that have not performed organisational innovations is due to the use of new processing technologies, and/or new product designs, an issue that also supports the proposals of PPMR. Unfortunately, almost all of the public databases on innovation do not have disaggregated data in order to make deeper explorations. These results partially coincide with those of Ballot et al. (2015), who found a complementary relationship between product innovation and process innovation in the French and UK companies which did not perform organisational innovation, and that there was no relationship when companies perform organisational innovation.

Therefore, in this paper, Hypothesis 1 is supported by the unconditional complementarity between product innovation and process innovation.

The results of hypothesis tests between product innovation and organisational innovation indicate that there is no relation between the two types of innovation. Among the companies that do not innovate in process and those that do, the result is the same: there is no statistically significant relationship between both types of innovation. This result supports the distinctive view. In this regard, we have already indicated that for product innovation the weight of organisational structure should not be too high. An excessively rigid and formalised structure stifles creative impulses. Product innovation requires powerful and sophisticated means (e.g. product design technologies) and the preponderance of informal over formal relations within the corresponding departments. In these contexts, organisational innovations (e.g. knowledge management and alliances) may have complementary effects with product innovation (for a review on the relationship between alliances and innovation, see Di Guardo and Harrigan 2012 and Colombo et al. 2015). However, overall, the reality of the Spanish productive structure is characterised by a predominance of small companies using traditional technology and with little cooperative relationships with other organisations. Therefore, we suggest that there is probably no connection between the two types of innovation in the Spanish productive structure. In this regard, Hypothesis 2 is supported by the unconditional no relation between product innovation and process innovation. This result agrees with the finding of Ballot et al. (2015) for the UK economy and partially coincides with that obtained for the French economy (complementary conditional). There is also agreement with the result obtained by Cozzarin (2015) for a labour intensive production structure, a distinct characteristic of the Spanish production system.

Finally, with regard to process innovation and organisational innovation, the results of hypothesis tests partially support Hypothesis 3. The relationship between both types of innovation is conditional substitutive. The relation is substitutive among firms that do not perform product innovation, and there is no relation among those that do perform product innovation. The relation found by Ballot et al. (2015) for France and the UK is also conditional substitutive, but such a relationship of substitutability occurs only between companies that carry out product innovation.

In the context of the productive structure of Spanish manufacturing companies, the substitutive relationship between process innovation and organisational innovation in companies that do not perform product innovation seems consistent. These are mostly companies that do not employ flexible manufacturing technologies. In such companies the improvements in the production process come from the purchase of machinery and equipment that incorporate more efficient traditional technologies (maintaining the same organisation of the production process) or from the modification of the organisation of the production process (using the same machinery and equipment that was previously used). In situations of this kind, process innovations and organisational innovations tend to substitute for each other, because when innovation is at the process level, there is not innovation at the organisational level, and vice versa.

Thus, the relationship between process innovation and organisational innovation complies with the tenets of the distinctive view, because it must be taken into account that the PPM framework only applies to the relation between product innovation and process innovation.

5 Conclusions

There is no unique relationship between the different types of innovation. The nature of the relationship depends on the types of innovation that interact. Furthermore, these relationships also depend on the level of technological complexity of the production structure under analysis and on the different industry characteristics. These different characteristics generate differences in the productivity of various types of innovation (Liang and Zhang 2012). Therefore, the relationship between two types of innovation is not necessarily the same in all countries. In addition, these relations are not stable, because they change over time due to the emergence and impact of new processing technologies, new product design technologies and new managerial practices. This heterogeneous and unstable reality has resulted in three different approaches in the innovation literature.

The first is known as the distinctive view and asserts that relationships are not complementary, i.e. different types of innovation are not related, or even that a relationship can be substitutive. Consequently, companies do not acquire any benefit from the simultaneous implementation of different types of innovation.

At the opposite end is positioned the integrative view. This approach emphasises that the different types of innovation are related to one another, and that this relationship is complementary. Therefore, the joint implementation of different types of innovation has impact on the company's performance greater than the sum of their separate implementations.

Finally, from within the sphere of the relationship between product innovation and process innovation, the PPM framework has emerged. The original version of this framework stresses that the relationship between product innovation and process innovation is substitutive: when the company increases its levels of customisation, the importance of product innovation increases at the expense of process innovation; when customisation requirements decrease, the opposite is true.

However, with the introduction in the production process of new processing technologies, new product design technologies and new managerial practices, some authors have stressed the need to reformulate the Original PPM. Ahmad and Schroeder (2002) have proposed the entry of a third axis to collect these new technologies and new managerial practices. In this new scenario, product innovation and process innovation are complementary.

The main objective of this paper is to test the relationship between product, process and organisational innovation, to check which approach prevails in each of the relationships. The tests were carried out in the context of Spanish manufacturing firms. To accomplish this task we used the complementarity approach. This approach is ideal for our purposes, since each test performed allows us to discern whether the relationship is substitutive or complementary or there is no relationship between the variables.

The performed tests indicate that the relationship between product innovation and process innovation is unconditional complementary. Therefore, this test supports the integrative view and the reformulated PPM framework. This occurs even in a production system such as the Spanish one, with a significant preponderance of traditional technologies.

As regards product innovation and organisational innovation, the tests indicate that there is no relationship between the two variables in an unconditional manner. This is likely to constitute a peculiarity of the Spanish productive system, characterised by a very low use of new processing technologies, new product design technologies and new

managerial practices. However, the same relationship occurs in the English production system (Ballot et al. 2015). In any case, the test indicates that the joint implementation of both types of innovation holds no advantage or disadvantage for Spanish companies. Thus, the results of this study on the relationship between product innovation and organisational innovation support the distinctive view.

Finally, we found that the relationship between process innovation and organisational innovation is substitutive among firms that do not perform product innovation. In this case, it appears that companies establish process innovation or organisational innovation, but not both at once. This suggests that the right strategy is to achieve complementarities by combining product innovation and process innovation. Organisational innovation can be the necessary companion, even the catalyst or trigger for certain complementarities, but tests reveal that without the simultaneous presence of product innovation and process innovation it is difficult to achieve complementarities. Moreover, among the companies that perform product innovation, the complementarity test indicates no relation between process innovation and organisational innovation. Therefore, in the relationship between process innovation and organisational innovation, the performed tests support the distinctive view.

In summary, we found that none of the three approaches is universally applicable to all pairs of relationships between different types of innovation. Therefore, as pointed out by Cassiman and Veugelers (2006) and Ennen and Richter (2010), the combination of corporate policies is complex and does not result in complementary effects per se, to the extent that the appearance of complementarity also depends on many other factors and the existence of favourable contextual conditions. However, we found that the relationship between product innovation and process innovation is complementary both when companies undertake organisational innovations and when they do not. This finding may be an important guide in the decision-making of managers and policy-makers. Managers can acquire additional levels of efficiency if they analyse the investments at the technological level as a whole, and implement them together. Moreover, this knowledge can help policy-makers to design better their policies to promote innovation.

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