Complementarity between internal R+D and buying knowledge: the case of manufacturing and innovative plants in Chile.

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Abstract

This study evaluates the hypothesis of complementarity in a case where a firm considers undertaking two types of possible innovation activities: internal R+D and buying external knowledge. The methodology to evaluate the hypothesis is based on Cassiman and Vegeuleres (2006) and Schmiedeberg (2008), which was applied in a transversal selection of manufacturing and innovative plants in Chile. The results do not support the hypothesis of complementarity and suggest a substitution between innovation activities that were taken into consideration. The absence of complementarity in the group of studied plants means that the incentives aimed at buying knowledge do not improve the performance of internal R+D capacities, at least within the 2003-2004 period. Furthermore, such incentives might even reduce the establishments' innovative performance.

1 Introduction

Firms that decide to innovate must, consequently, elucidate how they will organize themselves in order to do it; that is to say, they must choose activities which are non-exclusive. Some such activities include the production of internal knowledge, the buy of knowledge and the cooperation with other agents to create knowledge. The different combinations of activities make up the potential set of innovation strategies.

Trade literature shows that the combination of different innovation activities has positive effects on the innovative performance of a firm: internal R+D and external know-how (Cassiman and Vegeulers, 2006); internal R+D and R+D cooperation (Schmiedeberg, 2008). It can be observed in a wider context that the combination of external knowledge and internal knowledge has positive effects on a firm's productivity (Bonte, 2003; Lokshin et al., 2006). All the commented evidence supports what has been known as complementarity between innovation activities.

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Complementarity between innovation activities is a phenomenon principally studied in the developed world; however, in general, it is a little explored area in developing countries. Using information from Chilean plants some works have studied innovative performance (Benavente, 2005) and the determinants of cooperation in innovation activities (Benavente and Lauterbach, 2007), nevertheless, innovative performance has not yet been related to innovation activities.

This work evaluates complementarity between internal R+D innovation activities and buying knowledge. The methodology used is obtained from Cassiman and Vegeuleres (2006) and Schmiedeberg (2008), which is then applied to a transversal section of data from innovative and manufacturing establishments in Chile. The proposed procedure analyzes the determinants of adoption of innovation activities and the relation between these activities with the innovative performance of the plants is explicitly linked.

In addition to research innovation, the evaluation of the hypothesis of complementarity provides information with regard to the results expected from a subsidy to R+D outsourcing[1] . If the internal and external innovation activities are complementary, one of the possible effects of a subsidy for R+D outsourcing would be strengthening the capacity of "in-house" innovation.

The results permit us to conclude that innovation activities of doing R&D and buying knowledge are not complementary, and that they would even have a substitutive relation. The conceptual framework that guides this work suggests that there can be a replacement between doing R&D and buying knowledge when knowledge or technology bought outside the firm has scarce novelty in the firm's context.

For the group of studied plants, evidence suggests that the incentives for the buy of knowledge will not improve the performance of its internal R+D capacities, at least within the 2003-2004 period. Furthermore, such incentives might even reduce innovative performance of the establishments.

Below, we consecutively present the conceptual framework; the empirical evidence for complementarity between innovation activities; the methodology; the sample and the variables used; the results; and, finally, the conclusions.

2 Conceptual framework

The concept of complementarity between the activities available to a firm was coined by literature dealing with organizational design (Milgrom and Roberts, 1990; Athey and Stern, 1998). It was later employed for the study of complementarity between innovation activities (Cassiman and Vegeulers, 2006; Lucena, 2007; and, Schmiedeberg, 2008).

[1] Law 20.241 establishes a tax incentive for private R+D investment. First category taxpayers of the Tax Income Law may choose a subsidy of up to 46 % of R+D investment when R+D contracts are celebrated with research centers registered with CORFO and whose contracted amounts exceed 100 UTM.

When a firm can adopt two innovation activities, complementarity exists when the incremental performance reached by having adopted both activities is higher than performance achieved when an activity is carried out in the absence of the other one.[2]

The relation of complementarity between activities can be represented by super-modular functions of innovative performance.[3] For two activities any A_1 and A_2 with a value 1 when they are adopted and 0 in the other case $f(A_1, A_2)$ is a function of innovative super-modular performance if:

$$f(1,1) - f(0,0) \geq [f(1,0) - f(0,0)] + [f(0,1) - f(0,0)] \qquad (1)$$

The justification of the hypothesis of complementarity between innovation activities comes from the double role of internal R+D: it has been highlighted that in addition to the increase of the stock of internal knowledge created by R+D , it also allows the firm to improve the capacity to absorb knowledge and technology available externally (Cohen and Levinthal, 1989).[4]

At the same time, it has been indicated that once a new technology is acquired, an assimilation and learning phase begins in the context of the acquired technology, be it in order to adapt it to the means of use and/or to adapt the productive means to the new technology (Katz, 1976). A similar idea is offered by Zahra and George (2002), who indicate that to effectively absorb acquired technology it is necessary to assimilate, transform and develop it. All in all, once external technology is acquired, internal R+D activities might be required to achieve external knowledge absorption.[5]

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[2] The definition of the number of possible activities determines the firm's set of choice possibilities, which is known as ex ante.

[3] Milgrom and Roberts (1990) call a function super-modular if it displays complementarities between their arguments.

[4] It is supposed that the flow of external knowledge contributes to the firm's accumulation of knowledge, which has positive effects on the function of the firm's benefits, but at decreasing rates.
External knowledge can arise from the intra-industrial external factors, but also from other sources that are outside the economic classification that identifies firms as, for example, universities, technological centers and/or equipment suppliers.

[5] According to Zahra and George (2002), the definitions of the mentioned actions are:

1. **Acquisition:** refers to the skills of the firm to identify and to acquire knowledge created externally.
2. **Assimilation**: refers to the routines and processes that permit the firm to analyze process, interpret and understand the information coming from external sources.
3. **Transformation**: denotes the firm's skill to develop and improve the routines that facilitate the combination the existing knowledge with the recently acquired and assimilated knowledge.
4. **Development:** refers to the routines that permit the firm to refine, extend and leverage the existing competences, or to create new competences by incorporating acquired and transformed knowledge into its operations.

As long as external knowledge is innovative in the firm's context, it will be necessary to accumulate some degree of internal knowledge to use the market; at the same time, once innovative external technology is acquired, a phase of assimilation and learning is expected.

And to the contrary, if external knowledge is not innovative in the firm's context, the source of technology that provides the minimum total cost between outsourcing and internal creation of knowledge is chosen, given that knowledge created internally will be a perfect substitute for external knowledge.

The creation of knowledge compared to the production of other goods is highly suspenseful, it requires creative solutions and it must deal with potential technology leaks (Ulset, 1996), all the above increasing the cost of contracts. Consequently, the higher the costs of using the market, *ceteris paribus*, the higher the probability of internalizing the creation of knowledge in relation to of the probability of outsourcing the creation of knowledge.

Notwithstanding the above, when, in the firm's context, external knowledge is innovative there are incentives to acquiring it even in the presence of the costs arising from using the technology market.

3 Empiric evidence

The first studies which analyzed the relation between a firm's R+D activities focused on knowledge-intensive sectors such as, for example, the pharmaceutical sector. Among them, Arora and Gambardella (1990) indicate that the links between big pharmaceutical firm (United States, Europe and Japan) with similar companies, universities or new biotechnology firms were correlated positively, even after being controlled by the firms' characteristics. [6]

Furthermore, Pisano (1990) analyzes the decision to develop new pharmaceutical products based on biotechnology through the use of internal R+D or using contractual agreements with other firms. The study included a set of established pharmaceutical firms and there is evidence which indicates that transaction costs benefit R+D internalization. [7]

Other studies focused on establishing the relation between internal R+D expense and external R+D expense. For example, for a sample of manufacturing firms in the county of Flanders, Belgium, Vegeulers (1997) finds that R+D cooperation and, to a lesser degree, R+D outsourcing have a positive effect on internal R+D expense, but only if firms can absorb external knowledge through an R+D department. Additionally, he also indicates that with higher internal R+D expenditure, R+D expenditures on cooperation increases.

[6] The external links considered are as follows: research agreements with other firms; research agreements with universities; investment in stocks of new biotechnology firms; and, acquisition of new biotechnology firms.

[7] A small number of institutions that can continue R+D project development previously started by another proponent (small-numbers bargaining) benefits R+D internalization.

The study of the effect of external knowledge on productivity can be found in Bonte (2003). The author uses a sample of German firms where he identified a positive relation between total factor productivity and the quotient between external R+D expenditure and internal R+D expenditure, after having been controlled by the firm's other characteristics.

Cassiman and Vegeulers (2006) study the effect of internal R+D and the external know-how on the firm's innovative performance through a cross-section of manufacturing firms in Belgium. The study concludes that there is evidence of complementarity between both activities, even after controlling the endogeneity of innovation activities.

A similar study was carried out by Schmiedeberg (2008), who uses a cross-section of German manufacturing firms to study the relation between internal R+D and external R+D; and, between internal R+D and R+D cooperation. The study concludes that there exists evidence of complementarity between internal R+D and R+D cooperation, but that there is no strong evidence with regard to complementarity between internal R+D and outsourced R+D.

Other studies use panel information to study complementarity between R+D activities. Lokshin et al. (2006) analyzes the impact of internal and external R+D on work productivity for a set of innovative Dutch companies. The study indicates that external R+D expense has positive effects on work productivity only when there is sufficient expense on internal R+D.

At the same time, Lucena (2007) uses a set of Spanish manufacturing firms to analyze the relation between internal R+D, cooperative research and externalizing R+D. The study has found evidence in favour of complementarity between the three above mentioned activities.

It should be noted that no evidence has been found for Latin America. Nevertheless, for Chile some innovation cases have been documented where we can see the importance of external knowledge. [8]

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[8] For example, the SRC salmon vaccine was the result of a joint effort between Fundación Ciencia para la Vida (Dr. Valenzuela) and Fundación Chile (Dr. Parada); the innovation of Lucien Biotechnologies came from the interaction of a biochemist, an engineer and a doctorate student; the Valdez chair arose from the idea of making use of the quality of laminated wood used for tennis rackets; and, for the renowned biologist Humberto Maturana the experience of innovating can be summed up this way: " a person does something that for him or her seems absolutely natural and other people say: ahhhh ". All the cases were obtained from Innovation Made in Chile 2007. Fundación Chile País Digital. To see detail use link
http: // www.innovacionmadeinchile.cl/

4 Methodology

This section presents the methodology to evaluate the hypothesis of complementarity, when there are only two innovation activities and when transversal information is available, following the work of Cassiman and Vegeulers (2006) and Schmiedeberg (2008).

It is a three-step methodology: a model of innovation activities selection; a model of innovative performance to directly evaluate the hypothesis of complementarity between innovation activities; and, a procedure developed by Cassiman and Vegeulers (2006) to correct the estimation of innovative performance by the endogeneity of innovation activities.

4.1 Adoption of innovation activities:

The first complementarity test between innovation activities can be found within the framework of activity selection.

The presumption of the model is that the adoption of innovation activities corresponds to a maximization process of expected benefits and seeks to evaluate the sign of the conditional correlation between innovation activities, since in the presence of complementarity among innovation activities the quotient of conditional correlation must be positive.

This approach has been used in trade literature (Arora and Gambardella, 1990; Cassiman and Vegeulers, 1998; Schmiedeberg, 2008), however, even if it is conditioned by certain characteristics of the firm and of the firm's environment, the correlation might also be positive as a consequence of the non-observed heterogeneity (Arora, 1996; Athey and Stern, 1998). Consequently, it is only a weak test for complementarity.

In formal terms, let's suppose that the value of the adoption of innovation activities (A_1^i, A_2^i) depends on the expected net benefit associated with each activity, which is not observed by the investigator. The only available information is that each innovation activity has a value 1 when the firm undertakes it and 0 in the opposite case.

Where A_j^{i*} is the net expected benefit associated with activity j, with j = 1,2, which can be expressed in the following way:

$$A_j^{i*} = X^i B + e_j^i \text{ con } j \in [1,2] \text{, (2)}$$

Where X^i it is a vector of exogenous variables that influence the adoption of innovation activities (benefits and costs). At the same time, e_j^i follows a bi-varied distribution with average zero and a matrix of variances and co-variances as follows:

$$\Sigma = \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}$$

The ρ parameter is the correlation quotient between e_1^i and e_2^i.

Each activity is adopted if:

$$A_j^i = \begin{cases} 1 \ \ si \ \ A_j^{i*} > 0, \\ 0 \ \ si \ \ A_j^{i*} \leq 0 \end{cases} \quad para \quad j = 1,2$$

In this context, there will be evidence in favour of complementarity when ρ is statistically higher than zero.

4.2 Innovative performance:

The model which permits to directly evaluate the hypothesis of complementarity is the innovative performance model (Cassiman and Vegeulers, 2006; Lucena, 2007; Schmiedeberg, 2008).

In this case, it is assumed that there is a measure of innovative performance Π^i, which is a function of innovation activities A_1^i and A_2^i, and of exogenous variables vector Z^i.

$$\Pi^i(A_1^i; A_2^i; Z^i) = \alpha + A_1^i\beta_1 + A_2^i\beta_2 + A_1^iA_2^i\beta_{12} + Z^i\theta + \mu^i \quad (3)$$

In equation (3), μ^i represents the term of stochastic error which is not correlated with the determinants of the adoption of innovation activities, that is to say, it is supposed that innovation activities are exogenous.

The complementarity test means verifying that β_{12} is statistically higher than zero.[9]

[9] Schmiedeberg (2008) proposes this complementarity test which is equivalent to the one used by Cassiman and Vegeulers (2006) and consistent with the structure of a super-modular function.

4.3 Combination of adoption approach and innovative performance:

When relaxing the assumption that the "unobserved" determinants of the adoption of activities are not correlated with μ^i , the parameters associated with innovation activities are not necessarily consistent.

To obtain consistent estimators, Cassiman and Veugelers (2006) propose a two-stage procedure. The method consists of obtaining predictions of the model of activities adoption which in the second stage are used as innovation activities instruments in the function of innovative performance. In the second stage, the innovative performance model is estimated using the instrumental variables method.

5 The sample and the variables

The information at plant level comes from the IV Technological Innovation Survey (2005) developed and carried out by the National Statistics Institute (INE) and information corresponding to 2003 and 2004. The survey gathered information from 3,122 establishments from the following sectors: manufacture, mining, power generation and distribution and others. [10] The total number of surveyed establishments is representative of a universe of firms totalling more than 2,400 UF in sales per annum. It must be observed that the survey questionnaire follows the general guidelines suggested by the OECD for innovation surveys.

The survey gathers information with regard to different types of innovations, among which there are product, service and process innovations (technological innovation), but also design, packing and management. Consequently, an establishment is innovative if it can show it has obtained innovations in at least one of the above mentioned categories. [11]

To select the sample of establishments, two criteria were used: reduction of the unobserved heterogeneity or heterogeneity that the supposed methodological structure does not permit to control; and, at the same time, the availability of impact and control information.

To limit the exposure to unobserved or uncontrollable heterogeneity only one economic sector was selected, to be specific manufacture, and all the establishments that said to carry out cooperation in innovative activities were eliminated. [12] In relation to the availability of

[10] In the sample a firm can be an owner of a number of plants.

[11] It is shown that the majority of manufacturing and innovating establishments developed more than one type of innovation, and that the most popular ones are process, organisation and product innovations, respectively.

[12] The exclusion of firms that co-operate in the development of innovation activities permits to isolate the firms that certainly deal with a set of selection possibilities different from the one supposed for the work. It was shown that the total number of observations of cooperating plants was 68.

information, the construction of the survey establishes that the questions related to all the impact variables are answered only by the innovative plants. [13]

The sample includes 522 observations of manufacturing and innovative plants, equivalent to 45 % of the total observations of manufacturing plants considered in the survey. [14]

The sample includes the relatively large plants considered in the survey given that it does not represent the population of manufacturing firms' characteristics to the 2003 Annual National Industrial Survey (ENIA). And more specifically, there is an over-representation of medium and large plants. [15] The above is particularly noticeable in large plants whose presence in the ENIA and the sample is 9 % and 30 %, respectively. [16]

5.1 Model of innovation activates adoption

The innovation activities are constructed on the basis of the response to qualitative questions with regard to the origin of R+D or knowledge for the 2003-2004 periods, in such way that all the approaches to innovation activities are dychotomic variable (1 or 0).

The *make* variable approaches the development of internal R+D activities. The internal activities include those carried out by a department dedicated to the innovation such as those R+D activities that are sporadically undertaken by groups not specializing in innovation, for example, maintenance groups, quality control, processes engineering, client service, to mention a few.

In relation to the sources of external knowledge, it is supposed that a plant can acquire patents, licenses or know- how or can outsource R+D. In the last case, it is presumed that there exists a contract for the supply of services that involves a natural person, a public institution, a university or a private company. It is where a firm buys external knowledge (*buy*) when it acquires or outsources knowledge (Cassiman and Vegeulers, 2006).

The representation of innovation activities by dychotomic variables (1 or 0) has been widely used in trade literature (Cassiman and Vegeulers, 1998; Cassiman and Vegeuleres, 2006; Lucena, 2007; Schmiedeberg, 2008), however, it also has some disadvantages. The dychotomic variables only take into account the adoption of activities, but do not consider the intensity with which each activity is carried out (Lokshin et to., 2006; Schmiedeberg,

[13] The plants that do not report innovation only answer questions with regard to the acquisition of equipment; to the intellectual property rights and know-how; to innovation obstacles; and, the perspectives of future innovations.

[14] Expansion factors were not used since they are not related to the importance of the innovative reality of the plants, but also because the original sample was manipulated previously.

[15] 30 % of the plants in the sample are large, 33% medium-sized, 35% small and 2% micro. The classification of the size of the plants was done according to the number of employees reported by the plants in 2003. The large plants have 200 or more employees, the medium-sized ones between 50 and 199 employees, the small ones between 10 and 49 employees and the micro ones 9 employees or fewer.

[16] 2003 National Annual Industrial Survey Volume I and II (Encuesta Nacional Industrial Anual Volumen I y II) published in May, 2006 by the National Statistics Institute. Tables 18 A and 18 B.

2008); in turn, the plants that develop multiple projects may carry out activities simultaneously but they do not have an effective relation (Schmiedeberg, 2008).

A way of interpreting the adoption of innovation activities consists of supposing that it depends from the expected benefit net of expenses that each plants obtains when it undertakes them; however, the information used to size the expected net benefit from the adoption of activities generally is not observed directly. At the same time, there are no theoretical models that direct the selection of variables (Cassiman and Vegeulers, 2006).

The reviewed literature indicates that the adoption of activities has been linked to the scale of the firm, with inputs measures aimed at innovation, but also with the absorptive capacity of external knowledge and with knowledge adequacy (Cassiman and Vegeulers, 1998; Cassiman and Vegeuleres, 2006; Schmiedeberg, 2008).

The relatively large firms deal with economies of scale and scope that increases the probability of adopting the *make* activity. The scale of the plant is approximated by the number of workers employed in the plant in 2003 and its effect is controlled by the variable in levels and by square value.

The intensity with which the plants dedicate their resources to innovation might be relevant if it is related with the level of technological challenge that the plant is dealing with. A possible way of measuring the technological level of the plant is the R+D expense per worker in 2003.

The definition of absorptive capacity that includes all the others provided by trade literature can be found in the work of Zahra and George (2002), and is defined as a set of organizational routines and processes through which firms acquire, assimilate, transform and develop knowledge to produce a dynamic organizational ability (an ability to effectively create, manage and develop knowledge). A partial vision of absorptive capacity can be found in the work of Cassiman and Vegeulers (2006), who propose that the capacities of a firm to undertake basic R+D are usually made up by the firm's absorption capacity.

This work makes a supposition that the plants capable of perceiving the most basic knowledge as relevant to innovate have a relatively higher external knowledge absorption capacity. To be more specific, the declaration of each plant is used with regard to the importance for innovation of the information obtained from institutional sources in the 2003-2004 period. [17]

As the need for basic knowledge is linked to the economic sector in which each plant operates (Cohen and Levinthal, 1989), the average importance for the respective two-digit ISIC sector was deducted from each self-report. [18]

[17] Institutional sources are universities and other higher education entities, public or government research institutes.

[18] Another approach to absorptive capacity can be found in the work of Vegeulers (1997) who uses a dychotomic variable that identifies the plants with an internal R+D department with full-time staff. At the

It is expected that the higher the external knowledge absorption capacity, the bigger the probability of adopting *buy*, given that there are lower costs of knowledge acquisition (Contractor, 1983) and lower transaction costs. In the latter case, it is presumed that the plants with higher absorptive capacity have fewer difficulties to identify opportunities and risks, to choose suppliers and to monitor the progress of the projects. At the same time, higher external knowledge absorptive capacity can trigger assimilation cycles, knowledge transformation and development, which would probably require the implementation of internal R+D activities.

In relation to knowledge ownership, intellectual property rights (IPR) permit to turn the result of an investment (knowledge) with public good characteristics into a private good. The access to IPR promotes innovation, be it by means of internal or external activities, and it reduces outsourcing transaction costs. Since the access to IPR is heterogeneous according to the economic sector, it is approximated by the proportion of plants that have requested IPR by two-digit ISIC sector.

It is not always possible to protect knowledge through IPR. One example is when the result of R+D is tacit knowledge. In the last case other methods are used to protect knowledge, generally based on a company's internal processes (secrets, encrypting, passwords, employment contracts, complexity, among others), which make up what is known as strategic protection. It should be noted that strategic protection is only useful when protecting knowledge created within a company.

The information available in the survey does not permit to find an approach for strategic protection; however, a firm will perceive that the creation of knowledge is unprotected when it is complex to protect knowledge through IPR and through strategic protection. It is why a general measure of adequacy problems is used which is represented by the proportion of plants that perceive facility to imitate technology for two-digit ISIC sector.

It is expected that the bigger the lack of protection of knowledge perceived by the plants, the higher the probability of adopting *make*, be it as a protection measure or as a method that makes it easer to copy available knowledge.

In order control the heterogeneity of technology used by the plants they were grouped in three exclusive categories: low technology, medium-low and high technology. The classification low technology and medium- low technology was constructed following OECD (2003), while high technology corresponds to all the plants that were not classified under the previous categories, since they are relatively more technology- intensive.

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same time, Schmiedeberg (2008) approaches absorptive capacity by the proportion of qualified workers in the total number a company's employees.

5.2 Innovative performance model

The innovative performance is approached by the percentage of the sale of innovated products in relation to all the sales for the 2003-2004 periods. The same type of approach was used by Cassiman and Vegeulers (2006), Lucena (2007) and Schmiedeberg (2008). The use of this performance measure prevents unobserved heterogeneity deriving from the rest of the firm's operations that affects other performance measures of the firm such as, for example, the total factor productivity.

Since there exists a set of plants that lack product or services innovations introduced in the market and/or which through innovation do not seek sales but focus on other objectives (cost reduction or complying with environmental regulations, among other aims), the performance measure will be censured at 0 value. To capture the censure of the dependent variable, the model of innovative performance is estimated by means of the Tobit model. [19]

The Tobit model makes an assumption that it is only possible to observe the performance of the plants that could implement product or service innovations ($sales\_inn_i$), whose value depends on a latent variable ($sales\_inn_i^*$) that represents the implementation of product or service innovations, as shown below:

$$sales\_inn_i^* = \alpha + A_1^i\beta_1 + A_2^i\beta_2 + A_1^iA_2^i\beta_{12} + Z^i\theta + \mu^i$$

$$sales\_inn_i = \begin{cases} sales\_inn_i^* \text{ if } \text{sales\_}inn_i^* \geq 0, \\ 0 \ if \ \ \text{sales\_}inn_i^* < 0 \end{cases}$$

To prove the robustness of the results deriving from the Tobit model another approach of innovative performance is used. The alternative measure is on the reports of achievements in product or service innovations. In this case, the variable that represents the achievement of product or service innovations (pos_i) is dychotomic (1 or 0), since the equation (2) is estimated by a conventional Probit model. [20]

The reviewed literature suggests that in addition to the importance of innovation activities for a company's innovative performance, what is relevant is the scale of the establishment, the inputs for innovation and the exposure to competitiveness (Cassiman and Vegeulers, 2006; Lucena, 2007; Schmiedeberg, 2008).

The relation of the scale of the establishment with innovative performance is not clear, as detailed in Cassiman and Vegeulers (2006). Large firms can display higher market power or adopt economies of scale and scope, which would increase innovative performance; contrarily, small firms may be less beaurocratic and thus more efficient as to innovations; and, small firms might be better equipped to obtain a high participation in the sale of new

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[19] More details in Greene (2003) p. 829. As can be seen in table 5.1., the measure of innovative performance is also an ordered variable, which is not considered by the Tobit model.
[20] More details in Greene (2003) p. 751.

or innovative goods or introduced in the total number of their sales. As in the previous model, the scale of the establishment is approached by the number of workers in the establishment in 2003 and for the square of the number.

The inputs aimed at innovation have a direct bearing on innovative performance, be it because they increase innovating probability or because they increase the degree of innovations disruption. To measure inputs for innovation we use R+D expense per worker in 2003.

The exposure to competitiveness is also related to innovative performance. The exposure to competitiveness is approached by the export nature of the plant (the plant either exported products in 2003 or it did not), given that it is presumed they face higher competition than the firms that deal with the internal market. It is expected that there is a positive effect of the exposure to international competitiveness on innovative performance.

Notwithstanding the above, it is necessary to take into consideration that the export status of a plant can also promote innovative performance through other means: because the plant has access to external sources of knowledge and/or because the plant deals with a larger-sized market than the local market.

The innovative performance model also uses sector controls referred to in the activity adoption model.

Below, there are approaches to innovation activities, the measures of innovative performance and the independent variables used in the quantitative analysis. Table 5.1. details the variables that will be used in the empirical exercises and their respective descriptive statistics, whereas Annex 1 shows primary information extracted from the IV Technological Innovation Survey.

Table 5.1.: Description of variables and descriptive statistics

Name	approximation	mean	median	S.D.
sales_inn	Percentage of sales of innovated products in relation to the total sales for the 2003-2004 period: the variables takes 5 values: 0, 0.06, 0.21, 0.51 y 0.86, which correspond to the average of the extreme values of the reported percentage ranges [1 (0%), 2 (1-10%), 3 (10 to 30%), 4 (31-70%) y 5 (71-100%)].	0.21	0.06	0.25
inn_pos	Product or service innovation in 2003 and/or 2004: 1 if the plant innovated products or services; 0 otherwise.	0.79	1.00	0.41
make	Internal R+D in 2003 and/or 2004: 1 if R+D was carried out within the plant; 0 otherwise.	0.58	1.00	0.49
buy	Buy of external knowledge in 2003 and/or 2004: 1 if acquired or outsourced knowledge; 0 otherwise.	0.31	0.00	0.46
absorption	External knowledge absorption capacity: difference between the importance for the plant of information for innovation coming from institutional sources and the average of importance of the same information for its respective ISIC two digit classification	0.14	-0.16	1.10
ipr	Knowledge protection through Intellectual Property Rights (IPR): Proportion of plants that have requested IPR by ISIC two digit category.	0.39	0.32	0.27
adequacy	Knowledge adequacy problems: Proportion of plants that perceives some kind of lack of protection of knowledge by ISIC two digit category.	0.79	0.79	0.07
employment	Scale of establishment: hundreds of workers in 2003.	2.02	0.84	3.19
exports	Exposure to international competitiveness: 1 if the plants had exports in 2003; 0 otherwise.	0.49	1.00	0.50
int_inn	Inputs for innovation or innovation intensity: R+D expense per worker in 2003 (in millions of $ in 2003).	0.46	0.02	1.65
b_tec	Group that uses low technology: 1 if ISIC = 15 - 22, 36; 0 otherwise.	0.45	0.00	0.50
mb_tec	Group that uses medium-low technology: 1 if ISIC = 23, 25 - 28; 0 otherwise.	0.29	0.00	0.45
a_tec	Group that uses medium-high and high technology: 1 if ISIC = 24, 29, 31 - 35; 0 otherwise.	0.27	0.00	0.44

6 Results

The *make* and *buy* innovation activities are adopted by 58 % and 31 % of the sample, respectively. The highest rate of use of the *make* activity with regard to the *buy* activity corresponds to the evidence found in other empirical studies. When disintegrating the *buy* activity, one finds that 21 % of the plants outsourced R+D, whereas 17 % acquired external knowledge (see table 6.1). [21]

[21] The correlation quotient between outsourcing and acquiring knowledge is 0.23 and is statistically significant at 1 %.

At the same time, 23 % of the plants adopt both *make* and *buy*, for which group it can also be observed that to outsource R+D is more frequent that to acquire external knowledge.

About one third of the plants do not adopt any innovation activity, that is to say they are plants that report having obtained innovations in the 2003-2004 periods, but that they neither developed internal R+D activities nor did they buy external knowledge (passive plants).

Table 6.1.: Innovation activities

Activities	Nº obs.	% of N = 522
make	301	57.7
buy	160	30.7
outsource	109	20.9
acquire	87	16.7
make and buy	121	23.2
make and outsource	86	16.5
make and acquire	66	12.6
none	182	34.9

In relation to innovative performance, it was found that the average between innovated products or services sales and the total of sales was 21 %. Table 6.2. shows that the average performance of the groups of plants that adopt *making* and /or acquiring external knowledge is better than the average for the sample. On the contrary, the groups of plants that do not adopt innovation activities and those that adopt R+D outsourcing and *making* and R+D outsourcing obtain a lower than average performance.

When innovative performance is measured by the declaration of achievement in product or service innovations, one finds that the plants that carry out innovation activities perform better than the average in the sample.

Table 6.2.: Average innovative performance by innovation activity

Activities	Sales _inn	inn_pos
Make	0.23	0.87
buy	0.19	0.83
outsource	0.18	0.82
acquire	0.22	0.85
Make and buy	0.19	0.83
Make and outsource	0.17	0.81
Make and acquire	0.22	0.85
none	0.18	0.66
Whole sample	0.21	0.79

The results of the activity adoption model are detailed in table 6.3. and are aligned with the theory. [22] However, no evidence is obtained that would endorse the hypothesis of complementarity between the *make* and *buy* innovation activities.

From the activity adoption model it can be seen that the scale of the plant increases the probability of *make* and *buy*, but in case of *make* one finds that as the scale of the plant increases, the propensity to adopt it decreases. The last is captured by the negative squared sign of the employment variable.

The positive impact of employment on the probability of *make* is compatible with the hypotheses of economies of scale and scope, whereas the negative squared employment sign is compatible with the hypothesis of management diseconomies.

The relevance of the scale of the plant for *buying* knowledge can be a consequence of the fact that relatively large plants have access to assets that allow them to reduce transaction costs (for example, they may be clients of a legal counsel office or they may have teams of technical professionals).

The measure of external knowledge absorptive capacity helps to increase the probability of adopting both innovation activities although, with more intensity in *buying* than in *making.* This result suggests when it is less expensive for the firm to absorb external knowledge the propensity to *buying* increases, but simultaneously the probability of developing internal R+D activities increases. The above probably is due to the fact that higher exposure to external knowledge requires an investment also in assimilation capacities, or that it should be a reflection of the inertia of having accumulated knowledge in the past.

The obtained results show that the perception of lack of knowledge protection makes it more probable that plants adopt *make* and it seems not to affect the choice to buy. On the contrary, the IPR access increases the probability of *buy* and does not affect the activity of *make.*

The plants that put aside more resources for innovation adopt both innovation activities with more probability, while the controls of technological heterogeneity of the plants were not statistically relevant.

It is estimated from the activity adoption model that the conditional correlation of the *make* and *buy* activities is positive (0.12), but not statistically significant. The above is not compatible with the hypothesis of complementarity between *making* and *buying* knowledge.

The magnitude of the conditional correlation is lower than the level of unconditional correlation between both activities (0.24 %). The previous result shows that the unconditional positive correlation between the activities of *making* and *buying* is due to the scale of the plants, the capacity of knowledge absorption and the inputs for innovation,

[22] The results of the activities adoption model do not have significant differences when the plants that undertake cooperation in R+D activities are added to the sample (see Annex 2).

since such variables had parameters that coincided both in sign and statistical relevance for both activities (to see table 6.3.).

Table 6.3.: Activity adoption Biprobit

	Make		Buy	
employment	0.1995 (0.0391)	*	0.0748 (0.0384)	+
employment2	-0.0084 (0.0019)	*	-0.0024 (0.0020)	
absorption	0.1309 (0.0610)	**	0.3078 (0.0545)	*
inn_int	3.7210 (1.2761)	*	0.0736 (0.0401)	+
dpi	0.2005 (0.3160)		0.5438 (0.2876)	+
Adequacy	2,0222 (0.9227)	**	-0.4790 (0.8479)	
b_tech	0.1499 (0.2169)		-0.2553 (0.2015)	
mb_tech	0.1110 (0.1764)		0.0451 (0.1547)	
Constant	-2.3101 (0.8191)	*	-0.4773 (0.7600)	
Observations	522		522	
rho	0.1161			
W. chi2(16) = 105.92 (Prob > chi2 = 0.0000)				

note1: Standard errors between brackets.
Note 2:+ significant at 10%; * significant at 5%; ** significant at 1%.

The direct complementarity test was carried out using innovative performance model. For two measures of innovative performance used in this study no evidence is found in favour of the hypothesis of complementarity between *making* and *buying* for the 2003-2004 period (see table 6.5.). [23]

When performance is approximated by the percentage of sale of innovated products in relation to total sales, the quotient estimated for the joint adoption of the *making* and *buying* activities is negative and statistically different from zero. Additionally, evidence shows that

[23] The results of the innovative performance model with the inclusion of plants collaborating in R+D and for the combination of *making and acquiring* and *making and outsourcing* activities can be found in Annex 3. It can be seen from there that a negative sign of the parameter associated with the joint development of activities can be verified.

the parameter is statistically lower than zero.[24] The above is corroborated when innovative performance is measured through obtaining innovated products or services. Consequently, the hypothesis of complementarity is rejected but additionally evidence of substitution between the innovation activities of *making* and *buying* is found.

For both measures of innovative performance we can observe that the parameters associated with the activities of *making* and *buying* are positive. The parameter associated with the activity of *making* is statistically relevant for both performance measures, while the parameter related only to *buying* is for the case of obtaining product or service innovations (inn_pos).

In relation to the control variables, it can be observed that the scale of the plant negatively affects innovative performance measured as a percentage of sales of innovated products, which coincides with the hypotheses the bigger the scale, the more difficult it is to obtain high representations of sales of innovated products or that the bigger the scale, the more bureaucracy there is which suppresses innovative performance. At the same time, no evidence is found of effects on innovative performance of the second order of the scale of the plants.

For neither of two performance models can the relevance of exposure to competitiveness be verified nor the relevance of inputs for innovation. Nevertheless, it is necessary to emphasise that the sign of the parameters estimated for the export status of the plant was what had been expected. The above also occurs with R+D expense per worker in the Tobit model, but the sign is unexpected when innovative performance is measured through obtaining product or service innovations.

In the third step of the methodology, that is to say when *making*, *buying* and *making and buying* are instrumentalized using the projections of the activity adoption model, the negative sign of the parameter associated with *making and buying* is verified, but not its significance (see table 6.6.). However, it is necessary to bear in mind that no good instrument for the *buying* activity has been obtained and that the projections of the activity adoption model activities are highly co-linear, making that all estimated parameters showed considerable increases in their standard error.[25]

Despite the above, after the adjustment for endogeneity, the signs of the parameters of innovation activities remain the same, similar to the signs of the control variables that were statistically significant in the second step of the methodology.

The results permit to conclude that innovation activities of *making* and *buying* are not complementary, and that they would even have a substitutive relation. The conceptual

[24] A 1-tailed t test was applied to 5 % of significance for null hypothesis $\beta_{12} = 0$ and for the alternative $\beta_{12} < 0$ hypothesis.

[25] All the used instruments have a coefficient of unconditional correlation with the variables that respectively instrumentalize a positive sign. Nevertheless, the conditional correlation between the instruments and the instrumentalized variables is only statistically significant for *making*; and *making* and *buying*. This way, there is not good instrument for the *buying* activity.

framework that guides this work suggests that there may be a substitution between *making* and *buying* when knowledge or technology bought externally has scarce novelty in the context of the firm.

Low level of innovation can arise: first, because the plant cannot identify it ex ante the purchase, be it because of an error or absence in capacities. In this case, once knowledge was acquired, the lack of sufficient assimilation capacity can even lead to a saturation effect. Second, when firms look for smaller innovations in a technology in which they accumulate a high degree of knowledge. In this situation, the external knowledge is a perfect substitute for internal developments.

Tabla 6.5.: Innovative performance

	Sales _inn		**inn_pos**	
	Tobit		Probit	
employment	-0.0190	**	-0.0512	
	(0.0087)		(0.0453)	
employment2	0.0005		0.0018	
	(0.0004)		(0.0024)	
exports	0.0183		0.1736	
	(0.0303)		(0.1423)	
inn_int	0.0019		-0.0276	
	(0.0107)		(0.0426)	
make	0.1253	*	0.8237	*
	(0.0349)		(0.1615)	
buy	0.0750		0.4937	+
	(0.0544)		(0.2577)	
Make _buy	-0.1363	**	-0.7044	**
	(0.0643)		(0.3145)	
b_tech	0.0013		0.0196	
	(0.0340)		(0.1614)	
mb_tech	-0.0843	**	-0.2161	
	(0.0360)		(0.1742)	
Constant	0.1435	*	0.4660	*
	(0.0347)		(0.1559)	
Observations	522		522	

note1: Standard errors between brackets.
Note 2:+ significant at 10%; * significant at 5%; ** significant at 1%.

Table 6.6.: Innovative performance corrected by endogeneity

	Sales _inn	inn_pos
	IV Tobit	IV Probit
Make	0.1949 +	1,6306 *
	(0.1026)	(0.5645)
Buy	0,6935	3,9828
	(0.5830)	(2,9396)
Make _buy	-0.7612	-4,9082
	(0.5948)	(3,0118)
employment	-0.0156	-0.0396
	(0.0120)	(0.0593)
employment2	0.0002	0.0004
	(0.0007)	(0.0033)
exports	-0.0001	0.1207
	(0.0382)	(0.1896)
inn_int	0.0031	-0.0195
	(0.0108)	(0.0519)
b_tech	0.0110	0.0407
	(0.0401)	(0.2018)
mb_tech	-0.0821 **	-0.1661
	(0.0417)	(0.2085)
Constant	0.0601	-0.0886
	(0.0804)	(0.4021)
Observations	522	522

note1: Standard errors between brackets.
Note 2:+ significant at 10%; * significant at 5%; ** significant at 1%.

7 Conclusions

This study has used a methodology to evaluate the hypothesis of complementarity when firms can choose between two innovation activities. Specifically, the study deals with the case of complementarity between internal R+D activities and buying knowledge created outside the firm.

The methodology was applied to a sample of 522 manufacturing and innovative plants in Chile, representative of the group of manufacturing and innovating plants from the 2005 IV Technological Innovation Survey. Thus, the work contributes novel evidence on the case of a country of average development, but with results that cannot be extrapolated to the population of manufacturing plants in Chile.

The first exercise consisted of applying a weak complementarity test based on a model of selection of activities. It has been found that the conditional correlation between the studied innovation activities is positive, but statistically irrelevant. From the above it is possible to conclude that the evidence found is not compatible with the hypothesis of complementarity.

Subsequently, complementarity was evaluated within the framework of innovative performance model using a strong complementarity test. The results of the strong test for the different innovative performance measures that were used do not support the hypothesis of complementarity in the 2003-2004 periods. Even more, the results indicate that there is substitution between the *make* and *buy* innovation activities.

Finally, the endogeneity of innovation activities was corrected following a two-stage procedure proposed by Cassiman and Vegeulers (2006). The negative sign of the parameter that identifies the combination of the *make* and *buy* activities was confirmed, but not its statistical relevance. However, no adequate instrument for the activity of *buying* external knowledge was obtained and the instruments were highly co-linear, which reduced the precision of the estimated parameters.

The results permit us to conclude that *make* and *buy* innovation activities are not complementary, and that they would even have a substitutive relation. The conceptual framework that guides this work suggests that there can be a replacement between *make* and *buy* when knowledge or technology bought outside the firm has scarce novelty in the firm's context.

Low level of innovation can arise: first, because the plant cannot it ex ante the purchase, be it because of an error or absence of capacities. In this case, once knowledge was acquired, the lack of sufficient assimilation capacity can even lead to a saturation effect. Second, when firms look for smaller innovations in a technology in which they accumulate a high degree of knowledge. In this situation, the external knowledge is a perfect substitute for internal developments.

Evidence suggests for the group of studied plants that the incentives for the *buying* of knowledge will not strengthen the performance of its internal R+D capacities, at least in the 2003-2004 periods. Furthermore, such incentives might even reduce the innovative performance of the plants.

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Annex 1: Primary Information

Sales _inn	% of sales of new products over the total number of sales. The reported values are: 1 (0%), 2 (1-10%), 3 (10 to 30%), 4 (31-70%) and 5 (71-100%).
Inn _pos	During 2003 and/or 2004 the plants introduced technologically improved products, new for the establishment, new for the local market and/or new for the world (Yes = 1, No = 0). The structure of the question is identical for the case of services.
Make	Carried out research and development in the plant in 2003 and/or 2004 (Yes = 1, No = 0).
Buy	Did it carry out research and development outside the plant in 2003 and/or 2004? and Did it acquire external knowledge (i.e. patents, licences, know-how) in 2003 and/or 2004? (Yes = 1, No = 0).
absorption	How important have been for the plant's innovation activities sources of information such as universities or other higher education institutions, public or government research institutes? (low = 1, medium = 2, high = 3 and very high = 4)
dpi	Total number of intellectual property rights requested by your plant (does not include commercial trademarks).
adequacy	What other factors do you perceive as obstacles or disincentives to technological innovation? Very easy to imitate innovation (low = 1, medium = 2, high = 3 and very high = 4)
employment	Indicate the number of all the plant's employees (for each year indicate an average number)
exports	Indicate the amount of the plant's exports in pesos for each year
int_inn	All section 10 on R+D costs
b_tec mb_tec a_tec	ISIC two digit: 15 - 36.

Source: Questionnaire IV Technological Innovation Survey 2005.

Annex 2: Activity adoption model

Table A.2.1: Includes plants with R+D cooperation

	Make		Buy	
employment	0.1938	*	0.0916	**
	(0.0368)		(0.0372)	
employment2	-0.0075	*	-0.0037	+
	(0.0017)		(0.0021)	
absorption	0.1275	**	0.2884	*
	(0.0566)		(0.0506)	
inn_int	3.9945	*	0.0897	**
	(1,3167)		(0.0415)	
dpi	0.2979		0,6027	**
	(0.3009)		(0.2729)	
Adequacy	1,8761	**	-0.2710	
	(0.8832)		(0.7963)	
b_tech	0.2962		-0.1593	
	(0.2070)		(0.1909)	
mb_tech	0.2213		0.1304	
	(0.1691)		(0.1458)	
Constant	-2.3728	*	-0.7472	
	(0.7831)		(0.7170)	
Observations	590		590	
rho	0.1308			
W. chi2(16) = 119.83 (Prob > chi2 = 0.0000)				

note1: Standard errors between brackets.
Note 2:+ significant at 10%; * significant at 5%; ** significant at 1%.

Annex 3: Model of innovative performance

Table A.3.1: Includes plants with R+D cooperation

	Sales _inn		Inn _pos	
	Tobit		Probit	
employment	-0.0197	**	-0.0461	
	(0.0081)		(0.0431)	
employment2	0.0006		0.0021	
	(0.0004)		(0.0024)	
exports	0.0039		0.1379	
	(0.0281)		(0.1334)	
inn_int	0.0038		-0.0169	
	(0.0104)		(0.0456)	
Make	0.1220	*	0.7862	*
	(0.0335)		(0.1539)	
Buy	0.0596		0.4194	+
	(0.0526)		(0.2438)	
Make_buy	-0.1283	**	-0.5960	**
	(0.0620)		(0.2976)	
b_tech	-0.0283		-0.0994	
	(0.0322)		(0.1530)	
mb_tech	-0.0976	*	-0.2979	+
	(0.0345)		(0.1668)	
Constant	0.1824	*	0.5751	*
	(0.0336)		(0.1469)	
Observations	590		590	

note1: Standard errors between brackets.
Note 2:+ significant at 10%; * significant at 5%; ** significant at 1%.

Table A.3.2: Internal R+D and external knowledge acquisition

	Sales _inn		inn_pos	
	Tobit		Probit	
employment	-0.0193	**	-0.0520	
	(0.0089)		(0.0455)	
employment2	0.0005		0.0018	
	(0.0004)		(0.0024)	
exports	0.0128		0.1691	
	(0.0300)		(0.1415)	
inn_int	0.0009		-0.0274	
	(0.0104)		(0.0419)	
Make	0.1030	*	0.7339	*
	(0.0316)		(0.1440)	
acquire	0.1210		0.6474	+
	(0.0765)		(0.3534)	
Make _acquire	-0.1288		-0.7532	+
	(0.0871)		(0.4096)	
b_tech	0.0036		0.0132	
	(0.0342)		(0.1602)	
mb_tech	-0.0897	**	-0.2492	
	(0.0361)		(0.1734)	
Constant	0.1484	*	0.5081	*
	(0.0336)		(0.1528)	
Observations	522		522	

note1: Standard errors between brackets.
Note 2:+ significant at 10%; * significant at 5%; ** significant at 1%.

Table A.3.3: Internal R+D and commissioning external R+D

	Sales _inn		inn_pos	
	Tobit		Probit	
employment	-0.0182	**	-0.0486	
	(0.0088)		(0.0454)	
employment2	0.0005		0.0018	
	(0.0004)		(0.0024)	
exports	0.0184		0.1789	
	(0.0300)		(0.1415)	
inn_int	0.0024		-0.0257	
	(0.0105)		(0.0432)	
Make	0.1173	*	0.7791	*
	(0.0331)		(0.1507)	
outsource	0.0797		0.4601	
	(0.0647)		(0.3254)	
Make_ outsource	-0.1596	**	-0.7321	+
	(0.0733)		(0.3753)	
b_tech	0.0021		0.0172	
	(0.0340)		(0.1613)	
mb_tech	-0.0797	**	-0.1959	
	(0.0361)		(0.1737)	
Constant	0.1459	*	0.4898	*
	(0.0344)		(0.1547)	
Observations	522		522	

note1: Standard errors between brackets.
Note 2:+ significant at 10%; * significant at 5%; ** significant at 1%.