

Technical efficiency, combination of innovation strategies and group membership

Manuel Guisado-González, Jennifer González-Blanco and
María del Mar Rodríguez-Domínguez
University of Vigo, Vigo, Spain

European Journal
of Management
and Business
Economics

Received 14 May 2024
Revised 30 July 2024
28 September 2024
Accepted 4 October 2024

Abstract

Purpose – This research aims to study the impact that the interaction between internal R&D and R&D cooperation has on the technical efficiency of firms, as well as to analyse whether firms belonging to a group achieve any additional level of technical efficiency.

Design/methodology/approach – We employ the stochastic frontier version of a knowledge production function, particularly the inefficiency model, and we combine the stochastic frontier analysis (SFA) and the complementarity approach.

Findings – The interaction between internal R&D and R&D cooperation has a positive and significant impact on technical efficiency when the complementarity test is applied between companies belonging to a group, and there is no interaction when they do not belong to a group.

Practical implications – Knowing this type of information in advance is critical for managers and policymakers, as it allows them to avoid undesirable combinations of innovation strategies or contexts not favourable for their implementation, as well as the formulation of policies leading to an efficient allocation of public resources.

Originality/value – To the best of the authors' knowledge, this paper contributes an original approach in evaluating the complementarity of internal R&D and R&D cooperation from the perspective of technical efficiency and group membership, combining the SFA and the complementarity approach.

Keywords Internal R&D, R&D cooperation, Business group, Complementarity approach, Stochastic frontier analysis

Paper type Research paper

1. Introduction

At present, the flows of knowledge required by companies to sustain success are increasingly complex and have a very heterogeneous territorial and sectoral origin. As a result, a large number of companies cannot access all the technological knowledge they need to carry out their innovation activities through their internal R&D (Park *et al.*, 2004), and moreover, due to their strategic nature and their proximity to the so-called technological frontier, this knowledge is often not available on the market. In situations of this nature, the available alternative lies in the establishment of R&D cooperation agreements with other public and private organisations (Park *et al.*, 2004). Thus, R&D cooperation agreements pose an alternative that companies can use to complement their internal R&D capabilities (Vanhaverbeke *et al.*, 2002) by accessing the advanced technological knowledge of interest possessed by relevant partners (Rothaermel, 2001).

Now, the absorption of knowledge from these partners is not achieved by simple contact with them (Escribano *et al.*, 2009). In addition to occasional or intentional contact, companies need to possess a plethora of resources and skills that allow them to recognise the value of new external knowledge, assimilate it, and, finally, be in a position to use this knowledge for

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European Journal of Management and
Business Economics
Emerald Publishing Limited
e-ISSN: 2444-8494
p-ISSN: 2444-8451
DOI 10.1108/EJMBE-05-2024-0167

commercial purposes (Todorova and Durisin, 2007). In short, prior to the establishment of R&D cooperation agreements, companies must build a powerful absorption capacity (Cohen and Levinthal, 1989).

Not only is there a direct and positive influence of internal R&D and R&D cooperation on the productivity of companies, but there is also an indirect impact, derived from the potential complementary/substitutive relationship between both innovation strategies. This potential complementary effect stems from the dual nature of internal R&D (Cohen and Levinthal, 1989), as this process generates new knowledge and increases the company's ability to detect and integrate knowledge flows from other organisations. Therefore, the more a company invests in internal R&D, the more likely it is that the company will try to take advantage of external knowledge flows. In addition, as the company increasingly uses these external knowledge flows, the company will also have to correspondingly increase its internal R&D capacity (Becker and Dietz, 2004).

However, empirical studies on the complementarity between internal R&D and R&D cooperation have not led to conclusive results. Some studies have found that both strategies are complementary (e.g. Schmiedeberg, 2008), while others have concluded that they are substitutive (e.g. De Marchi, 2012). This heterogeneous behaviour does not constitute an idiosyncratic characteristic of the relationship between both strategies but is instead common to the interaction of the different innovation strategies (Catozzella and Vivarelli, 2014). In this regard, Cassiman and Veugelers (2006) have previously pointed out that there are characteristics of companies that favour complementarity, while others hinder it. For example, Hagedoorn and Wang (2012) have found that the existence of complementarity/substitutability is conditioned by the previous level reached by the corresponding internal R&D. In the same vein, it is worth pointing out that some studies have shown that the results of R&D activity are strongly conditioned by belonging to a group of companies (Cefis *et al.*, 2009; Hsieh *et al.*, 2010), to the extent that many R&D strategies are relatively frequently conceived and developed within these kinds of groups. However, to the best of our knowledge, there is a dearth of literature that analyses the influence of belonging to a group of companies on the results achieved at the R&D level, and we are not aware of any study that has analysed this influence from the complementarity approach. This is one of the gaps that this study aims to fill, thus contributing to expanding the existing literature on the influence of business groups on the results of innovation processes.

In addition, it is also worth noting that existing studies have analysed the relationship between different R&D strategies and some measures of firms' innovative performance. But to our knowledge, these studies have not used technical efficiency as a measure of innovative performance, even though differences in technical efficiency between firms reflect greater or lesser proximity to the corresponding innovation frontier. Consequently, in this study, we use technical efficiency as a measure of innovative performance, thus filling the existing knowledge gap and broadening the framework for analysing the impact of different innovation strategies on the innovative performance of companies.

Finally, as a consequence of the two gaps we try to fill, we combine the stochastic frontier analysis (SFA) and the complementarity approach in order to estimate the coefficients of the model we propose. This procedure in empirical research, to the best of our knowledge, is also a novelty.

In summary, the specialised literature is still at an early stage in terms of analysing the characteristics of companies that can act as catalysts for the complementarity between internal R&D and R&D cooperation. In this sense, regarding the complementarity between these two innovation strategies and the characteristics of the companies that have some kind of influence on it, this study makes two important contributions.

Firstly, for the extant analysis of complementarity, most of the studies that have used data from the Community Innovation Survey tend to regress companies' labour productivity (e.g. Belderbos *et al.*, 2004), or a measure of performance of the innovation process (e.g. Guisado-González *et al.*, 2019), through an exclusive combination of innovation strategies.

However, the literature on innovation strongly emphasises that productivity is driven by technical efficiency (Aigner *et al.*, 1977). It also posits that investment in R&D is characterised by decreasing marginal returns and by the fact that the effectiveness of firms' internal R&D efforts to produce innovation output varies drastically between companies (Mairesse and Mohnen, 2002; Korres, 2008), even between companies belonging to the same industry (Cohen and Levinthal, 1989; Thompson, 2001). There are notable differences in inefficiency between companies in their corresponding innovation processes.

Therefore, in order to adequately capture the joint interaction of two or more innovation strategies, it seems more convenient to use a measure of inefficiency instead of using productivity as a reference variable since inefficiency is possibly the variable that can best explain the existing differences across companies' innovative performances. In other words, there are companies that are close to the technological frontier and others that are further away. For this reason, when we implement the complementarity approach (Milgrom and Roberts, 1990), we use technical inefficiency as a dependent variable, estimated using SFA techniques, applied to a knowledge production function – that is, we combine the SFA with the complementarity approach. Therefore, following the analogy with the production function, which relates capital and labour inputs to production output, in this study, we use a knowledge production function that relates knowledge capital and labour inputs to an innovative output (Bos *et al.*, 2016).

Secondly, the relations of complementarity or substitutability between innovation strategies are not exogenous and automatic (Catozzella and Vivarelli, 2014). They can vary depending on the context in which the interaction between them takes place (Cassiman and Veugelers, 2006). In order to extend our knowledge about the importance of context, in this article, we analyse whether belonging to a group of companies influences the results of the interaction between internal R&D and R&D cooperation.

The ecosystem of companies that belong to a group is not exactly the same as that of companies that compete independently. Consequently, the companies' respective knowledge bases will also be different, as will their corresponding capacities to generate complementarity in the interaction between internal and external flows of knowledge. In fact, some studies have found that group-affiliated firms are more innovative than standalone firms (e.g. Chang *et al.*, 2006; Mahmood *et al.*, 2011). Likewise, different studies on absorptive capacity (e.g. Lane and Lubatkin, 1998) have suggested that the capacity of companies to absorb the knowledge of others decreases if their respective knowledge bases do not have a certain degree of similarity. However, belonging to a group of companies not only facilitates the transfer of intra-group knowledge but also facilitates the absorption of knowledge from organisations outside the group, even if the similarity between the knowledge bases of the companies that are associated is relatively distant (Carnabuci and Operti, 2013). Critically, the other companies in the group can supply the necessary knowledge to bridge these differences.

Finally, it should be noted that the shared norms and morality embedded in the intragroup network reduce the transaction costs of knowledge transfers between group members (Chang *et al.*, 2006). All these indications make us intuit that the groups of companies constitute an ecosystem that favours the appearance of complementarities between internal R&D and R&D cooperation.

2. Framework and hypotheses

Cohen and Levinthal (1989) were the first to argue that in order for companies to be able to identify and assimilate knowledge flows generated by other organizations, it is necessary that they have previously been capable of developing powerful internal R&D. Obviously, there are different ways in which companies can access available external knowledge, being R&D cooperation agreements one of the most efficient. This is because they allow access to complementary resources and capabilities, facilitate the availability of hard-to-reach advanced knowledge (Sampson, 2007), contribute to the gain of experience in the use of technologies and research methods that reinforce the corresponding absorption capacity (Schmiedeberg,

2008) and contribute to the reduction of costs and times of the corresponding internal activities research (Fleming and Sorenson, 2004). All of this can lead to the generation of important synergies between R&D cooperation agreements and the corresponding internal R&D.

However, the generation of synergies can still be much greater than previously specified, since the knowledge incorporated through R&D cooperation agreements can give rise to substantial modifications in the development and production of internal knowledge (Keil *et al.*, 2008). That would allow companies to broaden their respective knowledge bases (Vasudeva and Anand, 2011), which in turn can give rise to new applications and research routines (Rosenkopf and Nerkar, 2001). This broadening is possible as long as there is a delicate balance between similarity and disparity between the respective knowledge bases of the cooperating companies. In fact, a significant percentage of common knowledge between knowledge bases facilitates knowledge transfer and learning (Cohen and Levinthal, 1990), since the respective research teams share skills and languages that help communication and coordination between them, thus facilitating the absorption of new knowledge that they do not share (Lane and Lubatkin, 1998). All this facilitates the development of more elaborate ideas and greater efficiency of the corresponding R&D department. In addition, it also increases the chances that shared projects can be successfully completed (Bougrain and Haudeville, 2002), thereby increasing the confidence and experience of companies in the management of subsequent R&D cooperation agreements. Consequently, these deep synergies between R&D cooperation and internal R&D can positively influence innovation performance (Laursen and Salter, 2006).

However, outside the range in which the “similarity-disparity” of the partners reinforces the internal R&D capacities of each one of them, the transfer and learning of knowledge can be inefficient. On the one hand, if there is too much similarity between the knowledge bases of the partners, there is no opportunity for mutual learning, since these bases overlap and are redundant (Boschma, 2005; Vassolo *et al.*, 2004). On the other hand, if the similarity is too low and the disparity high, there is not enough absorption capacity to benefit from the new knowledge held by the other partner, nevertheless incurring high costs as a result of the established R&D cooperation agreement (Laursen and Salter, 2006; Sampson, 2007; Vasudeva and Anand, 2011). In either case, there is a high probability that the relationship between R&D cooperation and internal R&D becomes substitutive, which contributes to reducing the efficiency of the companies, or that there is no relationship between both innovation strategies, so that there is no additional impact on efficiency, that is, there is no complementarity.

Consequently, the literature indicates that companies tend to concentrate their learning efforts by establishing cooperation agreements with partners that have relatively similar knowledge bases so that the disparity between them is not too high (Ahuja and Katila, 2001; Keil *et al.*, 2008). Therefore, it is worth asking how wide or narrow the range in which the complementarity between R&D cooperation and internal R&D can take place.

In this sense, it should be noted that there is empirical evidence that this band is not too narrow, since the number of empirical studies that have detected complementarity is greater than those that have detected substitutability or no relationship (Martynov, 2019). For example, the following studies found evidence of complementarity between R&D cooperation and internal R&D: Choi *et al.* (2012) in relation to the firm’s share of sales from new products, Rothaermel and Hess (2007) and Schmiedeberg (2008) taking patent activity as a reference, Lin *et al.* (2012) on innovation performance, Zahra and Hayton (2008) on firms’ return on equity, and Martynov (2019) on the market value of the firm. Based on the cited literature, we propose the following hypothesis:

- H1. The relationship between R&D cooperation and internal R&D is complementary in relation to technical efficiency.

The complementary relationship between different innovation strategies is not predetermined, but, to a certain extent, depends on the context in which the joint implementation of these strategies takes place (Catozzella and Vivarelli, 2014). In this regard, Cassiman and Veugelers (2006) point out that there are characteristics of companies that favor complementarity, while

others hinder it. In this sense, some studies found that the effects derived from the combination of internal R&D and R&D cooperation show a certain dependence on market conditions, company characteristics and other factors. For example, [Hagedoorn and Wang \(2012\)](#) found evidence that the complementarity between internal R&D and R&D cooperation depends on the level of absorption capacity, since for high levels, the relationship is complementary, and for low levels, substitutive. Likewise, [Martynov \(2019\)](#) finds evidence that the complementarity/substitutability between internal R&D and R&D cooperation is related to the phase of the market cycle, which affects the level of technological uncertainty.

In this study, we are interested in exploring whether or not the complementarity between internal R&D and R&D cooperation is contingent on belonging to a group of companies. For the approach of the previous hypothesis, we had argued that there is a range of “similarity-disparity” in which the R&D cooperation can lead to a broadening of the knowledge base of the companies that cooperate. This generates an additional increase (complementarity) on the corresponding performance measure. Consequently, we intuit that belonging to a group of companies increases the extension of said range, contributing to an increase in the probability that complementarity will take place and that it will be more intense.

When two companies cooperate in R&D and their respective knowledge bases are very dissimilar, the emergence of complementarity is very difficult, since there is not a sufficient proportion of common knowledge base between both companies. In these cases, the cooperating companies are not capable of adequately and efficiently interpreting and assimilating the new knowledge that could be of interest to them. However, if one of the companies belongs to a group of companies, it may receive knowledge transfers and *ad hoc* resources from other members of the group that enable it to understand and integrate the new knowledge provided by the cooperating partners.

Consequently, belonging to a group of companies increases the probability that there will be complementarity between internal R&D and R&D cooperation. This probability will increase the higher the level of integration of the companies that make up the group and the greater the degree of diversity of their respective knowledge bases ([Carnabuci and Operti, 2013](#)). Groups with a high degree of integration between the companies that make them up facilitate the transfer of knowledge to those companies that need it ([Allen et al., 2007](#); [Burns and Stalker, 1961](#)) and, therefore, the continuous redefinition of tasks and methods in the corresponding R&D centers ([Burns and Stalker, 1961](#)). If the degree of integration between group companies is weak, that is, the intra-organizational network is more fragmented and transfers between group companies are lower ([Lazer and Friedman, 2007](#)). However, these companies always receive more transfers than companies that compete individually. In short, business groups constitute organizational structures that can achieve greater efficiency than independent companies ([Cainelli and Iacobucci, 2011](#); [Hamelin, 2011](#)). According to the aforementioned literature, we propose the following hypotheses:

- H2.1. The relationship between R&D cooperation and internal R&D is not complementary (it may be substitutive or independent) in relation to technical efficiency when companies do not belong to a group.
- H2.2. The relationship between R&D cooperation and internal R&D is complementary in relation to technical efficiency when companies belong to a group.

3. Data, variables and methodology

3.1 Data

The data used for the analysis is from the Survey of Innovation Technology Companies for 2016, available in the Technology Innovation Panel (PITEC). PITEC is a panel survey based on the Community Innovation Survey (CIS) and was carried out according to the methodological guidelines set out in the Oslo Manual ([OECD, 1997](#)). PITEC is a firm-level panel database on the

innovative activities of Spanish firms. We selected manufacturing companies from this database, and after removing the observations with missing values and those that had some sort of impact on the variables of interest, we obtained a database with 3,858 observations. Of these, we selected only innovative companies, those that report having introduced product or process innovations, and, at the same time, present a positive expenditure on innovation during the period analysed by the survey, leaving 2,218 observations.

3.2 Variables

In order to apply the complementarity approach it is necessary to use a measure of company performance as a dependent variable (Cassiman and Veugelers, 2006). Usually, the firm innovative or overall performance is used. In this study, we use a measure of inefficiency as a dependent variable, extracted from a knowledge production function of the companies and estimated using stochastic frontier techniques. Consequently, we combine the SFA (Coelli et al., 2005) with the complementary approach (Milgrom and Roberts, 1990). Using the complementarity approach requires that the variables whose complementarity is to be evaluated have to be defined in binary mode. Consequently, the variables internal R&D and R&D cooperation are thus defined in mode (0,1). That is, internal R&D and R&D cooperation take the value 1 if the company carries out R&D activities internally and cooperates in R&D with other organizations, respectively; and “0” otherwise.

In relation to the evaluation of complementarity, we have also introduced a set of control variables, according to their potential effect on the company’s innovation activities. Relying on the evidence in the economic literature, we incorporated the following variables: R&D subsidy, capital and high-tech. The R&D subsidy variable takes the value 1 if the company receives some kind of public support for innovation; and “0” otherwise. Using the 2003 OECD classification, the high-tech variable takes the value 1 if the company belongs to a medium-high or high technological intensity industry; and “0” otherwise.

We use the capital variable as a measure of firm size, as innovation performance could benefit from economies of scale and scope (Henderson and Cockburn, 1994). PITEC does not directly supply data on the capital variable, but it does provide information on the gross investment made by the company (I_t). Using the perpetual inventory method (OECD, 2009), and assuming the existence of a growth rate of total innovation expenditures (g) and a depreciation rate of accumulated knowledge (δ), we can construct a proxy for the capital stock using the following equation:

$$capital_t = \frac{I_t}{g + \delta}$$

In line with previous studies, the depreciation rate is assumed to be 15% and the pre-sample growth rate of gross investment 5% (e.g. Bos et al., 2016). Likewise, it must be considered that the gross investments of companies can experience strong variations from one year to the next. To minimize this kind of bias, in this study, we use five-year averages (in constant monetary units) instead of a single year. In this way, we generate more stable and reliable capital stock estimates (Harberger, 1978).

The knowledge production frontier is estimated using the standard variables comprising output, knowledge and labor. In relation to the output, we use the natural logarithm of the sales from new or improved products as our measure of innovation output (lnnewemp). The advantage of using this measure is that it directly captures the volume of the firm’s success in the commercial introduction of new products resulting from its innovative activity, as well as its corresponding failure. The knowledge variable [1] measures the accumulated knowledge stock of the company, and its construction follows the same procedure that we have used for the construction of the capital variable, using the average of the total innovation expenses of the last five years, measured in constant monetary units. The stock of accumulated

total innovation expenditures represents the knowledge capital of a company, that is, the accumulated innovation experience. Finally, the labour variable is represented by the number of employees in the company, expressed in natural logarithms.

In addition, to apply the Heckman correction, we also use the innovator variable, as well as a series of variables representing different obstacles to innovation. Innovative companies (innovator) are defined as those that report having introduced product or process innovations and, at the same time, present a positive amount of total expenditures on innovation.

3.3 Methodology

To implement the complementarity approach, it is necessary to have a measure of the company's performance. In this study, we use the technical efficiency (the ability of firms to produce maximum output for a given set of inputs), extracted from the estimation of the frontier knowledge function using SFA techniques. The SFA model has been proposed by [Aigner et al. \(1977\)](#) and [Meeusen and van den Broeck \(1977\)](#) to get the firm's technical efficiency value. The SFA specification (e.g. [Battese and Coelli, 1995](#)) involves a production model with two error components: the first explains the random effect (v_i) and the second the technical inefficiency (u_i). The SFA specification can be expressed as follows:

$$Y_i = X_i\beta + (v_i - u_i) \quad i = 1, 2, \dots, N \quad (5)$$

where, Y_i is the logarithm for the output of the i -th firm, X_i is the $(k \times 1)$ vector of input and other explanatory variables associated with the i -th firm and β is the $(k \times 1)$ vector of unknown parameters to be estimated. V_i is a random error assumed to be iid $(0, \sigma_v^2)$. U_i is a non-negative random variable, represents the technical inefficiency and is assumed to be independently distributed as truncations at zero of the (μ, σ_u^2) distribution.

With the assumption of a linear functional relationship, the mean distribution of u_i is a function of a set of explanatory variables (z_i) and can be specified as:

$$u_i = z_i\delta \quad i = 1, 2, \dots, N \quad (6)$$

where z_i is a $(p \times 1)$ vector of variables which may influence the (in)efficiency of the i -th firm and δ is a $(1 \times p)$ vector of unknown parameters to be estimated.

To estimate the parameters of Models (5) and (6) we use the one-step approach since it avoids the inconsistency that arises from using a two-step approach (e.g. [Amsler et al., 2016](#); [Kumbhakar et al., 2012](#)).

In general, in relation to the specification of [Equation \(5\)](#), without endogenous explanation of the inefficiency components, two basic specifications are usually considered ([Coelli et al., 2005](#)): a knowledge Cobb–Douglas production function and a knowledge translog production function. These basic specifications are initially used to explore which of the two is more appropriate. The one with the best fit will finally be used to analyse the relationship between inefficiency and the corresponding explanatory variables, expressed in [Equation \(6\)](#).

The complementarity approach ([Milgrom and Roberts, 1990](#)) starts from the basis that a pair of innovation activities is complementary if the sum of the benefits of doing just one or the other is no greater than the benefit of doing both together.

Suppose that there are two activities X_i and X_j and Z is a vector of exogenous variables in an objective function $F(X_i, X_j, Z)$ (in this study [Equation \(6\)](#)). Assume that X_i and X_j 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 the objective function on exclusive combinations of innovation activities and the vector of exogenous variables:

$$F(X_i, X_j, Z) = \beta_{00}(1 - X_i)(1 - X_j) + \beta_{10}X_i(1 - X_j) + \beta_{01}(1 - X_i)X_j + \beta_{11}X_iX_j + \beta_zZ + e$$

where

β_{11} measures partial cross return of choosing X_i and X_j jointly.

β_{10} measures the return of only choosing X_i .

β_{01} measures the return of only choosing X_j .

β_{00} measures the return derived from not choosing either of the two activities.

Then, X_i and X_j are complementary if:

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

Conversely, X_i and X_j are substitutes if:

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

In this study, we estimate four models. In Model 1, we estimate a knowledge Cobb–Douglas production function and in Model 2, a knowledge translog production function, both without endogenous explanation of the inefficiency components. The variables of interest in both models are knowledge and labour, expressed in natural logarithms. In addition, we use hightech as a control variable, since belonging to sectors with high or low technological intensity influences the innovative performance of companies (Veugelers and Cassiman, 1999).

Our analysis of complementarity is focused on innovative manufacturing companies (2,218), selected from the set of Spanish manufacturing companies (3,858). Consequently, the sample is not strictly random, so there may be sample selection bias. To correct this bias, the so-called Heckman correction method is used.

After applying the Heckman correction to Models 1 and 2, and estimating both models, we run the likelihood ratio test to verify which of the two models best fits the data.

Model 3 will have the previously selected functional form and will also incorporate Equation (6), that is, the variables that potentially affect inefficiency (internal R&D and R&D cooperation) as well as the corresponding control variables (R&D subsidy, hightech and capital), the latter expressed in natural logarithms). The implementation of the complementarity approach requires that the variables whose complementarity is to be tested are expressed through a combination of exclusive profiles. For this purpose, the dummy variables internal R&D and R&D cooperation are transformed into four exclusive profiles. For example, the exclusive profile (1 0) represents a company that has internal R&D and does not cooperate in R&D with other companies. The coefficients of these four exclusive profiles are essential to carry out the complementarity test, and, therefore, verify if Hypothesis 1 is fulfilled. Model 3 is implemented in innovative manufacturing companies (2,218 companies).

Model 4 is identical to Model 3, but instead of being implemented on all the innovative manufacturing companies, it is applied on two different subsamples: on the one hand, it applies to innovative manufacturing companies that do not belong to a group (998), and, on the other, to innovative manufacturing companies that belong to a group (1,120). In this way, we are in a position to test Hypotheses 2.1 and 2.2 and, consequently, to verify whether belonging to a group might be an important driver of the complementarity between internal R&D and R&D cooperation.

4. Results and discussion

The basic descriptive statistics of the variables used in this study are shown in Table 1. In this table, it can be verified that 87% of the innovative manufacturing companies develop internal R&D activities, 46% cooperate in R&D with other organizations, 45% receive some kind of public aid for innovation and 51% are medium-high and high technology intensity companies.

Table 1. Basic descriptive statistics

Variable	Average	Minimum	Maximum	SD
Newemp	17615186.65	0	3612114839.00	141680749.1
Knowledge	10986712.35	4412.00	1169353266.00	62912807.48
Labour	229.38	2.00	9941.00	614.57
Internal R&D	0.87	0	1	0.33
R&D cooperation	0.46	0	1	0.49
R&D subsidy	0.45	0	1	0.49
Capital	17775677.74	0	1371074581.00	82815500.39
Hightech	0.51	0	1	0.50
Observations	2,218			

Source(s): Authors' own work

Table 2 presents the results of the SFA estimates of Equation (5), centred on the basic Cobb–Douglas and translog specifications. In the first place, we try to check if there is inefficiency in both specifications, since if it is not detected, an ordinary least squares estimation would be more adequate instead of one with SFA. To do this, after making the corresponding estimates, we implement a likelihood-ratio test assuming the null hypothesis of no technical inefficiency ($H_0: \sigma_u = 0$). The results of both tests indicate that the null hypothesis must be rejected at the 1% level. Therefore, there is inefficiency in both specifications estimated with SFA. Next, it is a matter of checking which of the two specifications best fits the available data. To this end, we implement an likelihood ratio (LR) test that compares the log-likelihoods of the two basic specifications and tests whether this difference is statistically significant. If the difference is statistically significant, this assumes that the translog specification fits the data significantly better than the Cobb–Douglas specification. The value of the LR test is 8.74 and it is statistically significant at the 5% level, which means that the two specifications are not nested and that, therefore, the translog specification is better suited to the data. In addition, at the end of the aforementioned Table 2, it is reflected that the proportion ($\sigma_u^2 / \sigma_u^2 + \sigma_v^2$) is slightly higher for the translog specification than for the Cobb–Douglas. In this regard, we find that the aforementioned proportion is 0.9983 and 0.9984, respectively. That is, in the translog specification, 99.84% of the total variation from the frontier is due to technical

Table 2. Regression coefficients of the SFA. Innovative manufacturing companies

Variables	Model 1: basic Cobb–Douglas specification	Model 2: basic translog specification
lnKnowledge	0.0350692 (0.1119859)	0.6470763 (0.8260182)
lnLabour	1.165001*** (0.0709715)	1.408287*** (0.4219106)
1/2ln ² Knowledge	–	–0.0471283 (0.05999)
1/2ln ² Labour	–	–0.2406441** (0.0991352)
lnKnowledge lnLabour	–	0.0577067 (0.0482341)
Hightech	–0.2118566* (0.1278171)	–0.1132144 (0.1422059)
Constant	12.04565*** (1.67767)	5.443 (6.495939)
Observations	2,218	2,218
LR test of $\sigma_u = 0$	9.7e+02***	9.6e+02***
LR test (assumption: Model 1 nested within Model 2)	8.74**	
$\sigma_u^2 / \sigma_u^2 + \sigma_v^2$	0.9983	0.9984

Note(s): Standard errors are in parentheses

*Significant at 10%, **significant at 5%, ***significant at 1%

Source(s): Authors' own work

inefficiency. Consequently, in what follows we will use the translog specification, estimated using SFA.

In Table 3, we omit the presentation of the estimates of the frontier parameters since these are not the object of our investigation. We only show the results of the estimation of the determining parameters of inefficiency.

As the dependent variable of Equation (6) is inefficiency, and our hypotheses have been raised in relation to efficiency, the interpretation of the signs of the estimated parameters must be carried out exactly in the opposite sign of the one derived from the corresponding estimates.

It may turn out that the independent implementation of in-house R&D and R&D cooperation has a positive and significant influence on the technical efficiency of the company, but what happens when both innovation alternatives are implemented together? Does their joint implementation increase or decrease the sum of the corresponding individual impacts?

On this issue, we had already conjectured that R&D cooperation agreements not only provide new knowledge but also lead to a broadening of the corresponding knowledge bases. This effect allows the emergence of new research methods and routines, thus increasing the efficiency of R&D activities carried out internally. In addition, the expanded knowledge base makes it possible for the company to be in a better position to take advantage of new opportunities to incorporate knowledge and technologies from other organizations that were previously not feasible to access (Wang and Gao, 2021). All this is thanks to the fact that R&D cooperation agreements promote the exchange of heterogeneous knowledge (Fu, 2019) and increase the accumulated experience of the company (Van Burg and Van Oorschot, 2013). For all these reasons, we had hypothesized that the variables of internal R&D and R&D cooperation, in the context of innovative manufacturing companies, were complementary. In this sense, it is worth emphasizing that the estimators of Model 3, which are shown in Table 3, and the corresponding complementarity test, which is shown in Table 4, supports Hypothesis 1 of complementarity that we had proposed. Therefore, the combination of both innovation alternatives increases the efficiency of the company beyond the sum of their respective individual contributions. In previous empirical works, based on the role of technological spillovers, this type of complementarity has also been suggested (Arora and Gambardella, 1990; Cassiman and Veugelers, 2006). On the other hand, in the absence of

Table 3. Determinants of the inefficiency

Variable	Model 3	Model 4	Model 4.2
	Innovative manufacturing companies (innovator = 1)	Model 4.1 Innovator = 1 and Group = 0	Innovator = 1 and Group = 1
Internal R&D cooperation	—	—	—
R&D	—	—	—
β_{00}	4.845647*** (0.2044767)	4.824221*** (0.3001282)	4.840527*** (0.2899151)
β_{11}	4.465548*** (0.1749623)	4.574315*** (0.2581408)	4.378176*** (0.2464726)
β_{01}	4.879358*** (0.2280599)	4.678575*** (0.3696399)	4.895522*** (0.3026941)
β_{10}	4.76741*** (0.1688428)	4.802847*** (0.2534155)	4.746385*** (0.2370749)
R&D subsidy	0.1799818*** (0.0667922)	0.1736986* (0.0997972)	0.1905134*** (0.0899295)
lnCapital	0.0091358 (0.0087392)	−0.0033113 (0.0131913)	0.012731 (0.0127931)
Hightech	−0.1814565*** (0.0671373)	−0.210239** (0.1006647)	−0.1546067* (0.0914683)
Constan	—	—	—
Observations	2,218	998	1,220
Note(s): Standard errors are in parentheses			
*Significant at 10%, ** significant at 5%, *** significant at 1%			
Source(s): Authors' own work			

Table 4. Complementarity test in relation to efficiency and group membership

Sample/Sub-sample	Model	Complementarity test	Chi2	p-value
Innovative manufacturing companies (Innovator = 1)	3	$\beta_{11} + \beta_{00} - \beta_{01} - \beta_{10} = 0$ $\beta_{11} + \beta_{00} - \beta_{01} - \beta_{10} \leq 0$	3.01	0.0826 0.9587
Innovative manufacturing companies Innovator = 1 and group = 0	4.1	$\beta_{11} + \beta_{00} - \beta_{01} - \beta_{10} = 0$ $\beta_{11} + \beta_{00} - \beta_{01} - \beta_{10} \leq 0$	0.07	0.7938 No relation
Innovative manufacturing companies Innovator = 1 and group = 1	4.2	$\beta_{11} + \beta_{00} - \beta_{01} - \beta_{10} = 0$ $\beta_{11} + \beta_{00} - \beta_{01} - \beta_{10} \leq 0$	2.79	0.0946 0.9527

Complementary

Source(s): Authors' own work

spillovers and under certain market conditions, [Goyal et al. \(2008\)](#) also find that in-house R&D and R&D cooperation are complementary.

Finally, we suggested that belonging to a group of companies could be an important driver of complementarity between internal R&D activities and R&D cooperation agreements. In this regard, in [Hypotheses 2.1](#) and [2.2](#), we suggested a different behavior, depending on whether or not the companies belonging to a group of companies. In this sense, the hypothesis tests that we have implemented ([Table 4](#)) indicate that the internal R&D and R&D cooperation variables are complementary between the companies that belong to a group, while there is no relationship between these variables if the companies do not belong to a group. [Hypotheses 2.1](#) and [2.2](#) were therefore supported.

Different papers that have analysed the relationship between internal R&D and external R&D have found no complementarity between the two or have found indications that these strategies are substitutes (e.g. [Basant and Fikkert, 1996](#); [Blonigen and Taylor, 2000](#); [Hagedoorn and Wang, 2012](#); [Krzeminska and Eckert, 2016](#)). However, this non-complementarity may originate from an insufficient absorptive capacity of firms incorporating external knowledge. In this sense, some papers have found evidence that external R&D has a positive impact on firm productivity provided that there is a sufficient level of internal R&D expenditure ([Hagedoorn and Wang, 2012](#); [Lokshin et al., 2008](#)), i.e. sufficient absorptive capacity ([Griffith et al., 2004](#)).

External knowledge from the R&D partner is only valuable if it is internalized, incorporated, stored, combined and used together with the internal R&D of the absorbing company ([Peeters and Martin, 2015](#)). For this, the absorbing firm must have an appropriate absorptive capacity, otherwise, it is not possible to effectively internalize and combine externally obtained knowledge. Consequently, firms with low levels of absorptive capacity and low innovation dynamism will have to endure negative indirect effects as a result of the incorporation of external knowledge ([Gkypali et al., 2017](#)). However, the low absorptive capacity of the absorbing firm can be overcome if that firm belongs to a group of firms and receives appropriate knowledge transfers to adequately integrate knowledge from outside.

5. Conclusions

Companies have multiple alternatives to carry out their innovation processes. The literature on innovation has abundantly and reliably shown how these different alternatives have contributed to improving companies' performance. However, there is little empirical work that has examined which combinations or contexts should be avoided, since it is likely that there are policies or strategies that should never be implemented together or contexts that act as inhibitors of such combinations.

In this sense, we could say that internal R&D activities constitute the main ingredient of all the possible combinations of the different innovation alternatives available, as all knowledge

ultimately flowing in from outside the company must be valued and integrated by the corresponding internal R&D. That is why in this study we analyse whether, for Spanish innovative manufacturing companies, the simultaneous implementation of internal R&D activities and R&D cooperation agreements generates an impact on the technical efficiency greater than the sum of their respective individual impacts.

In the same vein, it is worth emphasising that the results of this study indicate that the combination of both innovation alternatives is complementary, meaning the aforementioned combination is extremely beneficial. But we have also analysed this combination in two different contexts, and we have verified that belonging to a group of companies constitutes a powerful driver of the complementarity of both alternatives, and that among companies that do not belong to a group, said complementarity does not exist.

In this regard, we had conjectured that belonging to a group allows companies to quickly and easily access the knowledge flows of the other companies in the group. This makes it easier for them to scan and integrate knowledge flows from external sources, thus helping to generate greater efficiency in their corresponding internal R&D activities and, therefore, contributing to the emergence of the corresponding complementarity.

In this way, we have filled the two gaps mentioned in the introductory section, since the use of a novel research procedure (combining the SFA and the complementarity approach) and the use of technical efficiency as a measure of innovation performance has led us to extend the existing literature on the influence of business groups on the outcomes of innovation processes.

Our finding has an important theoretical implication, as it contributes to the literature on open innovation with a specific relevant approach, insofar as it facilitates an understanding of how belonging to a group of companies influences the achievement of higher innovation performance. This is important, because in order to be successful in innovation processes, companies must master multiple knowledge types, and knowing the existence of contexts that positively or negatively influence these processes is critical in this regard. Relatedly, the results obtained allow us to confirm the existence of a positive link between innovative performance and belonging to a group of companies.

Furthermore, another relevant theoretical implication pertains to the possibility of using our novel working procedure (technical efficiency as a performance variable and the combined use of the SFA and the complementarity approach) to analyse the relationship of other innovation strategies and other contexts on the innovative performance of the company. For example, these methods can be used to investigate the influence of the interaction of R&D outsourcing and R&D cooperation on the technical efficiency of companies, differentiating between companies with high and low absorptive capacity.

Moreover, the empirical findings of our study have practical implications for both managers and policymakers. Knowing this type of information in advance is extremely important since it allows managers to avoid combinations or contexts that are presumably counterproductive. In addition, the results of this study have important implications for managers of companies with low absorptive capacity. If they choose to belong to an appropriate group, they may be in a position to take advantage of R&D cooperation agreements with more technologically advanced companies, achieving greater efficiency in the management of their internal resources. Likewise, these results are also relevant for policymakers, since they provide them with vital information for the design of their corresponding innovation promotion policies, thus helping to avoid the implementation of policies that lead to an inefficient allocation of public resources.

Notes

1. The variables capital, newemp and knowledge have observations with zero values. These variables are expressed in natural logarithms, and since the natural logarithm of zero does not exist and the natural logarithm of 1 is zero, before calculating the corresponding logarithm we add a 1 to the value of these variables, as is usual in this type of situation (e.g. [Escribano et al., 2009](#)).

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Corresponding author

Manuel Guisado-González can be contacted at: manuelguisado@uvigo.gal