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INTRAMURAL AND EXTERNAL R&D: EVIDENCE FOR COMPLEMENTARITY OR SUBSTITUTABILITY[†]

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Abstract. The aim of this study is to ascertain the impact of two firm innovation strategies – namely, intramural R&D and external R&D, including either contracted R&D and import of technology, upon total factor productivity (TFP). In order to evaluate these effects we consider robust estimates of TFP through a GMM approach where we account for the diverse innovation strategies carried out by firms (intramural only, external only or both). Using data for Spanish manufacturing firms drawn from the *Encuesta de Estrategias Empresariales* (ESEE), over the period 1991-2014, our results suggest that inhouse R&D and external R&D are complementary strategies only for large fims in high tech sectors. For the rest of firms, both strategies turn out to be substitutive.

Key words: intramural R&D, external R&D, complementarity, substitutability, TFP.

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1. Introduction

To the extent that R&D is an important determinant of firm's productivity, innovation and competitiveness (Griliches, 1980), the analysis of the impact of R&D on firm performance has attracted enormous attention in the literature. Nevertheless, empirical studies show a great disparity among firms in terms of their ability to benefit from their innovative efforts (Hall et al., 2009). However, it must be realized that not all innovations employed within a firm are induced by the firm through its own R&D: many innovations are acquired by the firm through technological licensing or in the form of externally contracted industrial research. Moreover, firms may combine these alternatives in order to shape their own innovation strategy. This paper attempts to contribute to the current literature measuring the effects of innovation strategies on firm performance, which has yielded mixed and inconclusive results. Particularly, the aim of our study is to analyse the impact of different innovation strategies – defined as intramural R&D and external R&D (including contracted R&D and imports of technology) - and their combinations upon total factor productivity (TFP).

More specifically, we seek to analyze the effects of two different innovation strategies and their combinations on firm's productivity for the Spanish manufacturing sector. To this end, we use the generalised method of moments (GMM) framework proposed by Wooldridge (2009) to jointly estimate the parameters of a Cobb-Douglas production function and the impact of the innovation strategies on TFP. In particular, in a similar fashion to Doraszelski and Jaumandreu (2013), we include in the law of motion of productivity a set of dummy variables fully characterizing past firms' innovation strategies. Lastly, we use the coefficient estimates of the innovation strategies to test for complementarity/substitutability between innovation choices (internal and/or external R&D). Additionally, we aim to analyse the effects of these innovation strategies in relation to firm's size and to the technological content of the industry where the firm operates. The analysis is performed for an unbalanced panel of

Spanish manufacturing firms drawn from the "*Encuesta Sobre Estrategias Empresariales*" (ESEE) and observed for the period 1991-2014.

Previous studies analysing the complementarity between innovation strategies on firm's performance have produced mixed findings. Complementarity (substitutability) exists between two strategies if increasing one strategy enhances (reduces) the marginal return to the other (Milgrom and Roberts, 1990). For instance, Cassiman and Veugelers (2006) in a study of Belgian firms found that internal R&D and external knowledge acquisition were complementary with respect to influencing innovation performance. In contrast, Laursen and Salter (2006) found evidence of a substitution effect between internal R&D and external knowledge sourcing strategies. Our study provides new empirical evidence on the effect of internal and external knowledge sourcing strategies adopted by Spanish manufacturing firms, on TFP. Our study differs from previous studies on several aspects: first, instead of relying on cross-sectional data (e.g. Cassiman and Veugelers, 2006), we explore a panel data set to examine these effects at firm level (see also Lokshin et al., 2008). Secondly, instead of looking at the correlation (or adoption) structure between internal and external sources of innovation[1], we examine the performance effect of three kinds of innovation-related strategies relative to abstaining: the decision to conduct R&D internally; the decision to acquire R&D externally (either through contracted R&D or acquiring foreign technology through licensing); and the decision to combine these two strategies. Thus, extending previous studies (see Cassiman and Veugelers, 2006; Vega-Jurado et al. 2009), we investigate the effects of intramural R&D and acquiring external knowledge (contracted external R&D and import of technology).

Our results reveal that doing R&D internally and externally has a positive direct effect on productivity. More precisely, the direct effect on TFP of doing only external R&D is

[1] This approach has been shown to suffer from measurement problems and inference difficulties (Arora, 1996; Piga and Vivarelli, 2004).

greater than doing only internal R&D in SMEs, independently of the sector, and in large firms belonging to low tech sectors. When analysing potential synergies between both strategies, only for large firms in high-tech sectors, in-house and external R&D are complementary innovation strategies for TFP. In contrast, for the rest of manufacturing firms external and internal R&D turn out to be substitutes.

The remainder of this paper is organized as follows. The next section reviews previous empirical studies on the relationship between internal and external sources of knowledge and their impact on firm's performance. In section 3 we present the empirical model and discuss the estimation methodology. Section 4 describes the data and section 5 presents the empirical results. Section 6 concludes.

2. Literature review

The distinction between internal and external sources of knowledge and the analysis of its various impacts on the returns to innovation has attracted great interest both theoretically and empirically. This trend of the literature is partly explained by the accelerating process in the use of external sources of knowledge that has been accompanied, in parallel, by a reduction of the presence of internal R&D departments (Narula, 2001; Bönte, 2003). However, the empirical evidence on the potential complementarities between these strategies and their differential impact on firm's performance is still inconclusive.

As regards the theoretical literature, there are both studies indicating the importance of external sources of knowledge in the innovation process (Chesbrough, 2003), and studies that argue that, in certain industries, the company's internal resources are the main drivers of the firm's returns to innovation (Freel, 2003). Besides, arguments in line with the transaction costs theory would suggest that the acquisition of external knowledge might substitute for intramural R&D (Williamson, 1985). From a more inclusive perspective, there are studies which point out that internal and external knowledge acquisition may be complementary strategies in the innovation process. These studies argue that the firm's internal sources of knowledge not only generate new knowledge, but at the same time they increase the firm's ability to exploit the external sources in the development of new products and processes. This is evocative of the notion of "absorptive capacity" (Cohen and Levinthal, 1989), which stresses the importance of internal knowledge to effectively absorb external know-how.

The empirical evidence on the complementarity in innovation performance between internal and external innovation strategies provides mixed findings. For instance, Cassiman and Veugelers (2006) find that intramural R&D and external knowledge acquisition are complementary in influencing innovation performance in Belgian firms, particularly for firms relying on 'basic' R&D. In the same line, Lokshin et al. (2008), using a dynamic panel of Dutch manufacturing firms, find also complementarities between the two strategies, but external R&D has only a positive impact on innovation performance in case of sufficient internal R&D. In contrast, Laursen and Salter (2006), for a sample of UK firms, find evidence of a substitution effect between internal R&D and external knowledge sourcing strategies. Similarly, Jirjahn and Kraft (2006), analysing whether firm's R&D intensity and R&D cooperative strategies are complementary in terms of innovative performance, interpret their findings as a hint towards a rather substitutive relationship. On the other hand, the results by Schiemdeberg (2008) provide evidence for significant complementarities between internal R&D and R&D cooperation in German manufacturing firms, but cast doubt on the complementarity of internal and externally contracted R&D. Finally, Love et al. (2014), for a sample of Irish manufacturing firms, find no evidence of complementarity between internal R&D and external innovation linkages. However, the dynamic switching to the joint use of internal and external innovation sources leads to increased innovation outputs.

Regarding the empirical evidence for Spanish manufacturing firms, there are also mixed results. On the one hand, Beneito (2006) finds a positive effect of externally contracted R&D when combined with internal R&D, pointing out the role of absorptive capacity. Based on the distinction between innovation types measured by patents and utility models, Beneito stresses a particular aspect of complementarity concluding that internal R&D produces rather significant innovation, whereas contracted R&D seems more orientated towards innovations of incremental nature. In the same line, Cruz-Cázares et al. (2010), analysing the different effect of R&D strategies upon innovation outputs, find that internal, external R&D and the combination of both strategies have a different impact on performance, with the combined strategy having the greatest impact (a sign of complementarity) and the external-only strategy having the lowest. The study by Vega-Jurado et al. (2009) confirms also the different impact of innovation strategies; in this case upon different innovation types (process and product), but in contrast to the previous studies, they are unable to find complementarities between internal and external sources.

By and large, these various strands of the empirical literature indicate the inconclusive nature on the debate between the different impact of innovation strategies and the complementarity between them in shaping firms' performance.

3. Empirical strategy.

Most of the above studies focus on the complementarity for innovation outcomes, while the existing literature on productivity effects from internal and external R&D is more limited. Previous studies analysing the complementarity or substitutability between firm's strategies for productivity have either used an augmented production function methodology or a two-stage procedure. When using the augmented production approach, a set of variables capturing firms' strategies are included as additional inputs into the production function.

Then, the estimated elasticities of these variables are used to test complementarity/substitutability (Lokshin et al. 2008). This strategy poses an obvious problem: introducing in the production function, for example, a dummy variable capturing whether the firm undertakes internal R&D implies that a firm can substitute any input with undertaking internal R&D at a constant elasticity of substitution (see De Loecker, 2013).

As for the two-stage strategy, the first stage consists in obtaining a productivity estimate as the residual of a production function estimation; and, in the second stage, this productivity estimate is regressed against a set of variables capturing the firm's strategies. The set of estimates of these strategy variables are then used to test for complementarity/substitutability. But for such methodology to make sense, past strategies should be allowed to affect productivity. Yet, most previous studies (implicitly) assume that the productivity term in the production function specification is governed by an exogenous Markov process (as in equation 5 below). It is this sort of assumption, often critical to obtain consistent estimates (Ackerberg et al., 2015), what makes these tests of complementarity/substitutability to lack internal consistency (see De Loecker, 2010 for a similar argument related to export).

In our estimation strategy, we address this drawback by considering a more general process driving the law of motion of productivity. In particular, in a similar fashion to Doraszelski and Jaumandreu (2013), we widen the law of motion of productivity to allow past technological strategies to shape current productivity. More specifically, we include in the law of motion of productivity a set of dummy variables fully characterizing past firms' technological strategies. Moreover, we incorporate this feature into the generalised method of moments (GMM) framework proposed by Wooldridge (2009). Lastly, we use the estimates of the technological strategy dummies (that are part of the law of motion of productivity) to test for complementarity/substitutability between technological options (internal vs. external R&D) using the procedure proposed by Carree et al. (2011).

3.1. Model and assumptions

We assume that firms produce a homogeneous good using a Cobb-Douglas technology:

$$va_{it} = \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \omega_{it} + \varepsilon_{it} \tag{1}$$

where va_{it} is the natural log of value added of firm i at time t, l_{it} is the natural log of labour (measured as the number of effective hours worked), and k_{it} is the natural log of capital (adjusted for capacity utilization). As for the unobservables, ω_{it} is the productivity (not observed by the econometrician but observable or predictable by firms) and ε_{it} is a standard *i.i.d.* error term that is neither observable nor predictable by the firm.

Under the assumption that capital is a state variable, whereas labour can be easily adjusted whenever the firm faces a productivity shock (i.e. it is a freely variable non-dynamic factor)[2], Olley and Pakes (1996) show how to obtain consistent estimates of the production function using a semiparametric procedure (see Levisohn and Petrin, 2003 for a closely related estimated strategy). However, in this paper we follow Wooldridge (2009) that argues that both Olley and Pakes (1996) and Levinsohn and Petrin (2003) can be reconsidered as consisting of two equations that can be jointly estimated by GMM: the first equation tackles the problem of endogeneity of non-dynamic inputs; and, the second equation deals with the issue of the law of motion of productivity.

To solve the problem of endogeneity of labour, both Olley and Pakes (1996) and Levinsohn and Petrin (2003) use a control function approach by using investment and materials respectively to proxy for "unobserved" firm productivity. Further, the proxy variable demand function, $m_t(\ )$, is assumed to have a unique unobservable among its

[2] The law of motion for capital follows a deterministic dynamic process according to which $k_{it} = (1\text{-}\delta)k_{it-1} + I_{it-1}$. Thus, it is assumed that the capital that the firm uses in period t was actually decided in period $t\text{-}1$.

arguments (*scalar unobservable assumption*) and to be strictly monotonic in unobserved productivity. Thus, given that in equilibrium the demand of the proxy variable only depends on state variables, if we follow Levinsohn and Petrin (2003) and rely on materials demand, we can write this demand as $m_{it}=m_t(k_{it},m_{it})$. Under the *scalar unobservable* and the *monotonicity assumption,* the demand of materials can be inverted to generate

$$\omega_{it} = m_t^{-1}\left(k_{it}, m_{it}\right) = h_t\left(k_{it}, m_{it}\right) \tag{2}$$

where h_t is an unknown function of k_{it} and m_{it}. Then substituting (2) into the production function (1) we get our first estimation equation:

$$va_{it} = \beta_0 + \beta_l l_{it} + \beta_k k_{it} + h_t\left(k_{it}, m_{it}\right) + \varepsilon_{it} \tag{3}$$

Since h_t is proxied by a third degree polynomial in its arguments, β_0 and β_k are not identified from equation (3). This is achieved by the inclusion of a second equation in the GMM system that deals with the law of motion of productivity:

$$\omega_{it} = f\left(\omega_{it-1}\right) + \xi_{it} \tag{4}$$

where $f(\ )$ is an unknown function that relates productivity in t to productivity in t -1, and ξ_{it} is an innovation term uncorrelated by definition with k_{it}. However, this assumption neglects the possibility of firms' previous technological strategies to affect future productivity. Consequently, here we consider a more general Markov process in which firms' technological strategies may influence the dynamics of productivity introducing in the law of motion of productivity a set of dummy variables fully characterizing firms' technological strategies (see Doraszelski and Jaumandreu, 2013 and De Loecker, 2010 for similar approaches for R&D and exports, respectively):

$$\omega_{it} = f\left(\omega_{it-1}\right) + \gamma_{(1,0)} s(1,0)_{it-1} + \gamma_{(0,1)} s(0,1)_{it-1} + \gamma_{(1,1)} s(1,1)_{it-1} + \xi_{it} \tag{5}$$

where $s(1,0)_{it-1}$ is an indicator for firms whose technological strategy in t -1 is *Internal R&D only*; $s(0,1)_{it-1}$ indicates that the firm's technological strategy in t -1 is *External R&D only;*

and, $s(1,1)_{it\text{-}1}$ indicates that the firm's technological strategy in t -1 is *Internal and External R&D* (the omitted strategy corresponds to the situation in which the firm chooses not to carry out R&D, i.e. $s(0,0)_{it\text{-}1}$).

Lastly, plugging (5) into the production function (1), our second estimation equation is given by:

$$\begin{aligned} va_{it} &= \beta_0 + \beta_l l_{it} + \beta_k k_{it} + g_t\left(k_{it-1}, m_{it-1}\right) + \\ &\quad \gamma_{(1,0)} s(1,0)_{it-1} + \gamma_{(0,1)} s(0,1)_{it-1} + \gamma_{(1,1)} s(1,1)_{it-1} + u_{it} \end{aligned} \tag{6}$$

where $g_t(k_{it\text{-}1},m_{it\text{-}1})= f(h_t(k_{it\text{-}1},m_{it\text{-}1}))$ is an unknown function proxied by a third-degree polynomial in its arguments and $u_{it} = \varepsilon_{it}+\xi_{it}$ is a composed error term.

Wooldridge (2009) proposes to estimate jointly equation (3) and (6) by GMM using the appropriate instruments for each equation. Following Wooldridge (2009) the simplest set of instrumental variables for equation (3) is:

$$z_{it1} = \left(1, l_{it}, k_{it}, c_{it}^{1}\right) \tag{7}$$

where c_{it}^{1} is a third-degree polynomial in k_{it} and m_{it} without including k_{it}.

As for the set of instruments for equation (6), it would include:

$$z_{it2} = \left(1, k_{it}, l_{it-1}, c_{it}, s(1,0)_{it-1} + s(0,1)_{it-1} + s(1,1)_{it-1}\right) \tag{8}$$

where c_{it} is a third-degree polynomial in k_{it} and m_{it}.

3.2. Testing for complementarity and/or substitutability.

To test for complementarity/substitutability between internal and external R&D strategies, we will use the set of parameters γ introduced in the law of motion of productivity to characterize firms' past technological strategies. Following Carree *et al.* (2011) and given that *s(0,0)* is the reference category, the null hypothesis of complementarity between internal and external R&D would require that the following inequality (strictly) holds :

$$\mathrm{H}_0: \quad \hat{\gamma}_{(1,1)} - \hat{\gamma}_{(1,0)} - \hat{\gamma}_{(0,1)} > 0 \tag{9}$$

That is undertaking both in-house and external R&D has a larger positive effect on TFP than the sum of the results obtained by performing in-house R&D and external R&D individually. In contrast, the null hypothesis of substitutability between internal and external would imply that:

$$\mathrm{H}_0: \quad \hat{\gamma}_{(1,1)} - \hat{\gamma}_{(1,0)} - \hat{\gamma}_{(0,1)} < 0 \tag{10}$$

4. The data.

To conduct our research we use a representative sample of Spanish manufacturing firms drawn from the *Encuesta sobre Estrategias Empresariales* (ESEE) for the period 1991-2014. This is an annual survey sponsored by the Spanish Ministry of Industry and carried out since 1990 that is representative of Spanish manufacturing firms classified by industrial sectors and size categories.[3] The sampling procedure of the ESEE is the following. Firms with less than 10 employees were excluded from the survey. Firms with 10 to 200 employees were randomly sampled, holding around 5% of the population in 1990. All firms with more than 200 employees were requested to participate, obtaining a participation rate of about 70% in 1990. Important efforts have been made to minimise attrition and to annually incorporate new firms with the same sampling criteria as in the base year, so that the sample of firms remains representative of the Spanish manufacturing sector over time. Firms in the ESEE correspond to 20 industrial sectors according to the 2-digit NACE classification for manufactures.

We consider this survey is quite unique to develop this piece of research, as this is a general survey with very rich information on firm activities and strategies[4] continuously (real panel data). Further, it covers 25 years of Spanish manufacturing. Among the variables we

[3] Our period of analysis starts in 1991 as information for some variables is only available from this year onwards.
[4] For example, innovation or export strategies pursued by firms.

find in the survey we can outline the following: complete information to construct the firm productivity index (TFP), very detailed information about firms' innovation activities (in particular, data on internal R&D expenditures, externally contracted R&D expenditures, and expenditures (revenues) for paying (selling) licenses.[5] Thus, we can relate firm innovation profiles with a broad range of firms characteristics (i.e., productivity, performance, etc.) and their environment.

The sample of firms for this period consists of 4773 firms (45215 observations). However, our final sample is an unbalanced panel of 3920 manufacturing firms (30685 observations) observed at least two consecutive years over the period 1991 to 2014, see Table 1. The panel is unbalanced due to the existence of missing observations in critical variables (see the appendix for definitions and data sources). In particular, to construct the final sample we selected firms that provided information for three or more consecutive periods on output, capital, materials, age and number of workers on the one hand, and on the expenditures on the three innovation strategies considered (i.e., expenditure on internal R&D, on external R&D and on imported technology through licenses).

[Table 1 here]

In Table 2 we provide descriptive statistics of the technological strategies followed by the firms (internal R&D activities, externally contracted R&D activities including imports of technology through licenses, and both internal and external), by technological intensity sector. We observe that 38.52% of the firms in our sample are involved in innovative activities.[6] With respect to the combination of R&D strategies, we observe that 20.34% of the firms combine internal and external R&D strategies and 10.95% of the firms only undertake internal activities. We also have that 7.23% of the firms only undertake external R&D

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[5] Further information about this survey can be found in the following web page, provided by FUNEP: http://www.funep.es/esee/en/einfo_que_es.asp.

[6] We define innovative firms those declaring positive R&D expenditures (either in internal or externally contracted R&D activities plus importers of technology through licensing) during at least one year of the observed period.

activities. Finally, we also observe important differences between large and small firms. While the most relevant strategy for large firms is to undertake both R&D strategies (46.52%), a higher percentage of small firms opt for doing nothing (76.82%).

By technological sector breakdown, it is interesting to underline some differences with the general pattern described. We observe that 41.93% of the firms operating in the high-tech sector undertake both innovation activities. This figure is 23.95% and 11.75% for the med and low-tech sectors, respectively. Further, we observe that 16.90% of firms in the high-tech sector undertake only internal innovation strategies, while 13.34% firms in the med-tech sector do so and only 7.76% of firms in the low-tech sector. The third different feature we observe is that only 8.33% of firms in the high-tech industries undertake external innovation activities, whereas 8.63% of firms in the med-tech and 6.08% of firms in the low tech do so.

From the above descriptive statistics, we can conclude that the innovation strategies pursued by firms operating in different technological intensity sectors are quite different. In particular, we see that the higher the technological intensity of the sector the higher the probability of performing internal and external R&D activities. Further, doing internal R&D is also related to the technological intensity of the industry, as 58.83% of firms in the high-tech sector develop internal R&D activities, as compared to 37.30% of firms in med-tech sectors and 19.51% of firms in low-tech sectors.

[Table 2 here]

Next, we identify some stylized facts about firms performing different innovation activities (only internal, only external and both) with respect to firms that do not, using a simple regression analysis (see Table 3). The objective is to explore the relationship between performing R&D activities at the firm level and some basic firm characteristics. In particular, output per worker, capital per worker, materials per worker and size of the firm are the main characteristics we focus on. To be more specific, we estimate an equation of the form:

$$\begin{aligned}\log\left(y_{it}\right) &= \beta_0 + \beta_1 s(1,0)_{it} + \beta_1 s(0,1)_{it} + \beta_1 s(1,1)_{it} \\ &\quad + \delta \log\left(size_{it}\right) + \sum_{i=2}^{20} \gamma_{it} ind_i + \sum_{i=1994}^{2014} \gamma_{it} year_t + \varepsilon_{it}\end{aligned} \qquad (11)$$

where the dependent variable is alternatively output per worker, capital per worker, materials per worker and size (measured as the number of employees). The variables s(1,0), s(0,1) and s(1,1) represent firms technological strategies as defined above. We also control for size[7], industrial sector and year.

[Table 3 here]

The differences (in %) between (internal, external and both) R&D performers and non-performers, computed from the estimated coefficient β_1 as $100(\exp(\beta) - 1)$, show the average percentage difference in the four firm characteristics considered, controlling for size, industrial sector and year. In all cases, we obtain that there are significant differences between R&D performers and non-performers. R&D performers are larger, more productive (in terms of output per worker), and are more capital and materials intensive than non-performers. These significant differences give support to the approach undertaken in this piece of research as regards to endogenously consider the link between any of the R&D strategies considered and productivity.

5. Results

Table 4 provides GMM estimates of the value added production function (1) with firms' R&D strategies in the Markov process that governs productivity (as described in equation 5). This approach is a version of the Controlled Markov Process of Doraszelski and Jaumandreu

[7] We exclude size in the control category when size appears as dependent variable.

(2013).[8] The estimates we obtain for labour and capital are similar to those obtained in previous studies —see Hall *et al.* (2009).

The main aim in this piece of research is to analyse the effects of the different R&D strategies on firm productivity. As discussed in the previous section, these are obtained directly from the Markov process coefficients of the corresponding R&D strategies.

[Table 4 here]

Prior to formally presenting the complementarity/substitutability tests, we present the results for the effects of the R&D strategies on firm productivity, obtained jointly with the parameters of the production function. Thus, in table 4 we present the coefficients for the labour and capital variables together with those corresponding to firms' innovation strategies. In particular, we report the results for the whole sample (column 1) and the breakdown by technological sector (columns 2-4). As for the innovation strategies, the reference category is s(0,0), i.e. performing neither internal nor external R&D. Therefore, the estimates for the innovation strategies dummies should be interpreted in relation to this category.

We start analysing the results for the whole sample of either large or small firms (first column). We find that both for large firms and for small firms, performing only any of the two R&D strategies (internal or external R&D) or both has a significant and positive effect on firms' productivity, as compared to not performing any of the R&D strategies. Further, for large firms, performing only internal R&D or external R&D has almost the same impact on TFP (4.9% and 4.8%, respectively) whereas performing both strategies almost doubles the impact (8.9%). However, for small firms, performing external R&D has the highest impact on TFP (9.0%), whereas performing internal R&D or both has a smaller effect on TFP (7.1% and 4.7%, respectively). These aggregated effects are masking the differential impact we observe when we analyse the effects of the R&D strategies by technological intensity

[8] We have also estimated the production function by OLS and using an exogenous Markov process. These results are available from the authors upon request.

breakdown. Thus, for large firms operating in low-tech sectors, the highest impact on TFP is found for firms performing only external R&D. However, for firms operating in med-tech and high-tech sectors, the highest impact is found for firms that combine internal and external R&D. As regards small firms, we find a different pattern as compared to large firms. We observe that the strategy with the highest impact on TFP across technological sectors is always performing only external R&D.

All in all, we can conclude that for large firms operating in med and high-tech sectors combining both internal and external R&D activities pays-off more than any other alternative. Whereas for small firms, regardless of the technological sector, it seems that performing external R&D is the most relevant strategy in terms of TFP. This result is also observed for large firms in low-tech sectors.

On the basis of the estimated coefficients, the next step is to formally test for complementarities/substitutabilities between innovation strategies (see table 6). For this purpose, we define $\hat{\delta} = \hat{\gamma}_{11} - \hat{\gamma}_{10} - \hat{\gamma}_{01}$, that measures the difference between the returns (in terms of productivity) of combining internal and external R&D and the sum of the returns of performing internal R&D only or external R&D only.

Our test of complementarity/substitutability consists of two-steps. First, we test whether $\hat{\delta}$ is significantly different from zero (two-sided test). Second, and conditional to rejection of the null in the first step, we test for complementarity in case $\hat{\delta}$ is positive (one-sided test) and for substitutability if $\hat{\delta}$ turns out to be negative (one-sided test). A positive and significant value of $\hat{\delta}$ should be interpreted as evidence of complementarity between internal and external R&D: the returns of combing internal and external R&D outweigh the sum of the returns of pursuing only one or the other innovation strategy. Conversely, a negative and significant value for $\hat{\delta}$ is a sign of substitutability between internal and external

R&D: the sum of the returns of performing only internal R&D or external R&D are larger than those associated to combining both strategies.

In table 5 we report the results of testing for complementarity or substitutability. First, we report the value of $\hat{\delta}$ and the *p*-value corresponding to the null of $\hat{\delta}=0$. Second, dependent upon $\hat{\delta}$ being positive or negative (and significant, according to the *p*-value of the corresponding one-sided test) we will have evidence of complementarity or substitutability. In column one, we report the results for the samples of large and small firms. For large firms, we find no evidence in favour of complementarity or substitutability as $\hat{\delta}$ is not statistically significant. However, for small firms we obtain significant evidence in favour of substitutability ($\hat{\delta}$ is negative and significant).

Next, we discuss the technological intensity breakdown of the complementarity/substitutability tests. First, for large firms operating in low-tech and med-tech industries there is significant evidence of substitutability as $\hat{\delta}$ is negative and significant. Second, and in contrast, for large firms operating in high-tech industries $\hat{\delta}$ is positive and significant suggesting the existence of complementarity between internal and external R&D. Finally, for small firms, and regardless the technological sector in which they operate, we find evidence of substitutability as $\hat{\delta}$ is always negative and significant.

[Table 5 here]

6. Conclusions.

The aim of our study is to analyse the impact of different innovation strategies –defined as intramural R&D and external R&D, which includes both contracted-out R&D and imports of technology, and their combinations upon TFP. This paper attempts to contribute to the current literature that analyses if engaging in one innovation activity increases the return from the other on firm performance, which has yielded mixed and inconclusive results.

Our results reveal that both *internal R&D and external R&D* strategies contribute positively to TFP. More precisely, for small firms and independently of the sector, the direct effect on TFP of performing only external R&D is greater than doing only internal R&D. This result is also found for large firms belonging to low-tech sectors. Moreover, when analysing potential synergies between both strategies, only for large firms in high-tech sectors in-house and external R&D are complementary innovation strategies for TFP. This means that in large firms in high-tech sectors, the productivity returns from engaging in in-house R&D increase with the engagement in external R&D, and vice versa. For the rest of firms, both innovation strategies turn out to be substitutive.

Our results point to the existence of different pattern of R&D (organisational, or other) costs by firm size and technological intensity that might have an effect on the way firms organize their innovation activities. Therefore, polices aimed at helping small or large firms should account for the different complementarities/substitutabilities of these activities in different firms operating in different sectors.

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Table 1. Number of firms by technological intensity breakdown.

Firms	All firms		Low-tech		Med-tech		High-tech	
Number of firms	3920		2149		1153		618	
Number of innovative firms	1458	37.19%	540	25.13%	234	43.80%	235	66.83%
Large firms								
Number of firms	983		367		355		261	
Number of innovative firms	704	71.62%	213	58.04%	266	74.93%	225	86.21%
Small firms								
Number of firms	2937		1782		798		357	
Number of innovative firms	754	25.67%	327	18.35%	239	29.95%	188	52.66%

Notes:

1. Innovative firms are defined as those that undertake internal and/or external R&D activities (accounting for imports of technology through licensing) during at least one year of the observed period.
2. The sample of 3920 firms corresponds to 30685 observations (8741 corresponding to large firms and 21944 to small firms), and the sample of innovative firms corresponds to 11820 observations (6733 corresponding to large firms and 5087 to small firms).

Table 2. Technological strategies for the innovative firms.

Strategy	All firms		Low-tech		Med-tech		High-tech	
All firms								
Only internal R&D	3360	10.95%	1261	7.76%	1277	13.35%	822	16.90%
Only external R&D	2220	7.23%	989	6.08%	826	8.63%	405	8.33%
Both internal and external R&D	6240	20.34%	1910	11.75%	2291	23.95%	2039	41.93%
None	18865	61.48%	12096	74.41%	5172	54.07%	1597	32.84%
Large firms								
Only internal R&D	1548	17.71%	532	16.07%	657	19.78%	359	16.95%
Only external R&D	1119	12.80%	427	12.90%	481	14.48%	221	10.43%
Both internal and external R&D	4066	46.52%	1136	34.31%	1595	48.01%	1335	63.03%
None	2008	22.97%	1216	36.73%	589	17.73%	203	9.58%
Small firms								
Only internal R&D	1812	8.26%	729	5.63%	620	9.93%	463	16.87%
Only external R&D	1101	5.02%	572	4.42%	345	5.53%	184	6.70%
Both internal and external R&D	2174	9.91%	774	5.97%	696	11.15%	704	25.65%
None	16857	76.82%	10880	83.98%	4583	73.40%	1394	50.78%

Table 3. Differences between R&D performers and non-performers.

	Difference in % (Only internal R&D vs. no performers)	Difference in % (Only external R&D vs. no performers)	Difference in % (Both internal and external R&D vs. no performers)
Large firms			
Output per worker	8.29***	25.69***	13.01***
	(0.020)	(0.023)	(0.017)
Capital per worker	19.25***	30.53***	29.29***
	(0.029)	(0.030)	(0.025)
Materials per worker	9.50***	32.03***	14.83***
	(0.025)	(0.027)	(0.022)
Size	25.94***	19.35***	57.58***
	(0.021)	(0.023)	(0.018)
Small firms			
Output per worker	27.07***	43.10***	33.75***
	(0.015)	(0.017)	(0.014)
Capital per worker	34.91***	51.88***	40.15***
	(0.022)	(0.027)	(0.021)
Materials per worker	36.08***	58.70***	46.35***
	(0.019)	(0.022)	(0.018)
Size	100.00***	97.43***	159.46***
	(0.020)	(0.024)	(0.018)

Notes: For the estimation of the differences in size across firms' groups we do not include *log*(size) as a regressor.

Table 4. Effect of the R&D strategy on firm productivity.

	All sample	Low-tech	Med-tech	High-tech
Large firms				
Labour	0.643***	0.676***	0.549***	0.699***
	(0.007)	(0.0109	(0.012)	(0.012)
Capital	0.261***	0.372***	0.218***	0.161***
	(0.018)	(0.025)	(0.033)	(0.035)
Innovation technological strategies				
s(1,0)	0.049***	0.027***	0.125***	-0.020
	(0.012)	(0.016)	(0.022)	(0.534)
s(0,1)	0.048***	0.065***	0.065***	0.010
	(0.013)	(0.017)	(0.024)	(0.785)
s(1,1)	0.089***	0.024***	0.136***	0.117***
	(0.010)	(0.013)	(0.019)	(0.029)
N. of obs.	8741	3301	3322	2118
Small firms				
Labour	0.705***	0.725***	0.647***	0.713***
	(0.004)	(0.005)	(0.006)	(0.011)
Capital	0.194***	0.204***	0.192***	0.155***
	(0.009)	(0.005)	(0.016)	(0.025)
Innovation technological strategies				
s(1,0)	0.071***	0.080***	0.057***	0.082***
	(0.009)	(0.014)	(0.015)	(0.020)
s(0,1)	0.090***	0.085***	0.086***	0.137***
	(0.011)	(0.015)	(0.019)	(0.028)
s(1,1)	0.047***	0.017	0.052***	0.091***
	(0.009)	(0.014)	(0.014)	(0.018)
N. of obs.	21944	12955	6244	2745

Notes:

1. The dependent variable is (log) value added.
2. Standard errors are in brackets.
3. ***, **, * denotes level of significance at 1%, 5%, and 10%, respectively.

Table 5. Testing for complementarity and substitutability between the different innovation strategies.

	All sample	**Low-tech**	**Med-tech**	**High-tech**
Large firms				
Complementarity test				
$\hat{\delta}$	-0.008	-0.068	-0.055	0.128
$Chi^2(1)$	0.21	8.20	3.52	9.25
Two-sided test p-value	0.645	0.004	0.061	0.002
One-sided test p-value	0.339	0.010	0.015	0.001
Small firms				
Complementarity test				
$\hat{\delta}$	-0.114	-0.148	-0.091	-0.128
$Chi^2(1)$	52.72	38.29	11.61	12.98
Two-sided test p-value	0.000	0.000	0.001	0.000
One-sided test p-value	0.000	0.000	0.000	0.000