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Innovation, R&D investment and productivity in Chile

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This paper studies the relationships between investment in research and development (R&D), innovation and productivity in the Chilean manufacturing industry using data from four waves of the national Technological Innovation Survey during the past decade. The analysis is based on a multi-equation model that takes into account the whole process of innovation, considering the determinants of firms' decisions to engage in innovation activities, the results of those efforts in terms of innovation and their impact on productivity. It is found that: (a) larger plants are more likely to invest in R&D, (b) R&D intensity increases the probability of process innovation, (c) R&D intensity does not affect the probability of product innovation, (d) low appropriability reduces the probability of process innovation, (e) larger firms are more likely to introduce product innovation, and (f) process innovation increases productivity.

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I

Introduction

The relationship between productivity and research and development (R&D) has been a topic of inquiry since the early work of Schultz (1953) and Griliches (1958). Since then, this area of research has produced a significant amount of empirical and subsequent theoretical work. Several recent theoretical models have attributed a substantial role to R&D in driving productivity and hence economic growth (Romer, 1990; Grossman and Helpman, 1991; Rivera-Batiz and Romer, 1991; Aghion and Howitt, 1992). From an empirical perspective, the literature has found that close to half of the income per capita and growth rate differentials across countries can be explained by differences in total factor productivity (TFP) (Hall and Jones, 1999), but most importantly it has also found that R&D activities could explain up to 75% of TFP growth rates, once externalities are considered (Griliches, 1995).

The rapid economic growth of East Asian economies has drawn attention to the role that R&D activities might play in charting the course of development. The Republic of Korea, for example, had an R&D-to-GDP ratio of close to 0.35% in the 1960s. During the four subsequent decades this figure increased almost constantly, to reach 2.4% in recent years. This increment has been credited as one of the causes of the significant growth in TFP and per capita GDP in the Republic of Korea since the 1960s. While yearly TFP growth averaged 1.11% for the period 1960-2000, per capita income expanded by over 6% each year during the same period.[1]

In contrast, Latin American and Caribbean countries showed a very modest rate of economic growth during the past decade, despite unusually favourable economic conditions. Unfortunately, this poor performance is not new in the region. Indeed, during the last four decades of the twentieth century the per capita income of the region grew 1.44% per year, while its TFP rose by a modest 0.29%.

Light may be shed on the poor economic performance of Latin America by comparing its R&D effort with that of other regions (see table 1). This indicator shows that the decade average for the Organization for Economic Cooperation and Development (OECD) during the period 1960-2000 fluctuated between 1.87% and 2.25%. The R&D effort of the Scandinavian countries increased from 1.12% in the 1960s to 2.71% in the 1990s. In contrast, R&D expenditure in Latin America fluctuated between

TABLE 1

Real expenditure on R&D as a percentage of GDP by country grouping (purchasing power parity), 1960-1999
(Percentages)

	1960-1969	1970-1979	1980-1989	1990-1999
Sub-Saharan Africa	0.21	0.32	0.53	0.56
Scandinavia	1.12	1.32	1.92	2.71
East Asia and Pacific	0.35	0.30	0.67	0.91
Europe and Central Asia (non-OECD)	–	–	0.64	0.90
Middle East and North Africa[a]	0.03	1.67	0.28	1.46
OECD	2.04	1.87	2.25	2.23
South Asia	0.23	0.39	0.74	0.64
Latin America and the Caribbean	0.44	0.48	0.36	0.52

Source: Prepared by the authors on the basis of A. Heston, R. Summers and B. Aten, Penn World Table Version 6.1, Center for International Comparisons of Production, Income and Prices, Philadelphia, University of Pennsylvania, 2002; D. Lederman and L. Saenz, "Innovation and development around the world, 1960-2000", Policy Research Working Paper Series, No. 3774, Washington, D.C., World Bank, 2005; and United Nations Educational, Scientific and Cultural Organization (UNESCO), Institute for Statistics, "R&D Expenditure Table", 2005 [online] http://stats.uis.unesco.org/unesco/TableViewer/document.aspx?ReportID=136&IF_Language=eng&BR_Topic=0

[a] Excludes Israel.

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[1] See Bravo-Ortega and García (2007).

0.36% and 0.52% of GDP during that period. Thus, an interesting question is: why is the R&D effort in Latin America —and in Chile particularly— so low?

The vast literature on the relationship between innovative activities and productivity has focused on developed countries (Hall and Rosenberg, 2010). Until recently, few innovation surveys had been conducted in developing countries. In addition, as pointed out by Figueiredo (2006), the existing studies for developing countries show an overwhelming majority of qualitative studies. In the recently published *Handbook of the Economics of Innovation*, Fagerberg, Srholec and Verspagen (2010) report only eight developing country studies that are similar in methodology to the analysis presented here. Most importantly, no clear statistical patterns can be inferred from those studies. This makes it extremely important, for the case of developing countries, to have as many country-specific studies available as possible.

Thus, the present study adds the case of Chile to the scarce quantitative evidence on the relationship between innovation and productivity in developing countries. To chart this evidence, use is made of a novel data set that merges several years of Technological Innovation Survey results with those of the Annual National Manufacturing Survey.

This paper aims to contribute to an understanding of the relationship between R&D and productivity in Latin America by focusing on the Chilean experience. The Chilean case is interesting for several reasons. First, Chile ranks relatively low in terms of innovation efforts. In fact, it spends only about 0.7% of its GDP on R&D, less than one third of the OECD average (OECD, 2007). Second, this level of R&D investment is lower than would be expected in relation to Chile's per capita income. Several works have shown that Chile suffers from an innovation shortfall (Kharas et al., 2008; Maloney and Rodríguez-Clare, 2007). Third, in the wake of the Asian financial crisis, the Chilean economy has been unable to recover the high productivity growth rates experienced during the preceding decades. This slowdown in productivity has occurred despite several public programmes to increase private R&D investment.

The study uses an estimation methodology developed by Crépon, Duguet and Mairesse (1998) for analysing the empirical relationship among R&D investment, innovation outcomes and productivity in Chilean manufacturing plants. This approach is based on a multi-equation model that takes into account the whole process of innovation. It considers the determinants of firms' decisions to engage in innovation activities, the results of those efforts in terms of innovation and their impact on productivity. Data are drawn from four waves of the national Technological Innovation Survey —for the years 1995, 1998, 2001 and 2004— and from the Annual National Manufacturing Survey for several years. The fact that the two surveys use the same plant identification numbers made it possible to merge the two sources of information at the plant level. This, in turn, enabled analysis of the impact of innovation not only on current productivity but also on future productivity.

A number of empirical analyses have examined the determinants of innovation using different versions of the innovation surveys carried out in Chile. Crespi and Katz (1999) and Crespi (1999) analysed how industry and plant characteristics might explain differences in innovation using the first version of the survey. Benavente (2005) extended that analysis using three versions of the surveys. Álvarez (2001) and Álvarez and Robertson (2004) focused on trade-related variables as main drivers of innovation activity. There is, however, little evidence of the effects of innovation on productivity in the case of Chile.[2]

This study's robust results across different specifications are as follows: (a) larger plants are more likely to invest in R&D, (b) R&D intensity increases the probability of process innovation, (c) R&D intensity does not affect the probability of product innovation, (d) low appropriability reduces the probability of process innovation, (e) larger firms are more likely to introduce product innovation, and (f) process innovation increases productivity.

The paper has the following structure: section 2 contains a description of the data; section 3 presents the methodology; section 4 shows the econometric results; and section 5 summarizes the findings.

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[2] One exception is Benavente (2006), which shows —using results from the 1998 wave of the Technological Innovation Survey— that research and innovation activities are positively affected by firm size and market power, but a firm's productivity is not affected by innovative results or by research expenditure. For evidence for Argentina, see Chudnovsky, López and Pupato (2006).

II

Data description

The main source of data on innovation activities in Chile is the national Technological Innovation Survey carried out by the National Institute of Statistics. The survey has been conducted every three years since 1995, with the exception of the last available survey (carried out in 2005). The questionnaire follows the guidelines of the Frascati Manual developed by OECD. Although there are some variations over time in the number and types of questions, the main structure of the survey is similar across the different versions. The questions are structured into the following main sections: (a) types of innovation implemented by the firm in the past three years, (b) goals of those innovations, (c) sources of the innovation ideas, (d) purchases of equipment, (e) obstacles to innovation, (f) links with science and technology institutions, (g) importance of innovation in the firm's business, (h) cost and financing of innovation, (i) expenditure on R&D, and (j) outlook for future innovations.

The present study drew upon information about innovation activities from four waves of the Technological Innovation Survey (1995, 1998, 2001 and 2004) complemented by firm characteristics from the Annual National Manufacturing Survey. These two sources of information were merged at the plant level using a plant identification number employed in both data sets. This matching between the two sources of information offers the advantage of using data to analyse not only the impact of innovation on current productivity, but also whether there are lagged effects. In fact, for the greater part of the four waves, it is possible to estimate the effect of innovation on forward values for productivity levels.

Inasmuch as the Annual National Manufacturing Survey covers only manufacturing industries, the study of the relationship between innovation and productivity is thus confined to that sector. The Technological Innovation Survey is intended to be representative at the 2-digit level of industry classification. The figure 1 shows the distribution of firms across the nine sectors for each wave of the survey. Although the distribution in general varies across the various waves of the survey, two sectors represent a large proportion of the firms surveyed: food and machinery, with shares close to 30% and 20%, respectively.[3]

Table 2 summarizes the descriptive statistics for each wave of the survey, including the number of available observations and the mean values for the dependent and explanatory variables used in the estimations. All variables are computed using expansion factors. It should be noted that descriptive statistics for several variables changed significantly from one survey wave to the next.

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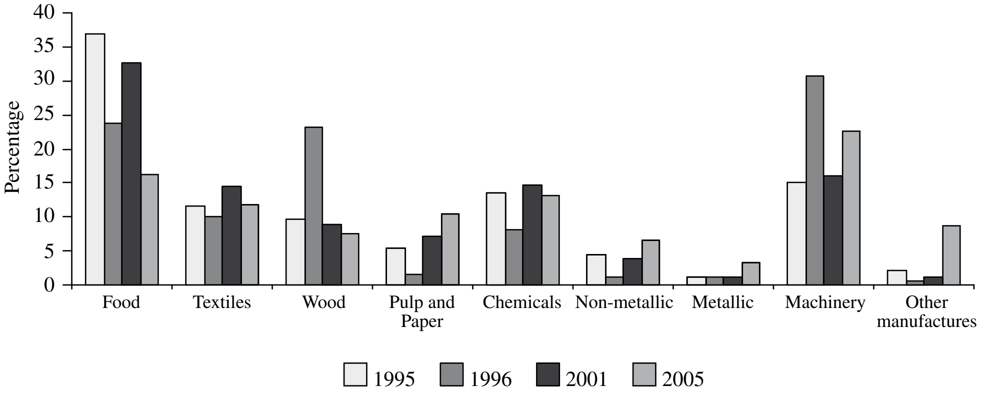
[3] The appendix presents a brief description of the Chilean manufacturing industry in the period 1995-2005.

FIGURE 1

Distribution of firms by sector and year

(Percentages)



Source: Prepared by the authors on the basis of the national Technological Innovation Survey.

TABLE 2

Data description: National Technological Innovation Survey Means of variables across survey waves, 1995-2004

	1995	1998	2001	2004
Innovation variables				
R&D intensity[a]	57.34	31.41	37.66	1113.7
Investment in R&D	0.270	0.121	0.175	0.842
Process innovation	0.491	0.094	0.310	0.348
Product innovation	0.293	0.140	0.358	0.231
Firm characteristics				
Labour productivity[a]	19 568	30 553	21 521	54 272
Capital per worker[a]	2 488	3 008	9 880	2 963
Competition	0.040	0.145	0.061	0.104
Employment[b]	87.52	74.81	81.50	81.9
Public support	0.040	0.012	0.092	0.189
Appropriability	0.102	0.043	0.088	0.068
Cooperation	0.149	0.062	0.122	0.016
Market share	0.007	0.005	0.008	0.009
Investment intensity[a]	556.8	884.2	965.6	1781.1
Distance to frontier	1.999	2.418	2.191	2.196
Demand pull				
Quality: high	0.295	0.248	0.332	0.333
Quality: low	0.272	0.202	0.165	0.133
Environment: high	0.429	0.435	0.424	0.287
Environment: low	0.298	0.261	0.247	0.152
Source of innovation				
Internal firm	0.099	0.014	0.083	0.225
Government	0.001	0.002	0.001	0.041
Internal group	0.001	0.003	0.001	0.205
Universities	0.029	0.007	0.007	0.010
Suppliers and customers	0.058	0.035	0.035	0.028
Competitors	0.027	0.006	0.015	0.013
Observations	525	390	410	823

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.
Note: Nominal variables were deflated using industry-specific deflators.
Unless otherwise indicated, the unit of measurement is the percentage, with the exception of distance to frontier, which represents the logarithmical difference with respect to the top 10% of the most productive firms in each industry.

[a] In thousands of pesos per worker
[b] Workers

This is explained partly by changes in the firm sample, as not all firms were interviewed in successive waves of the innovation survey. In addition, the possibility of significant measurement errors in these variables cannot be ruled out. This problem has been partly remedied by excluding outliers at the top and bottom 1% of the distribution for productivity and the top 1% for R&D expenditure. Since the majority of the significant changes occurred in the most recent survey wave, all the regressions in the present study were run excluding the year 2004. The results of this exercise, which are provided in the appendix, are similar to those presented in the following sections.[4]

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[4] These results show changes in the statistical significance, but not the sign, of the coefficients for some variables.

III

Innovation, R&D and productivity: the CDM model

This section follows the empirical research line initiated by the influential work of Crépon, Duguet and Mairesse (1998), known as the CDM model after its authors, and looks at the empirical relationship between R&D, innovation and firm productivity. The approach here is based on a multi-equation model that takes into account the whole process of innovation, considering the decisions of firms to engage in R&D activities, the results of those efforts and the subsequent impact on productivity.

The model is inspired by previous empirical and theoretical findings. Using firm-level data for the United States of America, Pakes and Griliches (1980) originally observed a positive correlation between firms' R&D expenditure and patent applications, which gave rise to the idea of a knowledge production function. As noted in the introduction, several theoretical models attribute a substantial role to R&D as an engine of productivity and economic growth (Romer, 1990; Grossman and Helpman, 1991; Rivera-Batiz and Romer, 1991; Aghion and Howitt, 1992). Aghion and Howitt (2005) presented a model of endogenous growth with innovation that incorporates effects of market structure and institutional factors that are consistent with several aspects of the CDM model.

Using microdata, Blundell, Griffith and Van Reenen (1999) analysed the impact of market structure on innovation. Competition was measured using market share, concentration and import penetration. As pointed out by Aghion and Griffith (2005), there are two main interpretations of Schumpeter's work. Under one interpretation, firms may need to rely on internal funds to finance innovation in the presence of market imperfections. Thus, larger firms have easier access to funds and therefore innovate more. Under the other interpretation, monopolists tend to innovate more than entrants because of the reduction in industry profits resulting from the entrance of new firms (the pre-emption effect). Conversely, some researchers have argued that monopolists innovate less because innovation reduces their rents, but it does not have this effect on entrants. However, Blundell, Griffith and Van Reenen (1999) found that industries with higher concentration and lower import penetration displayed less aggregate innovation and that firms with a larger market share innovated more. Their findings, then, favour the pre-emption effect of the innovation hypothesis discussed above. On a theoretical level, Aghion and Howitt (1992) argued that monopoly power is a central feature of the innovation process. This notwithstanding, in their model firms innovate in order to secure monopoly power, but once they are incumbent they do not. These Shumpeterian creative destruction models were successfully adapted by Howitt and Mayer-Foulkes (2005) in order to explain income convergence patterns across groups of countries, which in turn depend on patterns of R&D, implementation of new technologies and absorptive capacity.

The baseline model consists of four equations: (a) the firm's decision to invest in R&D, (b) the intensity of R&D, (c) the knowledge production function linking R&D intensity and innovation outcomes, and (d) the output production function, in which firm productivity is a function of innovation outcome.

The present analysis follows closely the estimation approach of Griffith et al. (2006). First, we perform a generalized Tobit model estimation that considers the decision to invest and the amount invested in R&D. Second, the predicted value of R&D intensity is taken as an explanatory variable in the knowledge production function, where the innovation outcome is measured by two categorical variables that account for product and process innovation. Finally, we use the predicted values of innovation outcomes as explanatory variables in the output production function.[5] Given that Chilean surveys differ from those applied in Europe, the sources of these differences are discussed when defining the dependent and explanatory variables.

1. Investment in R&D

A generalized Tobit framework is used to model the decision to invest and the amount invested in research activities. Hence, there are two linked equations: (a) the decision to invest in R&D, and (b) the amount of resources involved, measured as R&D expenditure per employee (in

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[5] This model may be estimated using alternative econometric techniques such as asymptotic least squares. In fact, the original paper by Crépon, Duguet and Mairesse (1998) used this methodology. However, recent works on this issue have tended to prefer the less computationally intensive technique of estimating the three components of the model separately using instrumental variables (Griffith et al., 2006; Hall, Lotti and Mairesse, 2008).

logarithms). More precisely, it is assumed that a latent dependent variable R_i^* exists for the firm i given by the following equation:

$$R_i^* = X_{1i}^{'}\beta + \varepsilon_i \qquad (1)$$

where $X_{1i}^{'}$ is a vector of explanatory variables, β is a vector of parameters and ε is an error term. The econometrician will observe that resources are invested in R&D activities if R_i^* is positive or greater than a given threshold.

The following selection equation is assumed, describing whether or not a firm is investing in R&D:

$$RD_i = 1 \; if \; RD_i^* = W_i^{'}\alpha + e_i > c, \; and \; 0 \; otherwise \qquad (2)$$

where RD_i is an observed binary variable equal to 0 for firms not investing in R&D and equal to 1 for those investing in R&D, RD_i^* is the corresponding latent variable such that a firm decides to invest in R&D if it is above a certain threshold denoted by c, and W is a vector of explanatory variables.

Conditional on investing in R&D, the observed R&D investment (R_i) is given by:

$$R_i = \begin{pmatrix} R_i^* = Z_i^{'}\beta + \varepsilon_i & if & RD_i = 1 \\ 0 \quad if \quad RD_i = 0 & & \end{pmatrix} \qquad (3)$$

The system of equations (2) and (3) is estimated as a generalized Tobit model by maximum likelihood.

The vectors of explanatory variables W and Z follow closely those used by Griffith et al. (2006) and are based on the original theoretical model proposed by Pakes and Griliches (1980) and subsequently studied by others.[6] Based on this, Crépon, Duguet and Mairesse (1998) suggested that a firm's probability of engaging in R&D increases with firm size, market share and with demand pull and technology push indicators. They also expected R&D intensity to increase with all the same variables except size (as research capital might be expected to be strictly proportional to size). Therefore, the firm's decision on whether to invest in R&D is modelled here considering the following explanatory variables:

— International competition: defined as the exports-to-sales ratio. This variable is used to capture exposure to international competition, and differs from that used by Griffith et al. (2006). In that work, a dummy variable identified whether the international market was the firm's most important market.[7]

— Appropriability conditions: defined as a dummy variable that takes the value 1 if the firm declares that ease of imitation is a major obstacle to innovation. This variable is intended to capture the effect of legal and formal protection of intellectual property in the country. In contrast to Griffith et al. (2006), Chilean surveys lack information on formal and strategic protection.

— Firm size: a set of four dummy variables is included for firms of 50-99 workers (size 1), 100-249 workers (size 2), 250-999 workers (size 3) and over 1,000 workers (size 4). The base category is small firms with fewer than 50 workers. There are other alternatives for defining firm size, such as total employment, sales or value added. This paper follows previous literature by using dummy variables, which offers the advantage of making its results comparable with other similar studies in this area.

— Technological opportunities and other invariant industry characteristics are controlled for by using a dummy variable for each 2-digit industry.

The set of explanatory variables for R&D intensity includes all the variables defined above except size (as suggested by Crépon, Duguet and Mairesse, 1998) and, in addition, the following ones:

— Cooperation: captured by a dummy variable that takes the value 1 if the firm has some cooperative arrangement on innovation activities. In the Chilean case, this variable measures specifically the existence of formal contracts with universities or technological institutes.

— Public resources: defined as a dummy variable that indicates whether the firm uses public resources for funding R&D investments. In contrast to Griffith et al. (2006), Chilean surveys do not distinguish between regional and national sources of funding.[8]

— Demand conditions: four variables are considered, related to the importance of quality standards and environmental considerations for engaging in innovation. All these variables are defined as

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[6] See, for example, Cohen and Levin (1989); Arvanitis and Hollenstein (1994) and Klepper (1996).

[7] It is acknowledged that this is not the only source of international competition faced by domestic firms. For a small open economy such as Chile, import competition may also generate significant competitive pressures in domestic markets. However, differences in import competition across manufacturing industries are captured in part by industry-fixed effects.

[8] For European countries, surveys distinguish between public financing from local and national governments and resources from the European Union.

industry-level shares. The first variable is the share of firms for which improvement of quality through the implementation of standards (ISO 9000 and others) was of high/medium importance. The second variable is the share of firms for which quality improvement was of low importance for innovation. The other two variables are defined in terms of the importance of reducing environmental damage through innovation. Thus, the third variable is the share of firms for which environmental concerns were of high/medium importance for innovation. And, finally, the fourth variable is the share of firms for which the environment was of low importance for innovation. The reference group in both cases is the share of firms for which quality and the environment, respectively, were qualified as not important.[9]

- Sources of information: six possible sources are considered, giving a set of six dummy variables that take the value of 1 when the firm considers the source as being of high importance for innovation. The six different sources are: (a) internal sources within the firm, (b) internal sources within the group to which the firm belongs, (c) universities, (d) public institutes, (e) suppliers and customers, and (f) competitors. There are two differences vis-à-vis the variable used by Griffith et al. (2006). First, that study had data on the importance of the government as a source of information. In the present analysis, that variable is replaced with information coming from activities carried out by public institutes. Second, it is not possible in this study to distinguish between suppliers and customers since, unfortunately, the surveys in Chile enquire into both in the same question.

Apart from their utility for the present study's identification strategy, some of the variables included in the R&D intensity equation might be perfect predictors of positive spending on R&D as suggested by Benavente (2006). This could be the case of the variables related to public funds, cooperation and sources of information. As an example, firms could decide to spend on R&D simply because public funds are available.

Several papers have included as an explanatory variable a proxy for market competition (Crépon, Duguet and Mairesse, 1998; Benavente, 2006). Traditionally, this effect is captured by the market share of the firm. Therefore, in its robustness check, the present analysis considers the firm's market share (in logarithms) as an explanatory variable in R&D decisions.[10]

Finally, the authors acknowledge ignoring the effect of human capital on R&D decisions and intensity. The main reason for this is that the data on human resources allocated to innovation are available only for the last wave of the innovation survey. In addition, the Annual National Manufacturing Survey data only allow distinguishing between blue- and white-collar workers. Therefore, based on the data available, it is not possible to produce acceptable measures of human capital affecting R&D. Despite this problem, the fact that some variables included in the set of controls (such as firm size and sector) are correlated with human capital means that the latter's effect is indirectly captured in the study specification.

2. Knowledge production function

In general, innovation output is assumed to be related to improvements in a firm's productivity. From an empirical standpoint, there are several ways to proxy innovation output. The most common proxies are number of patents and share of innovative sales. Following Griffith et al. (2006), two indicators of innovation output are used here. The first indicator relates to process innovation, and is defined as a dummy variable that takes the value 1 when the firm has introduced significant improvements in technological processes during the previous three years. The four available waves of the Chilean survey, however, differ in their questions regarding process innovation. In the last three waves, firms were asked whether they had introduced new technological processes for the market.[11] The second indicator relates to product innovation and is defined as a dummy variable that takes the value 1 for firms having introduced new products on the market during the previous three years.

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[9] The majority of the questions in the Chilean surveys use scales based on five possible values, ranging from 0 (no importance) to 4 (highest importance). In this case, medium/high importance is defined for responses with values of 3 and 4 and low importance for values of 1 and 2.

[10] Data from the Annual National Manufacturing Survey are used to compute the market share for each firm as its participation in total sales at 3-digit industries.

[11] Actually, the survey included three questions for product and process innovation. In the case of product innovation, firms were also asked about technological improvements to products and introduction of a product that was new for the firm but not new for the market. For process innovation, the approach was similar. Firms were asked about partial but important improvements and about technological processes that were new for the firm but not new on the market. The choice used here is based on the idea of innovations that were new to the firm and the market.

Two separate probit models are estimated for product and process innovation. These in turn can be modelled as follows:

$$I_i = \delta R_i^* + Y_i^{'} \gamma + \mu_i \qquad (4)$$

where I_i is equal to 1 when the firm has introduced an innovation; R_i^* is the predicted value of the firm's innovative effort (logarithm of R&D per worker) from the estimated generalized Tobit equations described above; and $Y_i^{'}$ is a vector of explanatory variables. This instrumental variable estimation, including the predicted value of R_i^*, takes into account the potential endogeneity of R&D investment.

The set of explanatory variables, following Griffith et al. (2006), considers:

- The predicted values of R&D intensity obtained from the Tobit model;
- Investment in machinery per employee.[12] It is assumed that this variable affects only process and not product innovation. The idea is that new machinery may challenge firms to change their technological processes but not necessarily the type of product they produce (at least not in a significant way);
- The same set of variables capturing demand conditions as used in the equation of determinants of R&D intensity;
- The four dummy variables for firm size;
- Dummy variables for each 2-digit industry.

The last three sets of variables tend to capture the idea that factors related to market structure and demand conditions —but not to research efforts— can affect incentives and flexibility to innovate. For example, product innovations can be used as a means for reducing competitive pressure in industries with highly standardized products. The basic identifying assumption in this methodology is that there are some variables affecting the R&D intensity decision that do not affect the innovation outcome. There are several variables —included in R&D decisions but not innovation outcomes— for which this assumption is likely to hold. Consider, for example, sources of information. It is difficult to argue that sources of information may directly increase the probability of introducing new products or new technological processes. By the same token, variables likely to affect the resources invested in R&D but not necessarily the innovation outcomes include cooperation and international competition.[13]

3. Output production function

Assuming a Cobb-Douglas production function, the effect of innovation on productivity can be estimated with the following specification:

$$y_i = \alpha_1 k_i + \alpha_1 I_i + \upsilon_i \qquad (5)$$

where y is labour productivity (logarithm of sales per worker), k is the logarithm of capital per worker[14] and I is the knowledge input proxied by product and process innovation.

As will be discussed below, the importance of product innovations in sales and exports is used as a measure of innovation outcomes. One way to deal with the endogeneity of this variable is to introduce in equation (5) the predicted values of the innovation variables from equation (4). As in the previous equation, the identification assumption is that some variables included in the knowledge production function —specifically, lower appropriability and interaction with suppliers and customers— affect the probability of introducing innovations but do not directly affect the productivity of the firms. As additional covariates for explaining productivity, the full set of size and industry dummy variables is included.

Estimations are presented for pooling the four different waves of the survey. Survey year-specific effects are included to control for time-varying shocks that may affect all plants. One better alternative would have been to exploit the panel dimension of the data. This would make it possible to control for firm-specific heterogeneity and to analyse dynamic issues more properly. However, the number of common firms covered in the different waves of the survey is too small to give meaningful results.[15]

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[12] For the 2001 and 2005 survey waves, it was necessary to use total investment, as information disaggregated by type of investment was not available.

[13] The national Technological Innovation Survey also provides information on the importance of innovated products relative to sales and exports. The first variable (the ratio of innovated products to sales) was used in previous work (Benavente, 2006; Crépon, Duguet and Mairesse, 1998). That information is used here as well, in an estimation of a linear model using innovative exports and sales as a dependent variable. The results, in general, do not show any impact of the innovation outcomes thus defined on productivity.

[14] Given that information on capital per worker is available for almost the entire period, this variable is preferred to gross investment per worker, as used in previous studies (Griffith et al., 2006).

[15] An earlier version of this paper contained four cross-section estimations for each wave of the survey. However, as the parameters tend to change in magnitude and significance across survey waves, the analysis became very confusing.

IV

Econometric results

Table 3 presents the results of the generalized Tobit model for both equations regarding R&D decisions.[16] As can be seen, no significant relationship is found between international competition and the decision to invest in R&D or the intensity of R&D. This is unexpected, especially in a very open economy such as Chile. It seems that exports do not contribute to increasing R&D efforts in Chile. A number of hypotheses may explain this result and they deserve further attention in future research. For instance, developing countries may be specialized in sectors where innovation is not especially important for international competition. In that case, export markets are not necessarily an incentive for investing more in R&D. There is evidence in the Chilean case that, in most export-oriented sectors, expanding the technological frontier is not a typical feature in successful Chilean industries. Case studies of firms in the wine sector and agro-industry have shown evidence in this regard (Moguillanski, Salas and Cares, 2006).

The effect of low appropriability of innovation is not statistically significant for either of the dependent variables, suggesting that imitation may not be an important issue in the Chilean context. In addition, use of public resources does not affect R&D intensity. This is an interesting result considering that, during the last decade, Chile developed several public instruments and programmes for increasing innovation. The present findings cast some doubts on the effectiveness of public resources in augmenting the R&D investment of private firms.

The demand pull variables are generally associated with higher intensity of R&D. Regarding the different sources of information for innovation activities, the results are generally not significant, with the exception of universities, whose presence as a source of information has a negative effect on R&D intensity by firms. Finally, in the case of R&D intensity, the analysis reveals a positive and significant effect of cooperation through formal contracts between firms and universities and/or technological institutes. In terms of plant size, the results suggest that larger firms —especially those with more than 100 workers— are more likely to invest in R&D.

In addition, important differences are found across manufacturing industries with regard to the probability of investing and investment in R&D. Recalling that the food industry was excluded from the computation of industry dummy variables, the parameters for the other industries represent the differences with respect to this one. The results in table 6 show that, controlling for all other variables, most of the industries have a lower probability of investing in R&D. However, for most of these industries R&D intensity is found to be greater than in the food industry.[17] In general, there is no clear association between natural-resources intensity and investment in R&D. The wood and pulp and paper industries, which may be qualified as resource-intensive industries, are less likely to invest in R&D than is the food industry, which is also a resource-intensive sector.[18]

Table 4 shows the results for the estimation of the knowledge production function using process and product innovation as indicators of innovation performance. In general, the predicted value of R&D intensity is positively associated with both indicators, although its statistical significance is lower for product innovation. Two further results are interesting to note. First, lower appropriability reduces process innovation, but it does not affect product innovation. Second, the relationship between size and innovation does not present a clear pattern. It is for the most part not significant for process innovation, but it is positive for product innovation.

These results notwithstanding, the main objective of this analysis is to investigate the effect of innovation on productivity. Table 5 shows the estimates for the output production function. The first column contains the results for contemporaneous productivity. They show that process innovation is associated positively with productivity, but there are no effects on product innovation. However, it can be argued that innovation takes some time to affect a firm's productivity. Taking

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[16] All regressions exclude potential outliers. The top and bottom 1% of firms have been excluded in the distribution of productivity and the top 1% in the distribution of R&D intensity. The bottom 1% was not excluded because the tail of the distribution contained many firms reporting no expenditure on R&D.

[17] This last result, as shown in the robustness check presented in table 9, is only valid for the chemicals industry.

[18] One interesting extension of this work could be a deeper analysis of these differences across industries, including how and why innovation may be carried out in manufactures or in the sector that exploits the resource directly. With the current information, this is not possible and lies beyond the scope of this paper.

TABLE 3

R&D decisions

(Parameters)

		Investment in R&D	R&D intensity
	Competition	0.133	0.175
		(0.95)	(0.75)
	Cooperation	--	0.346
		--	(2.35)*
	Appropriability	0.030	0.247
		(0.25)	(1.06)
	Public resources	--	-0.112
		--	(0.66)
Demand pull	Quality: high	--	0.577
		--	(0.35)
	Quality: low	--	1.465
		--	(0.91)
	Environment: low	--	3.571
		--	(3.10)**
	Environment: high	--	3.989
		--	(3.55)**
Sources of information	Internal firm	--	0.251
		--	(1.80)
	Government	--	0.288
		--	(1.25)
	Internal group	--	0.214
		--	(1.48)
	Universities	--	-0.860
		--	(2.20)*
	Suppliers and customers	--	-0.261
		--	(1.18)
	Competitors	--	0.090
		--	(0.21)
Size	Size 1: 50-99	0.140	--
		(1.49)	--
	Size 2: 100-249	0.477	--
		(6.03)**	--
	Size 3: 250-999	0.599	--
		(7.46)**	--
	Size 4: >1 000	0.916	--
		(4.55)**	--
Sector dummies	Textiles	-0.438	0.172
		(3.94)**	(0.76)
	Wood	-0.460	0.780
		(3.66)**	(2.74)**
	Pulp and paper	-0.302	0.508
		(2.59)**	(2.26)*
	Chemicals	-0.160	0.670
		(1.72)	(3.58)**
	Non-metallic	0.100	1.103
		(0.67)	(2.31)*
	Metallic	-0.187	0.316
		(1.14)	(0.90)
	Machinery	-0.279	0.692
		(3.10)**	(3.33)**
	Other manufactures	-0.284	1.276
		(1.29)	(3.56)**
	Observations	1 731	1 731
	Wald test (rho=0): *p* value	0.000	--

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.
Note: Survey-year dummy variables were included in the estimation. Robust *z* statistics in parentheses.

* Significant at 5%; ** significant at 1%.

TABLE 4

Knowledge production function

(Parameters)

	Process innovation	Product innovation
R&D intensity	0.334	0.067
	(5.26)**	(1.10)
Investment intensity	0.000	
	(0.39)	
Appropriability	-0.200	-0.021
	(3.75)**	(0.44)
Quality: high	0.003	0.520
	(0.01)	(1.89)
Quality: low	0.088	-0.643
	(0.27)	(1.97)*
Environment: high	-0.321	0.468
	(1.08)	(1.54)
Environment: low	-0.705	0.740
	(2.12)*	(2.22)*
Size 1: 50-99	0.095	0.088
	(2.39)*	(2.08)*
Size 2: 100-249	0.008	0.148
	(0.14)	(2.85)**
Size 3: 250-999	0.038	0.202
	(0.63)	(3.35)**
Size 4: >1 000	0.039	0.275
	(0.40)	(3.14)**
Textiles	0.079	0.129
	(1.16)	(1.93)
Wood	0.024	0.021
	(0.33)	(0.30)
Pulp and paper	-0.002	-0.008
	(0.04)	(0.16)
Chemicals	-0.082	0.074
	(1.84)	(1.75)
Non-metallic	-0.357	0.185
	(3.26)**	(1.89)
Metallic	-0.137	-0.336
	(1.81)	(4.48)**
Machinery	-0.043	0.066
	(0.80)	(1.28)
Other manufactures	-0.089	0.079
	(0.66)	(0.73)
Observations	1 689	1 728

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.
Note: Survey-year dummy variables were included in the estimation. Robust z statistics in parentheses.

* Significant at 5%; ** significant at 1%.

this into consideration, the model is estimated using labour productivity up to two periods after innovation as a dependent variable. For the surveys conducted in year t, the effect of innovation outcomes on productivity is estimated one and two years later ($t+1$ and $t+2$). The results are shown in the second and third columns. Both cases fail to show any strong positive relationship between product innovation and productivity, but the positive impact of process innovation holds for future values of productivity.

1. Robustness analysis

A number of exercises were conducted to check the robustness of the results. First, and considering the significant change in the descriptive statistics of some of the variables in 2004 as reported in table 2, estimates were made using a restricted sample that excluded 2004 (see tables 3-5). The results are qualitatively identical to the ones for the whole sample and are reported in tables A1, A2 and A3 in the appendix.

Second, the Tobit model was estimated considering the total expenditure in innovation reported by firms, i.e. not just the investment in R&D. The results for the three equations are shown in tables 6-8. For R&D decisions, most of variables are not statistically significant, with the exception of size dummies in the decision of investing in R&D. For innovation and productivity the main results are, in general, unchanged. The positive effect of R&D intensity on the probability of introducing process innovations and the positive effect of this last variable on productivity are robust to the change in the innovation investment variable.

The last set of robustness results corresponds to the inclusion of two additional variables in the first and second equations. First, the R&D regressions were run including a proxy variable for market structure. It is usually argued that innovation may be affected by the market share of a firm. As in Crépon, Duguet and Mairesse (1998) and Benavente (2006), this variable (in logarithms) was included in the selection and outcome equation of the generalized Tobit model. Second, in the spirit of Acemoglu, Aghion and Zilibotti (2006), a variable was included regarding the firm's distance to the technological frontier. This distance is defined as labour productivity relative to the average of the top 10% of the most productive firms in each 3-digit industry. This variable (measured in logarithms) is included in the innovation outcome equations.

The results for R&D decisions and the knowledge production function are shown in tables 9 and 10,

TABLE 5

Output production function

(Parameters)

	Productivity *(t)*	Productivity *(t+1)*	Productivity *(t+2)*
Capital per worker	0.356	0.431	0.424
	(19.12)**	(17.08)**	(14.70)**
Process innovation	1.104	0.981	1.586
	(3.36)**	(2.40)*	(3.18)**
Product innovation	-0.055	-0.108	-0.161
	(0.16)	(0.27)	(0.34)
Size 1: 50-99	-0.015	-0.121	-0.125
	(0.17)	(1.09)	(0.84)
Size 2: 100-249	0.007	-0.081	-0.089
	(0.07)	(0.66)	(0.57)
Size 3: 250-999	-0.163	-0.263	-0.279
	(1.36)	(1.73)	(1.49)
Size 4: >1 000	-0.434	-0.462	-0.451
	(2.57)*	(1.94)	(1.58)
Textiles	-0.366	-0.464	-0.462
	(4.92)**	(4.99)**	(3.65)**
Wood	-0.190	-0.160	-0.189
	(1.97)*	(1.28)	(1.40)
Pulp and paper	-0.105	-0.080	0.030
	(1.17)	(0.74)	(0.24)
Chemicals	0.067	-0.020	0.062
	(0.98)	(0.27)	(0.65)
Non-metallic	-0.082	-0.104	0.088
	(0.74)	(0.79)	(0.55)
Metallic	0.529	0.104	0.263
	(2.93)**	(0.49)	(1.16)
Machinery	-0.250	-0.257	-0.244
	(3.45)**	(2.86)**	(1.89)
Other manufactures	-0.305	0.064	0.102
	(2.26)*	(0.25)	(0.36)
Constant	7.096	6.800	6.467
	(30.69)**	(25.54)**	(18.25)**
Observations	1 520	1 090	730
R-squared	0.44	0.49	0.50

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.
Note: Survey-year dummy variables were included in the estimation. Robust *t* statistics in parentheses.

* Significant at 5%; ** significant at 1%.

TABLE 6

R&D decisions: Total investment in innovation

(Parameters)

		Investment in R&D	R&D intensity
	Competition	0.115	0.223
		(0.83)	(1.04)
	Cooperation		0.210
			(1.45)
	Appropriability	0.040	0.108
		(0.33)	(0.47)
	Public resources		-0.193
			(1.13)
Demand pull	Quality: high		-1.285
			(0.77)
	Quality: low		-0.411
			(0.26)
	Environment: high		0.094
			(0.08)
	Environment: low		0.464
			(0.39)
Sources of information	Internal firm		0.137
			(0.99)
	Government		0.335
			(1.41)
	Internal group		0.163
			(1.12)
	Universities		-0.825
			(1.91)
	Suppliers and customers		-0.058
			(0.24)
	Competitors		-0.040
			(0.09)
Size	Size 1: 50-99	0.154	
		(1.64)	
	Size 2: 100-249	0.499	
		(6.22)**	
	Size 3: 250-999	0.604	
		(7.38)**	
	Size 4: >1 000	0.869	
		(4.54)**	
Sector dummies	Textiles	-0.436	-0.288
		(3.91)**	(1.24)
	Wood	-0.460	-0.108
		(3.66)**	(0.37)
	Pulp and paper	-0.303	0.147
		(2.60)**	(0.63)
	Chemicals	-0.150	0.578
		(1.61)	(3.23)**
	Non-metallic	0.088	0.385
		(0.59)	(0.79)
	Metallic	-0.170	0.467
		(1.04)	(1.43)
	Machinery	-0.277	0.071
		(3.09)**	(0.35)
	Other manufactures	-0.262	0.224
		(1.15)	(0.64)
	Observations	1 730	1 730
	Wald test: rho / *p* value	0.44 / 0.000	--

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.
Note: Survey-year dummy variables were included in the estimation. Robust *z* statistics in parentheses.

* Significant at 5%; ** significant at 1%.

TABLE 7

Knowledge production function

(Parameters)

	Process innovation	Product innovation
R&D intensity	0.329 (3.49)**	0.052 (0.57)
Investment intensity	0.000 (0.32)	
Appropriability	-0.154 (3.07)**	-0.012 (0.26)
Quality: high	0.120 (0.41)	0.544 (1.96)*
Quality: low	0.272 (0.84)	-0.604 (1.85)
Environment: high	0.458 (1.76)	0.631 (2.36)*
Environment: low	0.075 (0.26)	0.906 (3.12)**
Size 1: 50-99	0.143 (3.82)**	0.099 (2.41)*
Size 2: 100-249	0.202 (6.07)**	0.188 (5.37)**
Size 3: 250-999	0.279 (8.30)**	0.252 (7.20)**
Size 4: >1 000	0.294 (5.10)**	0.325 (5.21)**
Textiles	-0.030 (0.42)	0.109 (1.71)
Wood	-0.037 (0.49)	0.012 (0.17)
Pulp and paper	-0.083 (1.49)	-0.021 (0.40)
Chemicals	-0.130 (2.46)*	0.071 (1.42)
Non-metallic	-0.246 (2.23)*	0.209 (2.24)*
Metallic	-0.256 (3.06)**	-0.348 (4.33)**
Machinery	-0.069 (1.24)	0.064 (1.23)
Other manufactures	-0.027 (0.21)	0.098 (0.92)
Observations	1 689	1 728

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.
Note: Survey-year dummy variables were included in the estimation. Robust *z* statistics in parentheses.

* Significant at 5%; ** significant at 1%.

TABLE 8

Output production function

(Parameters)

	Productivity *(t)*	Productivity *(t+1)*	Productivity *(t+2)*
Capital per worker	0.353 (18.93)**	0.428 (17.07)**	0.426 (14.65)**
Process innovation	1.695 (4.24)**	1.619 (3.46)**	1.705 (2.80)**
Product innovation	-0.183 (0.53)	-0.321 (0.80)	-0.268 (0.57)
Size 1: 50-99	-0.087 (0.93)	-0.201 (1.72)	-0.131 (0.84)
Size 2: 100-249	-0.086 (0.81)	-0.173 (1.35)	-0.099 (0.57)
Size 3: 250-999	-0.295 (2.23)*	-0.395 (2.48)*	-0.298 (1.37)
Size 4: >1 000	-0.581 (3.18)**	-0.605 (2.55)*	-0.440 (1.46)
Textiles	-0.303 (3.89)**	-0.403 (4.25)**	-0.440 (3.23)**
Wood	-0.150 (1.55)	-0.133 (1.08)	-0.209 (1.55)
Pulp and paper	-0.087 (0.97)	-0.085 (0.82)	0.008 (0.06)
Chemicals	0.086 (1.26)	-0.003 (0.04)	0.054 (0.58)
Non-metallic	0.013 (0.11)	0.012 (0.09)	0.131 (0.76)
Metallic	0.525 (2.91)**	0.062 (0.30)	0.200 (0.89)
Machinery	-0.203 (2.74)**	-0.219 (2.47)*	-0.247 (1.87)
Other manufactures	-0.254 (1.89)	0.083 (0.34)	0.021 (0.08)
Constant	6.804 (26.53)**	6.515 (22.94)**	6.428 (16.55)**
Observations	1 520	1 090	730
R-squared	0.45	0.49	0.50

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.
Note: Survey-year dummy variables were included in the estimation. Robust *t* statistics in parentheses.

* Significant at 5%; ** significant at 1%.

TABLE 9

R&D decisions including market share

(Parameters)

		Investment in R&D	R&D intensity
	Competition	0.246	0.229
		(1.72)	(0.99)
	Cooperation		0.347
			(2.35)*
	Appropriability	0.092	0.264
		(0.77)	(1.14)
	Public resources		-0.122
			(0.72)
Demand pull	Quality: high		0.401
			(0.24)
	Quality: low		1.427
			(0.88)
	Environment: high		3.632
			(3.15)**
	Environment: low		3.957
			(3.51)**
Sources of information	Internal firm		0.253
			(1.82)
	Government		0.294
			(1.28)
	Internal group		0.214
			(1.46)
	Universities		-0.861
			(2.21)*
	Suppliers and customers		-0.262
			(1.18)
	Competitors		0.092
			(0.22)
	Market share	0.080	0.017
		(6.23)**	(0.44)
Size	Size 1: 50-99	0.290	
		(2.96)**	
	Size 2: 100-249	0.596	
		(7.34)**	
	Size 3: 250-999	0.674	
		(8.24)**	
	Size 4: >1 000	0.918	
		(4.52)**	
Sector dummies	Textiles	-0.295	0.243
		(2.55)*	(1.07)
	Wood	-0.321	0.852
		(2.48)*	(2.99)**
	Pulp and paper	-0.151	0.596
		(1.24)	(2.67)**
	Chemicals	-0.019	0.754
		(0.19)	(4.06)**
	Non-metallic	0.260	1.147
		(1.64)	(2.41)*
	Metallic	-0.047	0.376
		(0.28)	(1.08)
	Machinery	-0.103	0.782
		(1.07)	(3.78)**
	Other manufactures	-0.129	1.332
		(0.56)	(3.71)**
	Wald test: rho / *p* value	0.48/0.00	
	Observations	1 731	1 731

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.
Note: Survey-year dummy variables were included in the estimation. Robust *z* statistics in parentheses.

* Significant at 5%; ** significant at 1%.

TABLE 10

Knowledge production function

(Parameters)

	Process innovation	Product innovation
R&D intensity	0.258 (4.82)**	0.054 (1.04)
Investment intensity	0.000 (0.29)	
Appropriability	-0.206 (3.83)**	-0.020 (0.42)
Quality: high	0.163 (0.58)	0.588 (2.13)*
Quality: low	0.151 (0.47)	-0.643 (1.97)*
Environment: high	-0.248 (0.86)	0.432 (1.46)
Environment: low	-0.580 (1.79)	0.734 (2.27)*
Distance to frontier	-0.020 (1.30)	-0.030 (1.96)*
Size 1: 50-99	0.018 (0.38)	0.065 (1.34)
Size 2: 100-249	-0.056 (0.86)	0.124 (1.99)*
Size 3: 250-999	-0.020 (0.26)	0.180 (2.49)*
Size 4: >1 000	-0.004 (0.04)	0.263 (2.69)**
Textiles	-0.035 (0.50)	0.090 (1.38)
Wood	-0.067 (0.89)	-0.003 (0.04)
Pulp and paper	-0.107 (1.89)	-0.040 (0.76)
Chemicals	-0.166 (3.26)**	0.049 (1.01)
Non-metallic	-0.370 (3.34)**	0.174 (1.73)
Metallic	-0.200 (2.41)*	-0.328 (4.13)**
Machinery	-0.150 (2.59)**	0.035 (0.64)
Other manufactures	-0.132 (0.98)	0.064 (0.58)
Observations	1 689	1 728

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.
Note: Survey-year dummy variables were included in the estimation. Robust z statistics in parentheses.

* Significant at 5%; ** significant at 1%.

respectively. An increase in market share seems to be positive and significantly associated with an increase in the probability of investing in R&D. Regarding R&D intensity, the effect of market share is positive, but not significant. The results for the knowledge production function suggest that distance to the frontier has a negative effect on the probability of introducing product and process innovations, but the effect is only significant for product innovation. This is consistent with Acemoglu, Aghion and Zilibotti (2006), meaning that less-efficient firms are less likely to innovate.

The results for productivity in *t*, *t+1* and *t+2* are shown in table 11. Including these two additional variables generates an important change vis-à-vis previous results for productivity. As can be seen, the positive effect of process innovation on productivity remains unchanged, but now product innovation also affects productivity positively. In addition, the lagged effects of process innovation still hold and now product innovation also has lagged effects on productivity.

Table 12 summarizes the main and most interesting results across different specifications to show which results are more robust than others. In general, the robust results tend to be that: (a) larger plants are more likely to invest in R&D, (b) R&D intensity increases the probability of process innovation, (c) R&D intensity does not affect the probability of product innovation, (d) low appropriability reduces the probability of process innovation, (e) larger firms are more likely to introduce product innovation, and (f) process innovation increases productivity.

TABLE 11

Output production function

(Parameters)

	Productivity (*t*)	Productivity (*t+1*)	Productivity (*t+2*)
Capital per worker	0.299 (16.62)**	0.347 (14.04)**	0.344 (12.21)**
Process innovation	2.988 (9.77)**	3.498 (9.13)**	4.322 (9.06)**
Product innovation	1.429 (4.34)**	1.262 (3.32)**	0.925 (2.18)*
Size 1: 50-99	-0.407 (5.05)**	-0.615 (6.36)**	-0.628 (4.68)**
Size 2: 100-249	-0.601 (6.92)**	-0.831 (7.88)**	-0.866 (6.49)**
Size 3: 250-999	-1.013 (9.63)**	-1.321 (10.16)**	-1.352 (8.58)**
Size 4: >1 000	-1.519 (9.59)**	-1.930 (9.14)**	-1.907 (7.69)**
Textiles	-0.110 (1.71)	-0.034 (0.42)	-0.026 (0.23)
Wood	0.213 (2.41)*	0.290 (2.59)**	0.166 (1.38)
Pulp and paper	0.118 (1.42)	0.274 (2.81)**	0.375 (3.31)**
Chemicals	0.044 (0.69)	0.075 (1.07)	0.127 (1.43)
Non-metallic	0.098 (0.84)	0.204 (1.41)	0.484 (2.98)**
Metallic	1.307 (7.68)**	0.989 (4.98)**	0.942 (4.55)**
Machinery	0.028 (0.43)	0.136 (1.75)	0.144 (1.27)
Other manufactures	-0.108 (0.84)	0.449 (1.98)*	0.347 (1.41)
Constant	5.882 (32.72)**	5.450 (27.58)**	5.087 (17.70)**
Observations	1 520	1 090	730
R-squared	0.51	0.56	0.58

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.

* Significant at 5%; ** significant at 1%.

TABLE 12

Summary of results and robustness

(Parameters)

Basic model	Total investment in innovation	R&D investment + market share and distance to frontier
R&D decisions		
Cooperation increases R&D intensity	No	Yes
Larger plants are more likely to invest in R&D	Yes	Yes
Knowledge production function		
R&D intensity increases the probability of process innovation	Yes	Yes
R&D intensity does not affect the probability of product innovation	Yes	Yes
Low appropriability reduces the probability of process innovation	Yes	Yes
Larger firms are more likely to introduce product innovation	Yes	Yes
Output production function		
Process innovation increases productivity	Yes	Yes
Product innovation increases productivity	Yes	Yes

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.

V

Conclusions

The vast body of literature on the relationship between innovative activities and productivity has focused on finding evidence for developed countries (Hall and Rosenberg, 2010). The present analysis adds the Chilean case to the scarce and inconclusive quantitative evidence on the relationship between innovation and productivity in developing countries.

This paper presented a quantitative analysis of the effect of innovation activities on productivity in Chilean manufacturing plants. The analysis was conducted using technological innovation surveys matched with plant-level data taken from official surveys for four years (1995, 1998, 2001 and 2004) and following the approach of Crépon, Duguet and Mairesse (1998) and Griffith et al. (2006).

Faced with the technical impossibility of using panel data, the analysis focused on pooled regressions whose results can be interpreted as the average across different surveys. The robustness of the results was checked against different specifications. In general, the results were found to be robust, supporting the assertions that: (a) larger plants are more likely to invest in R&D, (b) R&D intensity increases the probability of process innovation, (c) R&D intensity does not affect the probability of product innovation, (d) low appropriability reduces the probability of process innovation, (e) larger firms are more likely to introduce product innovation, and (f) process innovation increases productivity.

In particular, robust evidence was found of a contemporaneous effect of process innovation on productivity, together with less-robust evidence that product innovation affects productivity contemporaneously. This less-robust effect of product innovation contrasts with evidence from studies of other countries. The study results show as well the presence of lagged effects of process innovation on productivity, and again less-robust evidence of such a lagged effect for product innovation.

The presence of lagged effects of process and product innovation on productivity might be consistent with a very slow process of learning by doing in the mastering of new production processes by Chilean firms. These slow and, most of the time uncertain, gains in productivity could help to explain the low levels of investment in R&D activities by Chilean firms.

The analysis yields some important findings for policy discussion. First, it was found that public financing is not positively associated with innovation investment. This casts doubts on whether or not the increase in public funds channelled to innovation in recent years has been an effective tool for increasing innovation and productivity in the Chilean economy. More research is needed to investigate where these public resources are going and why they are not generating an increase in private investment in innovation. Second, the study also found significant differences across manufacturing industries with regard to the probability of investing and investment in R&D. At least for the industries considered in the study, there is no apparent relationship between innovation investment and natural-resources intensity. Further work needs to be done to identify the causes of these differences and whether or not public policy should consider specific policies for lagged industries in innovation activities.

(Original: English)

APPENDIX

TABLE A1

R&D decisions: Sample 1995-2001

(Parameters)

	Investment in R&D	R&D intensity
Competition	0.198	0.264
	(1.33)	(0.85)
Cooperation		0.256
		(1.69)
Appropriability	0.010	0.210
	(0.07)	(0.65)
Public resources		0.058
		(0.26)
Quality: high		1.151
		(0.47)
Quality: low		1.672
		(0.88)
Environment: high		3.241
		(2.13)*
Environment: low		3.443
		(2.30)*
Internal firm		0.075
		(0.38)
Government		0.938
		(2.83)**
Internal group		0.457
		(2.13)*
Universities		-1.009
		(2.12)*
Suppliers and customers		-0.463
		(1.69)
Competitors		-0.697
		(1.22)
Size 1: 50-99	0.127	
	(1.22)	
Size 2: 100-249	0.431	
	(5.06)**	
Size 3: 250-999	0.553	
	(6.56)**	
Size 4: >1 000	0.924	
	(4.42)**	
Textiles	-0.539	-0.161
	(4.28)**	(0.48)
Wood	-0.549	0.718
	(3.93)**	(1.84)
Pulp and paper	-0.325	0.480
	(2.50)*	(1.43)
Chemicals	-0.124	0.948
	(1.26)	(4.28)**
Non-metallic	0.157	1.439
	(1.02)	(2.01)*
Metallic	-0.118	0.677
	(0.67)	(1.60)
Machinery	-0.331	0.848
	(3.37)**	(3.34)**
Other manufactures	-0.515	2.180
	(1.35)	(2.54)*
Observations	1 321	1 321

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.

Note: Survey-year dummy variables were included in the estimation. Robust *z* statistics in parentheses.

* Significant at 5%; ** significant at 1%.

TABLE A2

Knowledge production function: Sample 1995-2001

(Parameters)

	Process innovation	Product innovation
R&D intensity	0.118	-0.047
	(1.63)	(0.65)
Investment intensity	0.000	
	(0.13)	
Appropriability	-0.154	-0.029
	(2.60)**	(0.54)
Quality: high	0.337	0.370
	(0.84)	(0.97)
Quality: low	0.452	-0.659
	(1.20)	(1.81)
Environment: high	0.050	0.673
	(0.14)	(1.89)
Environment: low	-0.337	1.050
	(0.87)	(2.72)**
Size 1: 50-99	0.177	0.194
	(3.60)**	(3.74)**
Size 2: 100-249	0.202	0.285
	(3.38)**	(4.60)**
Size 3: 250-999	0.289	0.351
	(4.25)**	(4.88)**
Size 4: >1000	0.295	0.405
	(2.75)**	(3.83)**
Textiles	0.051	-0.009
	(0.43)	(0.08)
Wood	0.061	-0.026
	(0.61)	(0.27)
Pulp and paper	-0.020	-0.051
	(0.26)	(0.72)
Chemicals	-0.043	0.125
	(0.82)	(2.48)*
Non-metallic	-0.096	0.274
	(0.64)	(2.09)*
Metallic	-0.161	-0.287
	(1.89)	(3.43)**
Machinery	-0.004	0.025
	(0.06)	(0.36)
Other manufactures	0.276	0.004
	(1.44)	(0.02)
Observations	1 297	1 321

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.

Note: Survey-year dummy variables were included in the estimation. Robust *z* statistics in parentheses.

* Significant at 5%; ** significant at 1%.

TABLE A3

Output production function: Sample 1995-2001

(Parameters)

	Productivity (*t*)	Productivity (*t+1*)	Productivity (*t+2*)
Capital per worker	0.412 (18.07)**	0.434 (17.47)**	0.430 (14.97)**
Process innovation	1.168 (2.59)**	1.122 (2.35)*	1.538 (2.35)*
Product innovation	-0.262 (0.68)	-0.133 (0.32)	-0.207 (0.43)
Size 1: 50-99	-0.116 (0.92)	-0.163 (1.19)	-0.147 (0.80)
Size 2: 100-249	-0.103 (0.72)	-0.135 (0.85)	-0.113 (0.51)
Size 3: 250-999	-0.290 (1.58)	-0.345 (1.70)	-0.320 (1.14)
Size 4: >1 000	-0.519 (2.10)*	-0.529 (1.89)	-0.451 (1.22)
Textiles	-0.391 (4.02)**	-0.423 (3.91)**	-0.436 (2.90)**
Wood	-0.164 (1.58)	-0.156 (1.25)	-0.217 (1.57)
Pulp and paper	-0.065 (0.61)	-0.061 (0.55)	0.059 (0.43)
Chemicals	0.029 (0.40)	-0.034 (0.45)	0.042 (0.43)
Non-metallic	-0.119 (0.93)	-0.109 (0.78)	0.055 (0.31)
Metallic	0.291 (1.56)	0.096 (0.47)	0.219 (0.99)
Machinery	-0.298 (3.45)**	-0.265 (2.89)**	-0.273 (1.97)*
Other manufactures	-0.367 (1.73)	-0.125 (0.51)	-0.205 (0.78)
Constant	6.811 (23.47)**	6.735 (22.43)**	6.514 (15.59)**
Observations	1 206	1 090	730
R-squared	0.47	0.49	0.50

Source: Prepared by the authors on the basis of the national Technological Innovation Survey.
Note: Survey-year dummy variables were included in the estimation. Robust *z* statistics in parentheses.

* Significant at 5%; ** significant at 1%.

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