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Governing Innovation Projects in Firms: The Role of Competition between Innovation Projects and Interdepartmental Collaboration

Younes Iferd[1], Torben Schubert[2]

Karlsruhe, Fraunhofer ISI

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[1] Fraunhofer Institute for Systems and Innovation Research ISI and Christian-Albrechts-Universität zu Kiel

[2] Fraunhofer Institute for Systems and Innovation Research ISI and CIRCLE, Lund University

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Abstract

The existing literature shows that interdepartmental collaboration within companies enhances innovativeness due to easier access to and integration of knowledge spread over dispersed actors. As companies are well aware of these benefits they also use competition between innovation projects to organize their innovation projects. Such competitive mechanisms have often been regarded as problematic because of their adverse effects on collaboration and knowledge sharing. At the same time, they have the power to expedite innovation processes. Based on German CIS data, we use a stochastic frontier approach to show that competition across innovation projects tends to increase innovation efficiency for firms faced by predatory product market competition, while interdepartmental collaboration is efficiency increasing when competition is low. Furthermore, we were also able to show that with increasing innovation radicalness interdepartmental collaboration enhances the innovation process and that with increasing innovation incrementality competition across innovation projects becomes beneficial.

1 Introduction

Over the last few years, firms have become more and more interested in stimulating, facilitating, and maintaining collaboration between their departments in innovation processes. Empirical evidence shows that interdepartmental collaboration increases firms’ innovation performance (Luca and Atuahene-Gima 2007; Swink and Song 2007; Troy et al. 2008) because it increases knowledge integration (Luca and Atuahene-Gima 2007) and thereby increases the number of ideas that can lead to innovations (Milliken and Martins 1996) and improve the functional performance of new products (Olson et al. 2001).

Creating incentives for interdepartmental collaboration, however, requires appropriate incentives. Several authors have suggested that incentive schemes inside firms should be low powered because otherwise knowledge sharing and collaboration will be undermined (Kogut and Zander 1992). Typical problems are information hoarding and knowledge monopolization (Nickerson and Zenger 2004). Therefore a recommendation seems to be to avoid elements of internal competition concerning innovation.

Despite these arguments, competition in innovation processes exists on another organizational level. Instead, firms often implement explicit elements of competition. A leading example is parallel innovation, where several independent teams compete to solve the same problem (Nelson 1959, 1961; Abernathy and Rosenbloom 1969). The benefits of parallel innovation are that firms can evaluate more than one solution simultaneously (Smith and Reinertsen 1991) and that performance incentives are high, whereas the downside is that collaboration across the innovation process is undermined. The aim of this paper is threefold. First we highlight that the simple recommendation either to avoid or to implement competition is too simple. In fact, interdepartmental collaboration can co-occur with competition between individual innovation projects. Thus, more attention needs to be paid to a distinction between the organizational level of the competition/collaboration trade-off. Second, we provide evidence of the effects of competition between innovation projects and interdepartmental collaboration. In particular, we propose that firm-internal and firm-external key contingencies moderate the importance of interdepartmental collaboration and competition between research projects.

As far as the external contingencies are concerned, we focus on the degree of competition on the final product market. Our main argument is that enterprises usually offer homogenous goods when they are subject to strong competition. Under these circumstances, innovative strategies tend to be directed to quick reaction times and to improving existing products' cost performance parameters (Green and Scotchmer 1995). This may be fostered by stronger competition between individual innovation projects, because performance incentives on the individual level can be boosted. In contrast, low degrees of competition tend to be associated with higher entry barriers, which are often the result of high degrees of product differentiation (Shaked and Sutton 1982). Pure speed may often not be a central strategic parameter, contrary to the ability to create unique products. This ability may require much more internal knowledge sharing between different functions/departments within the cooperation including R&D, sales, marketing, and production staff. We therefore assume that low degrees of market competitiveness are associated with higher degrees of knowledge sharing between different departments.

On the internal side we focus on the radicalness of the innovation strategy. Radical innovations require the generation of new knowledge (Levinthal 1997; March 1991) which is often based on recombining (Fleming 2001) and integrating previously unrelated knowledge bases (Grant 1996). As these knowledge bases are rather spread out across different employees (Yayavaram and Ahuja 2008; Nickerson and Zenger 2004), knowledge sharing across departments becomes more important. Incremental innovations, however, are rather based on a consolidation of existing knowledge. The knowledge exchange between departments may become less important because the novelty of the innovations is lower while the importance of speed and time to market offered by "parallel search" (Pich et al. 2002) is higher. Therefore the competitive generation of knowledge is advantageous.

Using the German Community Innovation Survey (CIS) data from 2011 we employ a parametric frontier approach to measure the efficiency of the innovation processes in the sample firms. We show that enterprises, exposed to strong product market competition, increase their innovation efficiency, when they put a higher emphasis on competition between innovation projects. We also find evidence that collaboration between departments may be more efficient when radical innovations are concerned. Correspondingly, competition between innovation projects tends to be more efficient in the case of incremental innovations.

2 Theory and hypotheses

It is commonly argued that internal collaboration between departments within firms enables companies to generate new knowledge by combining complementary types of knowledge (Dalkir 2011) held by different key actors (employees and departments) that are involved in the innovation process (Hansen 2009). Consequently, collaboration between departments offers the possibility of combining unconnected ideas, technologies and processes which involves increasing enterprises‘ potential to introduce breakthrough innovations onto the market (Singh and Fleming 2010). Strong incentive mechanisms (e.g. strong elements of competition) are often seen as detrimental, because they tend to dissuade the sharing of knowledge.

While this generic argument has some appeal, it is problematic for two reasons. First, it does not sufficiently distinguish between the level of collaboration or competition. We will introduce a distinction between first, the collaboration between different functional departments within the firm and secondly, the degree of competition between individual projects within the firm. Second, we will analyze the role of key-contingencies governing the importance of interdepartmental collaboration and competition between projects.

Interdepartmental collaboration can boost innovative performance by contributing to effective knowledge sharing/transfer across departments. At the same time implementing collaboration is often difficult also because incentives for information hoarding need be overcome (Nickerson and Zenger 2004; Foss et al. 2010). In addition, knowledge integration is often costly (Grant 1996) even if disincentives for knowledge hoarding are successfully managed, e.g. due to coordination problems (Becker and Murphy 1992). This is particularly relevant when implicit knowledge is involved which is difficult to transfer (Grant 1997). It is also not easy for enterprises to control each actor’s contribution when production is organized in teams (Eisenberg 2001; Alchian and Demsetz 1972). When the actors anticipate that their enterprise is incapable of checking and evaluating each individual‘s knowledge output then their motivation to collaborate diminishes (Aghion and Tirole 1994), which makes enterprises vulnerable to problems of shirking and free-riding (Pisano 1990). Overcoming or at least reducing these difficulties by creating a suitable compensation structure or by creating a corporate culture of knowledge sharing becomes necessary.

On the level of individual projects, the innovation processes in firms are often organized as a series of directly competing projects, i.e. parallel innovation (Abernathy and Rosenbloom 1969; Gerchank and Mark Kilgour 1999; Ding and Eliashberg 2002). The downside of competition between individual innovation projects are the reduced incentives to share knowledge across teams, which eventually leads to cost duplications. On the other hand, competition between innovation projects allows for fast scanning and the assessment of a large number of technological alternatives or different innovation opportunities where the best is eventually chosen (Kornish and Ulrich 2011). Therefore increasing competition between innovation projects may increase the efficiency of the use of scarce resources devoted to innovation processes (Birkinshaw 2002; Carroll and Tomas 1995; Marino and Zábojník 2004).

In the following we will argue that the choice for interdepartmental collaboration and competition between innovation projects will depend on both internal and external contingencies. Specifically, we will analyze the role of the strength of product market competition and the firms’ orientation towards radical vs. incremental innovations.

2.1 Product market competition

Strong degrees of product competition exert enormous pressure on companies. Such types of competition are usually the result of more or less homogenous products. Competition parameters then usually shift to the price or cost-performance-ratios. This requires firms to reduce their production costs or to improve the performance of the product (Green and Scotchmer 1995). Speed also becomes a competition parameter because customer loyalty is often lower when compared to differentiated product markets. Thus product improvements by rivals can undermine other companies‘ own market shares quickly (Christensen 1997; Martin and Mitchell 1998). Increasing competition between parallel innovation projects can be advantageous due to two potential effects. In particular, parallel innovation allows for the quicker scanning of a broader range of alternatives or it can result in technology races to find a solution for the same problem (Reinganum 1985). The time to success may be sped up because the likelihood that at least one project finds a solution within a specified time increases in the number of projects.

In contrast, low degrees of product competition are often associated with differentiated products with high degrees of product differentiation (Shaked and Sutton 1982). Under such conditions customer loyalty is usually higher because customers value the specifics of a certain product. Even if a competitor introduces a novel feature through innovation, the loss of customers may be limited (Gupta and Loulou 1998). Therefore, speed may be less important, reducing the importance of parallel innovation. Instead, the ability to create unique products which appeal to the specific preferences of the customer base becomes crucial. Effectively mastering these requirements tends to demand a considerable degree of knowledge sharing not only between projects but also between functional departments (Lawson et al. 2009), as a result of the less-clearly identifiable customer needs. Sharing information about the appropriate direction of the innovation projects may thus be important. This requires the effective collaboration across functional departments, e.g. marketing, sales, and product development.

Hypothesis 1: The higher the product market competition, the more advantageous competition between innovation projects becomes.

Hypothesis 2: The lower the product market competition, the more important effective collaboration between functional departments becomes.

2.2 Radical vs. incremental innovation

Radical innovation aims at meeting consumers‘ or the markets‘ new demands (Benner and Tushman 2003; Danneels 2002) by offering new designs, opening up new markets and developing new distribution channels (Abernathy and Clark 1985). Abernathy und Clark (1985) emphasize that radical innovations destroy or significantly reduce the value of the company’s existing knowledge bases (Tushman and Anderson 1986).

We argue that innovation projects with radical outcomes imply the creation of new knowledge or significant deviations from existing knowledge (Benner and Tushman 2002; Levinthal and March 1993; McGrath 2001). If knowledge is spread across different actors in the organization, supporting the free flow of knowledge through knowledge sharing becomes a central issue. Knowledge sharing may be highly important because of the need to recombine different knowledge sources within the firm (Fleming 2001; Neuhäusler et al. 2015). In that respect it can be expected that firms with greater interdepartmental knowledge sharing and lower competition between individual innovation projects perform better.

Hypothesis 3a): The higher the radicality of innovation activities, the more advantageous is the collaboration between functional departments.

Hypothesis 3b): The higher the radicality of innovation activities, the less beneficial is the competition between individual innovation projects.

Instead, incremental innovations aim at meeting the demands of existing consumers and markets (Benner and Tushman 2003; Danneels 2002). They extend existing knowledge and capabilities and achieve an improvement of existing products and distribution channels (Abernathy and Clark 1985). Therefore incremental innovations build on the enhancement of existing competences and structures (Abernathy and Clark 1985; Benner and Tushman 2002; Levinthal and March 1993; Lewin et al. 1999). Incremental innovation usually builds on a knowledge base that is well understood. The underlying scientific principles are usually codified. Instead of recombining very distant knowledge and thereby effectively overturning the existing knowledge base, investments are made into strengthening, deepening and extending the existing competence and knowledge base (Tushman and Anderson 1986). This usually requires specialized expert knowledge rather than general knowledge from diverse knowledge bases (Dosi et al. 2006). Thus, the need to share knowledge between innovation projects becomes less pressing. Instead, the speed to implement incremental improvements may be considerably more important. Also the need for cross-functional collaboration may be lower, because competitor behaviors, consumer preferences and technological principles are very well understood. In general, the environments are relatively stable. This reduces the need for intense communication across departments. This may even be detrimental because it slows down the speed of decision-making processes.

Hypothesis 4a): The higher the incrementality of innovations, the more advantageous a competitive organization of innovation projects becomes.

Hypothesis 4b): The higher the incrementality of innovations, the less advantageous cross-functional collaborations become.

3 Data and methodology

When studying firm-level innovation, researchers distinguish between two key concepts, innovation input and innovation output (Adams et al. 2006). While most researchers assume that a positive correlation exists between innovation input and innovation output (Acs and Audretsch 1988; Dosi 1982), they differ in their conversion rate, because their innovation capabilities are heterogeneous (Dosi and Nelson 2010). The heterogeneity between the firms directly draws attention to the role of efficiency of firms' innovation processes. In this article we will therefore test our hypotheses by investigating the predicted relationship in terms of the efficiency of the resource use in the innovation processes by setting inputs of the innovation process in relation to the resulting outputs. We will now describe the data and the variables used for analysis and the methodology in more detail.

3.1 Description of data

We base our analysis on the Mannheim Innovation Panel (MIP), which is the German contribution to the "Community Innovation Surveys" (CIS) of the European Commission. MIP is based on a stratified random sample of companies located in Germany whose economic activities cover a large part of the economy and include firms in mining, manufacturing, other industries, wholesale trade, transportation and storage, information and communication services, financial and insurance activities, and other business-oriented services.

Peters and Rammer (2013) provide a detailed MIP overview. In this study we use the survey from 2011 (in which 6851 companies participated) and we restrict ourselves to innovative firms that continually or occasionally engage in internal R&D activities. We also exclude the services sector, as the innovation process of the services and the manufacturing sectors are not comparable. This heterogeneity manifests itself particularly in the intangible character of services. This makes measuring innovations with conventional methods (e.g. R&D investments) more difficult (Gallouj and Weinstein 1997) and would lead to results which are difficult to interpret. Companies with fewer than five employees are also excluded from this data set. Our data set comprises 1610 firms in total. After the exclusion of companies, which exhibit missing input, our data consists of 478 observations.

3.2 Variables of analysis

A descriptive depiction of the variables used in this study can be seen in Table 1 below.

Table 1. Descriptive statistics of the variables used

Variables	**Description**	**Mean**	**Std**
stochastic distance frontier function			
OUTPUT			
Y_{INO}	Share of turnover with new or improved products* (%)	29.72	25.5
Y_{RED}	Per unit cost reductions (%)	5.51	6.51
INPUT			
X_{EXP}	Innovation expenditures as a share of turnover * (%)	12.8	34.52
X_{RDP}	R&D personnel as share of total personnel ** (%)	13.42	16.8
*Sector controls****			
SB	Science based (0/1)	0.29	0.27
FP	Fundamental basis (0/1)	0.08	0.42
CS	Complex (knowledge) system (0/1)	0.24	0.39
PE	Production engineering (0/1)	0.18	0.37

Variables	Description	Mean	Std
CP	Continuous process (0/1)	0.16	0.73
Inefficiency model			
Company competences for innovations			
dev.Techn.Sol	Development of new technological solutions	4.01	0.73
creat.Empl	Creativity of employees	3.84	0.69
comp.Proj	Promoting internal competition of project	2.21	0.90
collab.Departm	Internal collaboration between departments/ functional area	3.70	0.82
Moderating factors			
radic.Innov	share in sales of radical product innovations *	10.24	17.79
incre.Innov	share in sales of incremental product innovations *	9.16	17.85
prod.Mar.Comp	Product market competition	1.70	0.85

(*) as a share of the total company turnover

(**) as a share of the total number of employees

(***) as a share of the total number of companies

3.2.1 Variables of the stochastic distance frontier function

As technological innovations can comprise product as well as process innovations we consider both the revenue from product and process innovations on the output side (in the stochastic frontier distance function model (Eq.1)). We use the share in turnover for new products (Mairesse and Mohnen 2002) as the generally accepted proxy for the success of product innovation because it represents an ex-post result in which the market has positively welcomed the new products introduced by the firm (Barlet et al. 2000) whereas the effects of process innovation are recorded by the achieved reduction of cost per unit as the process innovation activates are typically introduced for reducing costs (Simonetti et al. 1995).

On the input side we use the innovation expenditures as a share of turnover, measured in terms of the total turnover and the share of R&D employees of the total number of employees. In addition to internal and external R&D expenditure, the expenditure for innovations also comprises other payments for innovations as for example, further education for innovation, purchasing machinery, plants and software for innovations and market launches of innovations. Expenditure for innovations therefore comprises also the non-

R&D innovation expenditures, which are of great importance for innovation success (Felder et al. 1996)

Empirical studies have confirmed that innovation patterns are technologically specific and change for different sectors (Nelson and Winter 1982; Dosi 1988). Sectors strongly differ in technological opportunities and appropriability conditions, as well as in the cumulative nature of the knowledge base (Marsili 2001). In order to control the sector-specific and innovation-driven effects we use the sector taxonomy developed by Marsili (2001) in this study. For a short summary of the most important properties of the individual groups see annex Table A.1 and for detailed information see Marsili (2001).

3.2.2 Variables of the inefficiency model

3.2.2.1 Company competences for innovation

In the efficiency model in Eq. (3) different variables are included in order to explain the technological inefficiency of companies. These variables explain how competent a company is in terms of innovations and quality which range from 1 (poor) to 5 (strong). These variables are: development of new technological solutions, creativity of employees, support of internal competition of project and internal collaboration of departments and functional areas.

3.2.2.2 Moderating factors

In line with our hypotheses we use three moderating factors. The first is the degree of the product market competition (also qualitative, weak competition=0 ... very strong competition=3).The second moderating factor provides information on the degree of newness of the innovations and is covered by two variables. The first variable is the share of turnover of the product innovations launched between 2008 and 2010 which the respective company introduced onto the market as the first supplier. This variable measures the economic success of the radical innovations and consequently the radicality of the innovations. The second variable measures the economic success of the incremental innovations and consequently also the incrementality of the innovations. It is covered by the share of turnover of the product innovations launched between 2008 and 2010 for which there are already alternatives or similar products on the market.

3.3 Estimation approach

As mentioned above, we will test our hypotheses by investigating the predicted relationship in terms of the efficiency of the resource use in the innovation processes. Measurement of efficiency starts with the description of production technology in the form of frontiers. This study is based on the firm level knowledge production function of Pakes and Griliches (1980) and used the R&D expenditure and R&D manpower as inputs to produce multiple outputs, including share of turnover with new or improved products (revenue from product innovation) and per unit cost reductions (revenue from process innovation). This study thus applies the output distance function approach of SFA (Coelli and Perelman 1996) to evaluate the firm level R&D efficiency by considering multiple outputs. There are two components for the analysis of innovative efficiency; the first one is to estimate the stochastic frontier output distance function that serves as a benchmark to estimate the technical efficiency. This stage is based on the functional form of the distance function of Shepard (1970) and can be implemented as follows for a production technology with two outputs ($\mathrm{y_{1i}\ and\ y_{2i}}$) and two inputs ($\mathrm{x_{1i}\ and\ x_{2i}}$) (for a detailed illustration see Coelli and Perelman (1996)):

$$
\begin{aligned}
&-ln\, y_{1i} = \alpha_0 + \alpha_1\, ln\left(\frac{y_{2i}}{y_{1i}}\right) + 0.5\, \alpha_{11} ln\left(\frac{y_{2i}}{y_{1i}}\right)^2 + \beta_1 lnx_{1i} + \beta_2\, lnx_{2i} + \beta_{12} lnx_{1i} lnx_{2i} + \\
&0.5\, \beta_{11} lnx_{1i}{}^2 + 0.5\, \beta_{22} lnx_{2i}{}^2 + \gamma_1 lnx_{1i}\ \ ln\left(\frac{y_{2i}}{y_{1i}}\right) + \gamma_2 lnx_{2i}\ \ ln\left(\frac{y_{2i}}{y_{1i}}\right) + u_i - v_i \qquad (1)
\end{aligned}
$$

v_i is a random error term and u_i is a not-negative random variable which stands for a technical inefficiency. The second component concerns the explanation of variations in efficiency and specifies the inefficiency term (u_i) as a function of possibly exogenous factors ($\mathrm{z_{li}}$), which influence technological inefficiency (Battese and Coelli 1995):

$$
u_i = \mathrm{\delta_0} + \sum_{\mathrm{l=1}}^{\mathrm{k}} \mathrm{\delta_k z_{li}} + \mathrm{\varepsilon_i} \qquad (2)
$$

The second Model (Eq.2) is more interesting for our study, as we will test our hypotheses there.

The unknown parameter of the distance translog function (Eq.1) and the inefficiency model (Eq.2) are simultaneously estimated with the Maximum-Likelihood-Method. The test for the absence of the inefficiency effects and the verification that the technical inefficiency is not stochastic are done using a generalized-likelihood-ratio test.

We will now briefly explain a standard framework in which *H1-H4* can be estimated.

3.4 Estimation strategy

H1 and ***H2***: *H1* states that firms, which are subject to more intense product market competition, will have more efficient innovation processes if they strongly rely on competition between their internal innovation projects. According to *H2* we expect that if there is a low level of product market competition, firms that succeed to fertilize cross-functional collaborations internally well achieve a higher innovation efficiency. For testing these hypotheses we parameterize the inefficiency model (Eq.2) as follows:

$$\mathrm{inef.} = \delta_0 + \mathrm{X}\delta + \delta_{\mathrm{m1}}(\mathrm{comp.Proj} * \mathrm{prod.Mar.Comp}) + \delta_{\mathrm{m2}}(\mathrm{collab.Departm} * \mathrm{prod.Mar.Comp}) + \varepsilon \quad (3)$$

This model includes two interaction terms, which are at the core of hypotheses *H1* and H2. The X Matrix contains the variables that constitute the interaction terms, the development of new technological solutions and the creativity of employees. The last two variables say nothing about our hypotheses but they are incorporated in the model in order to improve the goodness of fit of the inefficiency model.

If *H1* is true the coefficient for the interaction term between promoting internal competition between innovation projects and predatory competition on the market should be negative because this will indicate reduced inefficiency. If H2 is true, the coefficient for the interaction term between internal collaboration between departments and functional areas and predatory competition on the market should be positive.

H3 and *H4*: Based on our two indicators of radical innovation and incremental innovation, we parameterize the inefficiency model (Eq.2) as follows:

$$\mathrm{inef.} = \delta_0 + \mathrm{X}\delta + \delta_{\mathrm{m1}}(\mathrm{collab.Departm} * \mathrm{radic.Innov}) + \delta_{\mathrm{m2}}(\mathrm{comp.Proj} * \mathrm{radic.Innov}) + \delta_{\mathrm{m3}}(\mathrm{comp.Proj} * \mathrm{incre.Innov}) + \delta_{\mathrm{m4}}(\mathrm{collab.Departm} * \mathrm{incre.Innov}) + \varepsilon \quad (4)$$

Under *H3a* we expect that the coefficient of interaction between the share of turnover from radical innovations and internal collaboration between departments and functional areas is negative (indicates reduced inefficiency), while according to *H3b* we assume that the coefficient of interaction between the share of turnover from radical innovations and promoting internal competition between innovation projects is positive (indicate increased inefficiency). In an analogous manner, *H4a* would require the coefficient of the interaction between the share of turnover from incremental product innovations and promoting internal competition between innovation projects' ideas to be negative while *H4b* would predict a positive sign of interaction between the share of turnover from incremental product innovations and internal collaboration between departments and functional areas.

4 Empirical results

As argued before, each estimated model consists of a basic model (Eq.1) from which the efficiencies are derived and a second model (Eq.2) which tries to explain the efficiencies by exogenous factors. The interest obviously lies in the latter. Because of that we defer the basic model to Table A.2 and Table A.3 in the Appendix. Nonetheless, it should be noted that the models are reasonably specified. The estimates of the variance parameters σ_u, σ_v, $\text{lamda}\ (\sigma_u/\sigma_v)$ and gamma $\sigma_u^2/(\sigma_u^2+\sigma_v^2)$ are highly and significantly different from zero (see Table A.2). This speaks for a good model fit and confirms the distribution assumption that lamda is greater than one. Therefore the inefficiency term u dominates the systematic term v .This suggests that the inefficiency effects significantly influence the level and variability of output. The estimated value of gamma ($\hat{\gamma}$) is relatively close to one (see Table A.2) and therefore the deviation from the production frontier function mostly stems from the inefficiency effects u and less from the effects of stochastic influences v.

The test hypotheses (see Table A.4) regarding the structure of the innovation production function, which claim that there are no inefficiencies and that all deviations from the innovation production function are caused by white noise, are rejected.

4.1 Testing the hypotheses

In this section we present the results of the inefficiency model by investigating the effect of the moderating factors (extent of predatory competition and the type of innovations) on the implementation of competitive or collaborative elements in innovation projects.

4.1.1 The effect of product market competition

The effect of product market competition on the choice of either more collaboration between departments and less competition between innovation projects or more collaboration and less competition is studied on the basis of the results of the first estimates of the sub-model (Eq.3) (Table A.2).

Table 2. Maximum-likelihood for parameters of inefficiency effects model in stochastic frontier production function

Variable	Estimated value	S.E	t-statistic
Constant	0.999	0.656	1.52
Development of new technological solution	-0.170*	0.101	-1.68
Creativity of employees	-0.247**	0.117	-2.12
competition of project ideas	0.458**	0.211	-2.17
Product market competition	0.399	0.262	1.52
(competition of project) * (Product market competition) ***H1***	-0.239**	0.11	-2.18
collaboration between departments	0.008	0.091	0.09
(collaboration between departments) * (Product market competition) ***H2***	0.158*	0.09	1.76

Note: * p<0.10, ** p<0.05, *** p<0.010, Log likelihood = -479.5761 , N=478

A positive coefficient means that the associated variable increases innovation inefficiency. As already mentioned, *H1* and *H2* predict a negative sign for the first and a positive for the latter. Indeed, this is confirmed by the results although the positive coefficient of the interaction between cross-function collaboration and the degree of product market competition is only marginal. Nonetheless, the evidence suggests that higher degrees of product market competition tend to favour the organizational setups within companies that foster competition between innovation projects, while intense cross-functional collaboration seems to increase inefficiency. In summary we find evidence of both *H1* and *H2*.

4.1.2 The effect of types of innovations

In Table 3 the results of the second estimation defined in Eq. (4) are listed. The effect of the types of innovations on the use of collaboration between departments and competition between innovation projects is examined there.

Table 3. Maximum-likelihood for parameters of the inefficiency effects model in stochastic frontier production function

Variable	**Estimated value**	**S.E**	**t-statistic**
Constant	1.877***	0.343	5.48
Development of new technological solution	-0.087	0.066	-1.33
Creativity of employees	-0.180**	0.07	-2.56
Promoting internal competition of project ideas	0.072	0.061	1.18
internal collaboration between departments/functional area	0.162**	0.065	2.50
share in sales of radical product innovations	-0.166**	0.068	-2.45
share in sales of incremental product innovations	0.182***	0.066	2.76
(collaboration between departments)* (radical product innovations) ***H3a***	-0.016***	0.005	-3.00
(competition of project) *(radical product innovations) ***H3b***	0.005	0.007	0.66
(competition of project)*(incremental product innovations) ***H4a***	-0.015**	0.007	-1.98
(collaboration between departments)* (incremental product innovations) ***H4b***	-0.006	0.004	-1.47

Note: * p<0.10, ** p<0.05, *** p<0.010, Log likelihood = -395.1678, N=465.

As already mentioned, *H3a* predicts a negative coefficient of the interaction between cross-functional collaboration and the degree of radicality, while we expect a positive coefficient of the interaction between competition between innovation projects and radicality from *H3b*. As we see, the results provide evidence only of *H3a*. Thus, we can indeed corroborate that cross-functional collaboration is more important the more radical the innovation outputs are.

Furthermore, *H4a* predicts a negative coefficient of the interaction between competition between innovation projects and the incrementality of the innovation. *H4b* foresees a positive effect on the interaction between cross-functional collaboration and incrementality. Here we find evidence only of *H4a*, while no significant coefficient emerges for *H4b*. Thus, we can indeed corroborate that competition between innovation projects becomes more important the more incremental the innovation outputs are.

5 Conclusion and discussion

We have shown that the effects of interdepartmental collaboration and competition between innovation projects depend on the strength of product market competition and the radicalness of the firm’s innovation orientation. With respect to strong product market competition we have shown that strong competition between innovation projects/ideas increases innovative efficiency. On the contrary, under strong product market competition high degrees of interdepartmental collaboration reduce innovation efficiency. We explain this by the fact that strong product market competition is usually the result of higher product homogeneity. Competition parameters shift towards price competition and cost-output ratios, implying that speed of the innovation processes becomes critical.

As concerns innovation strategy we found that for firms following radical innovations competition between innovation projects reduces efficiency. We explain this by the fact that radical innovation requires intensive knowledge sharing between key actors in the firm. As competition between innovation projects increases, incentives for knowledge sharing erode. In addition, we have found that firms following radical innovation paths critically rely on cross-departmental collaboration. We argue that cross-departmental collaboration allows the knowledge sharing that is necessary for the creation of new knowledge, which, in turn, could lead to radical innovation.

On a theoretical level we contribute to the literature by complementing the knowledge-based view (Zander and Kogut 1992; Grant 1996). The knowledge-based view highlights that heterogeneous knowledge bases and capabilities among firms are the main determinants of sustained competitive advantage and superior corporate performance. To explain this heterogeneous distribution, the proponents of this theory assert that knowledge sharing between departments at the organizational level is critical to realize high performance and competitive advantage (Kogut and Zander 1992). In doing so, in particular the literature downplays to some degree the role of incentive mechanisms (which can be implemented as supporting measures supporting internal competition). Only in the earlier literature, some authors have acknowledged that high-powered market-based incentives can play an important role in improving innovation performance under certain conditions (Nickerson and Zenger 2004; Felin and Zenger 2011). Despite these advances the understanding of how the conditions under high-powered incentives in innovation can be beneficial is still limited. By analyzing the role of product market competition as an external contingency and the radicalness of the innovation strategy we provide as an internal contingency some insights into how firms can choose appropriate organizational setups raising their innovative capabilities.

From a managerial standpoint, we argue that managers should take into consideration the firm’s exposure to product market competition and its orientation towards radical or incremental innovations. Specifically, with higher competition on the product market, managers should move away from high collaboration between departments toward supporting more competition between innovation projects. Conversely, when a firm faces less intense competition on the product market, managers are in the better position to take on collaboration between departments. Furthermore, managers shall emphasize the collaboration between departments more if they plan radical innovation and give more support to the competition between innovation projects in cases of incremental innovation.

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Appendix

Table A.1. Application of Marsili's typology (2001) of technological regimes

Technological Regime	Characteristics	NACE Classification
Science based	High technological opportunity; high entry barriers; high cumulativeness of innovation; focus on product innovation.	30, 31 32, 33
Fundamental basis	Medium technological opportunity; high entry barriers, strong persistence on innovation; focus on process innovation.	10, 11, 12, 13, 14, 23, 24
Complex (knowledge) system	Medium to high levels of technological opportunity; entree barriers and persistence on innovation; high degree of differentiation.	29, 34, 35
Production engineering	Medium to high levels of technological opportunity; low entry barriers to innovation, medium persistence of innovation; high technological diversity, focus on product. innovation	25, 26, 27, 28
Continuous process	Low levels of technological opportunity, entry barriers and innovation persistence; heterogeneous technology; differentiated knowledge base.	15, 16, 17, 18, 19, 20, 22, 36, 37

Note: Sectors are defined according to NACE 2 industry classification.

Table A.2. Maximum-Likelihood estimates for parameters of translog distance function

Variable	Parameter	Estimated value	S.E	t-statistic
Stochastic distance function				
Constant	α_0	1.634	0.129	12.7***
Y_{RED}/Y_{INO}	α_1	0.654	0.050	13.16***
$0.5*(Y_{RED}/Y_{INO})^2$	α_{11}	0.152	0.022	6.86***
X_{EXP}	β_1	-0.151	0.039	-3.93***
X_{RDP}	β_2	-0.129	0.056	-2.32*
$0.5*(X_{EXP})^2$	β_{11}	-0.039	0.014	-2.75**
$0.5*(X_{RDP})^2$	β_{22}	-0.081	0.041	-1.96*
$X_{EXP}*X_{RDP}$	β_{12}	0.013	0.020	0.65
$X_{EXP}*(Y_{RED}/Y_{INO})$	γ_1	-0.041	0.019	-2.21*
$X_{RDP}*(Y_{RED}/Y_{INO})$	γ_2	-0.021	0.025	-0.84
SB	ϕ_1	-0.150	0.092	-1.64
FP	ϕ_2	0.183	0.120	1.53

Variable	**Parameter**	**Estimated value**	**S.E**	**t-statistic**
CS	ϕ_3	-0.184	0.090	-2.03*
PE	ϕ_4	-0.261	0.099	-2.65**
Variance parameters of distance function				
LAMBDA	σ_u / σ_v	2.30	0.11	21.33***
GAMMA	$\sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$	0.81	0.07	12.34***
Log likelihood	-483.92			

Notes: * $p<0.10$, ** $p<0.05$, *** $p<0.010$,
All variables are in natural logarithm.

Table A.3. Distance elasticities and monotonicity for inputs in the model

Variable	**Distance elasticites at mean values**	**Percentage of observations violating the monotonicity assumptions**
Share of turnover with new or improved products	2.94	7.71
Innovation expenditures as a share of turnover	-0.63	9.79
R&D personnel as share of total personnel	-0.42	10.00
Elasticity of scale	1.05	

Table A.4. Generalized likelihood ratio tests of hypotheses of inefficiency effects model

Null Hypothesis		**Test statistic** [a]	**Critical value** [b]	**Decision**
First estimation	H_0: Gamma=δ_0= δ= δ_{m1}=δ_{m2} =0	42.74	$16.27(9)^c$	Reject H_0
Second estimation	H_0: Gamma= δ_0= δ= δ_{m1}=δ_{m2} =δ_{m3} =δ_{m4}=0	171.07	$20.24(12)^c$	Reject H_0

Notes: a: The test statistics have χ^2 distribution with degree of freedom equal to the difference between the Parameters involved in the null and the alternative Hypothesis

b: For a 95% significant level. Degrees of freedom are in parentheses

c: As Gamma takes values between 0 and 1. The statistic is distributed according to a mixed χ^2 whose critical value is obtained from (Kodde and Palm 1986).