

R&D EXPENDITURE, MARKET STRUCTURE AND "TECHNOLOGICAL REGIMES" IN CHILEAN MANUFACTURING INDUSTRY

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Abstract

This research submits evidence on the nature of the accumulation of knowledge in Chilean manufacturing industry. Microeconomic data shows that factors which are both firm and the industry specific are relevant to the decisions to invest in innovation. Among the former it is worth mentioning the age of the plants and the past investment decisions; among the latter, market structure is meaningful. Furthermore, the evidence also shows that the pattern of accumulation of knowledge differs according to the scale, which leads to the existence of two differentiated technological regimes.*

Resumen

Esta investigación presenta evidencia sobre la naturaleza de la acumulación de conocimiento en la industria manufacturera chilena. Utilizando datos microeconómicos se encuentra que, tanto factores específicos a la firma como a la industria son relevantes para las decisiones de invertir en innovación. Entre los primeros se destaca el grado de madurez de las plantas y las decisiones pasadas de inversión; entre los segundos, la estructura de mercado. Adicionalmente, se aprecia que el patrón de acumulación de conocimiento difiere según la escala, existiendo por lo menos dos regímenes tecnológicos diferenciados.

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1. INTRODUCTION

Although economists, engineers and politicians usually agree in considering technical progress as "the" factor which ultimately "explains" productivity growth and welfare expansion in any given society, most of the available evidence concerning the "*economics of technological change*" comes from studies carried out within the context of developed countries.

There are few studies on the determinants of the accumulation of knowledge in less developed societies.² In these studies, domestic inventive activity is understood as a complementary input needed for the absorption of external technologies and for the adaptation of such technologies to local conditions.

In this paper, we examine the determinants of the innovative activity among Chilean manufacturing industries. Available evidence shows that national expenditures in research and development does not exceed 0.8% of GDP, a figure which is only one third of that reported by developed countries and only one half of that recorded in some of the countries of high growth. Such figure was only 0.4% of GDP only ten years back, thus suggesting that expenditure in R&D in Chile has been increasing over time *pari passu* with the growth in aggregate investment and with higher imports of capital goods and direct foreign investment.

In order to examine the determinants of microeconomic behaviour in this field, we specify an empirical model which includes the more relevant aspects in the determination of technological behaviour of private agents in the context of a society which is well behind of the international technological frontier. To do so, we use microeconomic data "at the plant level" taken from the *First Survey on Technological Innovation in the Manufacturing Industry* conducted in 1995 by the National Statistical Institute (NSI) and the Executive Secretariat of the Program of Technological Innovation (PTI).

2. THE EMPIRICAL MODEL

Many studies have attempted over the last decade to examine inter-industry differences in "technological regimes" which lead companies to undertake different levels of expenditure in R&D activities.³ The point of departure for this type of analysis is the hypothesis advanced by Schumpeter (1950) who, in his study on the role of economic agents in technical progress, argued that large companies are proportionally more innovative than the smaller ones. He also acknowledged the positive effect of concentration on innovation.⁴ Here "size of the firm" and "degree of industry concentration" appear to be part of the "technological regime" that differentiates one industry from other.

On the basis of the Schumpeterian hypotheses and their subsequent rationalisation, empirical work has been carried out to throw light upon this

² For an exception, see J. Katz (1974).

³ For a survey see Cohen and Levine (1989).

⁴ Kamien and Schwart (1982) analyse in detail which are the reasons pointed out by Schumpeter that make it possible to uphold both hypotheses.

topic. Econometric models were formulated in which the dependent variable, which could be an input of innovation as, for instance, the ratio of expenditure in R&D to sales, was regressed against the size of the plant and some index of industrial concentration.

Subsequently, the models were extended to include other variables aimed at capturing others firm-specific and industry characteristics omitted in the original models such as technological opportunity, finance, economies of scale, etc.

In general, most of these studies, apart from showing problems of empirical specification, also show a serious shortcoming in that when working with firms, as a rule, non-random samples were used, because only agents reporting R&D expenditure, or large firms were taken into account; in many cases this resulted in sampling selection bias.⁵

The model developed in this section to explain the determinants of innovation is a simple version of the Levin and Reiss model (1986). The model assumes that firms are optimising agents who have an oligopolistic Cournot-type behaviour, that exists free access to each market and that expenditure in R&D serves to bring downwards the costs function. Then, the unit cost of firm i will be given by the following expression:

$$(1) \quad C(X_i, Z) = \beta X_i^{-\alpha} Z^{-\gamma}$$

where $X(i)$ is the firm's investment in R&D and Z is the investment made by all firms in the industry, including those of firm i . As can be seen, the technology is such that there are positive but decreasing returns both to firm's own R&D efforts as well as to those carried out by the industry as a whole. The importance of this specification is that it enables us to emphasise the existence of externalities in the process of improvement. Actually, an increase in the firm's R&D not only reduces its production cost, but also, brings about some reduction in the cost of other firms in the industry. This makes possible the inclusion of differences in the degree of appropriability, influencing the decision to invest in R&D.

Given that the interest of the study resides in the technological and behavioural aspects of the dimensions of technological appropriability and opportunity a simple isoelastic unit demand will be assumed given by:

$$(2) \quad P = \frac{\alpha}{Q}$$

The assumption that the firms have a Cournot behaviour implies that they act considering that their rivals do not react on deciding a change, either in production or in R&D. This may be summed up in the following two behavioural expressions:

⁵ See Lee (1996).

$$(3) \quad \frac{\partial Q}{\partial q_i} = 1$$

$$(4) \quad \frac{\partial Z}{\partial X_i} = 1$$

The firm's benefit functions and their corresponding first-order conditions are shown below:

$$(5) \quad \pi_i = \left[\frac{\alpha}{Q} - \beta X_i^{-\alpha} Z^{-\gamma} \right] q_i - X_i$$

$$(6) \quad \frac{\alpha}{Q} [1 - S_i] = \beta X_i^{-\alpha} Z^{-\gamma}$$

$$(7) \quad \beta [\alpha X_i^{-(1+\alpha)} Z^{-\gamma} + X_i^{-\alpha} \gamma Z^{-(1+\gamma)}] q_i = 1$$

Where S_i is the market share of firm i . These equations show how the private solution will not be a social optimum. Thus, while expression (6) shows the departure of the price in relation to the marginal cost needed to finance the expenditure in R&D, expression (7) indicates that the investment in R&D is chosen by each company in relation to its size, when the social optimum would have been that this should be chosen on the basis of the market's production scale.

The free access condition will entail that the benefits will be strictly equal to zero (equation 8). However, it is acknowledged that insofar as there exists a restriction in integers, it could well happen that the equilibrium will contain a small number of firms gaining positive benefits, but in a situation such that the entry of an additional firm generates negative benefits for all.

$$(8) \quad \left[\frac{\alpha}{Q} - \beta X_i^{-\alpha} Z^{-\gamma} \right] q_i = X_i$$

In order to analyse market equilibrium, the condition that it is symmetric with n identical firms will be imposed (as is standard in this type of models), so $q_i = q$, $X_i = X$, and $S_i = 1/n$.

By adding the expression (8) to n companies and dividing both sides by PQ , expression (9) is obtained, where (et) is the ratio of the investment in R&D to sales in the industry (identical) for each firm in particular.

$$(9) \quad \frac{[\alpha/Q - \beta X^{-\alpha} Z^{-\gamma}]}{\alpha/Q} = et$$

Combining this expression with expression (6), we obtain that the intensity of the expenditure in R&D at an industry level is proportional to the degree of industrial concentration in this market (in this case with a proportionality factor equal to 1) (expression 10). This equation may be interpreted as a structural equation reflecting market structure, which captures much of the Schumpeterian spirit

$$(10) \quad \frac{1}{n} = et$$

In order to derive the structural expression for the intensity of R&D expenditure the firm, we multiply both members of expression (7) by $et = x/pq$ and reorder the terms, to obtain:

$$(11) \quad \left[\alpha + \frac{\gamma}{n} \right] \frac{\beta X^{-\alpha} Z^{-\gamma}}{\alpha/Q} = et$$

An expression which through the use of expression (9), may be written as (12).

$$(12) \quad \left[\alpha + \frac{\gamma}{n} \right] (1 - et) = et$$

It may be convenient to re-write this expression so as to express the identity of et to the production costs of each company (13).

$$(13) \quad et = \frac{et}{(1 - et)} = \alpha + \frac{\gamma}{n}$$

Expression (13) is a structural equation for the intensity of a firm's expenditure in et . This intensity will be positively associated with the degree of the reduction of costs that is derived from R&D, an aspect which may be related to the degree of technological opportunity existing in the industry, and also on the conditions of appropriability, because when the firm spends in R&D, it contributes to the common pool of knowledge in the industry. It is in this sense that the market structure becomes relevant, since the benefits which the company will appropriate as a consequence of its contribution to the pool of knowledge of the industry will be greater, the greater its participation in the market (and the higher $1/n$ is). If the company is a monopoly, the contribution to the pool of knowledge is appropriated only by the company itself. On the other hand, if n

tends to infinitum and the structure of the market approximates a competitive system, the appropriation by the firm of its own contribution to the common pool of knowledge of the industry will be very small.

It could well be that the major criticism levied against the above models is due to the outcome of a proportional relationship between the intensity in R&D expenditure and the degree of concentration. This fact does not seem to be corroborated by the preliminary empirical findings where in most of cases there appears to be an "increasing" relationship at a "decreasing" rhythm which would be reflecting the existence of optimal private levels of concentration when the forces of appropriability are offset by those deriving from the lack of competitive pressures. The same can be said in relation to the assumption of proportionality between expenditure and size.

3. EMPIRICAL ANALYSIS OF THE DETERMINANTS OF INVESTMENT IN INNOVATION

This paper is based mainly on the survey on "Technological Innovation in the Manufacturing Industry" jointly conducted during 1995 by the National Statistical Institute (NSI) and the Executive Secretariat of the Technological Innovation Program (ESTIP).

The information collected includes both quantitative variables related to technological innovation (R&D expenditure, investment in machine and equipment, exports, age of plants, etc.) as well as qualitative variables related to the decision to innovate. The survey was targeted to establishments and not to companies, because the intention was to detect behaviour at the plant level. In any case, when companies had more than one establishment, the survey was applied at the central level so as to capture innovative efforts implemented out of the establishment.

The sample was selected from the Directory of establishments from the Annual Industrial National Survey (AINS) conducted by NSI, on a nation-wide basis. We used an stratified probabilistic sampling, defining two great strata in terms of the size of the establishments. The variable chosen for the sampling design was value added per establishment, which was used in order to assign the selection probability to each one of them.

The sample design considered two types of establishments. The first of them was designated as the stratum of *forced inclusion* (FI). The criteria to include an establishment in this category was that it should at least contribute 2% of one of three variables (value added, exports or investment) to its sector (ISIC at two digits). The second type of establishment was designed as random inclusion. The selection was made in each strata by size, with a probability proportional to the added value of each establishment. The sample obtained was 541 establishments, which represented 99% of the target. The method warrants that the sample is representative of manufacturing industry as a whole, with a sampling error of 5.1% at 95% of confidence.

In general, it can be seen that average expenditure is rather low, as it is less than half a percentage point of Industrial GDP by comparison to an average of 1.7% in developed countries, though at levels similar to those of developing countries such as Argentina (0.5%) and Brazil (0.4%). Furthermore, this expenditure is strongly concentrated in only 25% of industrial plants; furthermore,

100 establishments out of a total of 5000 (a 2%) concentrate 51% of total R&D expenditure and 10 establishments account for 21%.

Broadly speaking, we observe that average expenditure in innovation amounted to 32 thousand dollars per plant in 1995, of which 51% are R&D expenses, and 49% are expenses in tests, training, licenses, etc. As regards the origin of funds for such investment, 75.7% of the establishments cover it fully with own resources. Table N° 1 shows some of the quantitative characteristics of the establishments under study.

TABLE N° 1
ECONOMIC INFORMATION FOR FIRMS IN SAMPLE

Variable	Average	DS	Minium	Maximum
Private Expenditure in R&D at Value Added	0.0046	0.0475	0	2.4653
Age of plant (years)	22.2508	17.6721	0	169
Exports at Added Value	0.1240	0.7850	0	42.2877
Physical Investments at Added Value	0.0726	0.3150	0	15.7751
Concentration ⁶ (C4)	0.2844	0.1838	0.1009	1
Fraction of Plants with Investment in R&D	0.2455	0.4308	0	1
Employment (headcount)	83.8507	151.5612	10	3445

In order to conduct a preliminary exploration of the interdependencies between R&D expenditure and the characteristics of the firms, we calculated the corresponding correlation matrix between the variables mentioned. The estimator for the correlation coefficient is as follows:

$$\hat{\rho} = \frac{\sum_{i=1}^n w_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n w_i (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n w_i (y_i - \bar{y})^2}}$$

Where W_i is the respective population weight and

$$\bar{x} = \left(\frac{\sum w_i x_i}{\sum w_i} \right)$$

The level of significance of p is calculated in a non adjusted manner and it is such that values lower than 0.05 reject the H_0 on which both variables are independent.

$$p = t \text{ prob} \left(n-2, \hat{\rho} \frac{\sqrt{n-2}}{\sqrt{1-\hat{\rho}^2}} \right)$$

⁶ It refers to the concentration of the four largest ones at the most disaggregated branch level possible, that is, at four digits of ISIC oodes.

TABLE Nº 2
CORRELATION MATRIX BETWEEN VARIABLES

	R&D/VA	Age	Exp/VA	INV/VA	C4	VA	Employment
R&D/VA	1.0000						
Age	0.0752 (0.0937)	1.0000					
Exp/VA	0.0584 (0.1929)	-0.0093 (0.8357)	1.0000				
INV/VA	0.3751 (0.0000)	0.0451 (0.3148)	0.1366 (0.0023)	1.0000			
C4	0.0305 (0.4969)	0.2560 (0.0000)	0.0343 (0.4445)	0.0313 (0.4855)	1.0000		
VA	-0.0005 (0.9904)	0.1174 (0.0087)	0.0659 (0.1419)	0.0179 (0.6899)	0.1777 (0.0001)	1.0000	
Employment	0.0246 (0.5843)	0.1955 (0.0000)	0.1300 (0.0037)	0.0825 (0.0660)	0.1412 (0.0016)	0.4972 (0.0000)	1.0000

The correlation matrix indicates the existence of a positive and statistically significant correlation between innovative effort and age of the plants on the one hand and with investment rate on the other. However, no association of any type was found between innovative effort and the degree of concentration and scale. On the other hand, the variable for age appears to be correlated with concentration and size. The degree of internationalisation shows a positive correlation with size (measured in terms of employment) and investment, whereas the latter is also correlated with employment.

Finally, an additional characteristic of the data is the presence of a highly censored sample in the R&D expenditure variable. This clearly involves an additional degree of complexity in the estimations which follow, but also affords the advantage of having random samples clearly suggesting that the innovators "club" is quite restrictive.

On the basis of the theoretical model discussed before now proceed to explain private investment in R&D in terms of variables which are specific to the companies and structural to the industry. These are summed up in the concepts of *technological opportunity* (OT) which the company faces and *technological appropriability* (AT) prevailing at the industrial level. This may be represented by the following expression:

$$(1) \quad \frac{\text{Private Expenditure Innovation}}{\text{Sales}} = et = F(OT, AT)$$

With the data available to us we could only use proxy variables for *technological opportunity*. There exists some consensus that opportunity in part, depends on the supply of knowledge available to the firm. In this sense, a first source of this stock of knowledge is internal to the firm and is related to the position it occupies along its own learning curve.⁷ In our case, a proxy variable for opportunity is the age of the plant (A).

However, the knowledge of the company not only thrives on the firm's internal sources. The absorption which the firm makes of external knowledge coming from the international frontier is also important. In fact, it is well documented in the empirical literature on international trade and economic growth that there exists a positive correlation between exports and technological absorption capacity.⁸ The rationale for this specification relates the capacity to absorb knowledge from the technological frontier to the rate of participation in external markets. In this sense, a good indicator of the degree at which a company captures international knowledge is its exporting intensity, defined as the ratio of exports to added value (XR).

Technological opportunity is also related to the complementary nature of knowledge "embodied into" the investment goods and in the disembodied knowledge accumulated inside the firm. The latter is due to the need to bring about adaptations to the machinery and equipment acquired so as to adjust them to the idiosyncratic nature of the firm.⁹ We could represent this adaptive nature of technological effort by the ratio of investment to value added (INVR).

Finally, it can also be assumed that the technological opportunity is correlated with the size of the productive unit, because the greater the size, the greater the complexity of the existing productive processes and the greater the alternatives for development. Also, in these cases, the degree of productive diversification may be relevant. Consequently, a size effect is added to the model by using E (employment) as a proxy for it.

Briefly stated, technological opportunity was modelled as

$$(2) \quad OT = F(A, XR, INVR, E)$$

Though the fact that *technological appropriability* (AP) increases with concentration is implicit to the model, it is necessary to define which indicator for concentration will be resorted to. In this study, the indicator chosen stands for the one which is typical in the literature, namely, sales concentration coefficient in the four largest companies of the sector at four digits (C4), though with an additional squared component.

$$(3) \quad AP = F(C4, C4^2)$$

⁷ Some authors call this aspect of technological opportunity its "cumulative" dimension. See Pavitt (1986).

⁸ However, there are other interpretations. Braga and Willmore (1991), in a study on the determinants of the innovative dynamics and quality in Brazil suggest that it is most likely that the higher investment in export firms be due to the supposedly more rigorous quality requirements of the external markets. In any event, these arguments warrant the introduction of the exports variable into the model.

⁹ See Katz, (1976), chap III.

An important problem arises at the time of the estimation due to the existence of a strong lower censorship in the observations of R&D expenditure, as the sample selected includes nearly 30% of the companies reporting a null expenditure in R&D activities.¹⁰

A reason that is ascribed to this censorship relates to the existence of a minimum threshold of expenditure (C) in which the company must incur to undertake any innovation (for instance, the one needed to hire an engineer). Then, for any company, the amount of the expenditure observed at a given moment of time (designated by Y) is:

$$(4) \quad Y_i = \begin{cases} Y_i^* & \text{if } Y_i^* \geq C \\ 0 & \text{if } Y_i^* < C \end{cases}$$

That is, the observed amount of the expenditure will be the optimal private level or will be 0, which simply reflects that $Y < C$. Assuming that the threshold is known for all the companies, the model may be re-written by subtracting C on both sides. The constant term will be then the original constant minus C .

$$(5) \quad \begin{aligned} et_i &= X_i' \beta + \mu_i & \text{if } X_i' \beta + \mu_i > 0 \\ et_i &= 0 & \text{otherwise, where:} \end{aligned}$$

$$X_i' = \left[1 \ A_i \ XR_i \ INVR_i \ E_i \ C4_i \ C42_i \ \sum_{i=1}^P D_i \right]$$

Where D_i are categorical variables standing for fixed sectoral effects, so as to capture aspects of the sectors which each firm belongs to not considered in the other variables (such as demand elasticities, dynamism of the knowledge frontier, etc.).

Unfortunately, Ordinary Least Squares estimates using conventional methods is biased and inconsistent.¹¹ The strategy followed in this paper is to estimate the model through maximum likelihood. To do so, we consider that the likelihood of the sample contains two components; one for the observations which are positive and another for the observations which are zero. If f_i y F_i are the density and the distribution of normal standard evaluated in $Z_i = \frac{X_i' \beta}{\sigma}$. For the observations $et_i = 0$ we know that $X_i' \beta + \mu_i < 0$ o $\mu < -X_i' \beta$:

$$(6) \quad \Pr [et_i = 0] = \Pr [\mu_i < -X_i' \beta] = \Pr \left(\frac{\mu_i}{\sigma} < -\frac{X_i' \beta}{\sigma} \right) = 1 - F_i$$

¹⁰ Though it is also likely that some of the companies were not able to identify this expenditure because they did not have separated records of the R&D expenditure or perhaps the nature non routinized the many innovation activities (Katz 1974).

¹¹ See Judge, *et. al.* (1985), pp. 779-783.

Then the likelihood function may be expressed as¹²:

$$(4) \quad \ell = \prod_0 (1 - F_i) \prod_1 (2\pi\sigma^2)^{-\frac{1}{2}} \exp \left\{ -\frac{(et_i - X_i'\beta)^2}{2\sigma^2} \right\}$$

and its logarithmic version will be the following.¹³

$$(5) \quad \log \ell = -\frac{1}{2} \sum_{j \in C} w_j \left[\left(\frac{et_i - X_i'\beta}{\sigma} \right)^2 + \log 2\pi\sigma^2 \right] \\ + \sum_{i \in L} w_j \log \left[1 - \Phi \left(\frac{et_{il} - X_i'}{\sigma} \right) \right]$$

Where W_j is the population weight which corresponds to the observation.¹⁴ As a basis of comparison we also add the OLS estimations.

The results deriving from the OLS estimations show the relevance of both historical exports as well as past physical investments to explain current expenditure in R&D. However, the incorporated component of this technical change is far more relevant. The variable for employment reflects the existence of slight decreasing yields with size. On the other hand, no significance at all was obtained from the variables for market structure.

As mentioned earlier, the above results would be biased by the presence of censorship in the companies' responses. Therefore, we proceeded to re-estimate the model through maximum likelihood. The results changed radically. As regards the coefficients obtained, the one which goes with the variable for age reduces its value, though once again it is not statistically significant. The employment coefficient, in turn, changes its sign and though its value is numerically very low, it is also statistically significant. The exports coefficient grows strongly, while the one for investment goes down slightly. However, the investment coefficient still is much higher than that for exports. Finally, the two coefficients that go with concentration are statistically significant and show the expected signs. Actually, the results suggest that the degree of concentration which maximises the intensity of expenditure of each firm is 0.48, much higher than the one actually prevailing in most sector.

¹² This likelihood function is often called Tobit model.

¹³ However, a potential problem with this approach is the assumption that the coefficients affecting the decision of spending in R&D are the same affecting the expenditure level in R&D. That is, the model assumes the condition that the relationship generating the ones and zeros is the same as the process that produces the positive values. We analyse this constrain in the Appendix.

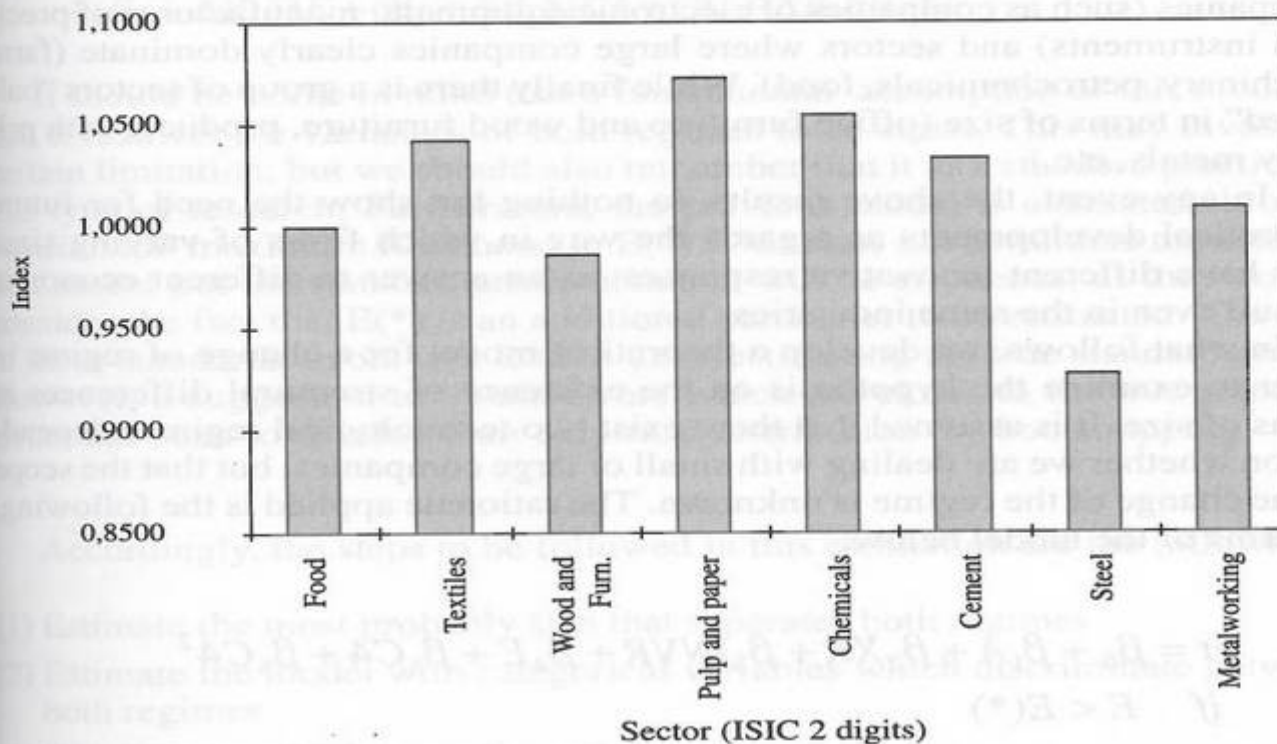
¹⁴ Given the presence of heteroscedasticity, we proceeded to re-estimate the model using White's consistent estimator for heteroscedasticity. See Green (1997).

TABLE N° 3
ESTIMATIONS WITH ROBUST VARIANCES
(* Significant at 10%, ** Significant at 95%)

Method	OLS	ML
Variable	Coefficient	Coefficient
Constant	-0.0282 (0.0219)	-0.2001** (0.0750)
A	0.0058 (0.0004)	0.0001 (0.0044)
E	-0.00003** (0.00002)	0.0009** (0.0004)
XR	0.0047** (0.0009)	0.0116** (0.0049)
INVR	0.0822** (0.02881)	0.0669** (0.0291)
C4	0.1184 (0.0781)	0.4366* (0.2331)
C42	-0.1255 (0.0840)	-0.4610** (0.2286)
σ		0.0947*** (0.0366)
Obs	261	541
F / CHI2	9.36	74.66
R2	0.2428	

A by-product of the above estimations are the sectoral fixed effects, which represent non observable specific factors for each sector that are not captured by the variables included. In general, no great differences are perceived in the sectoral fixed effects (maybe the degree of aggregation is much too high), yet they are statistically significant. Considering the above, it is worth mentioning the pulp and paper sector as the most dynamic one, followed by chemicals, textiles and cement. Sectors with a low relative dynamism are food, steel, wood and furniture and metalworking. However, once again the global range of variation never exceeds 20% (see Graph N° 1).

GRAPH N° 1
FIXED SECTORAL EFFECTS



Summing up, the results suggests that Chilean industrial plants derive their innovative dynamism from the flow of ideas coming mostly from “outside”, either through their insercion in world markets and the adaptation of the physical investments made previously in plant and equipment. However, that does not allow us to argue that the problems of appropriability are absent since the variables related with market structure show statistical significance. Actually, the results suggest that market structures which are much more concentrated than those now existing point to the private optimal in innovation. We have not been able to reject the structural heterogeneity of a sectoral nature from a statistical standpoint, though the coefficients obtained do not show great sectoral differences.

4. THE EXISTENCE OF DIFFERENT “TECHNOLOGICAL REGIMES” BY SIZE

It could well be that one of most relevant shortcomings in the estimates is to assume that the heterogeneity of behaviour is due to sectoral factors when it could really be due to factors of scale at the plants.

Some evidence of the existence of heterogeneity depending on the productive scale is reported by Acs and Audretchs.¹⁵ In fact, after analysing a sample of more than eight thousand innovations carried out in the United States in 1982 and classify them in terms of the productive companies, they conclude

¹⁵ Acs and Audretchs (1992), chap. 3.

that the sectoral heterogeneity interacts with the heterogeneity of scale, so that it is possible to identify sectors where the dynamics is dominated by the small companies (such as companies of electronic equipment, manufactures of precision instruments) and sectors where large companies clearly dominate (farm machinery, petrochemicals, food). While finally there is a group of sectors "balanced" in terms of size (office furniture and wood furniture, products with primary metals, etc.).

In any event, the above results do nothing but show the need for future theoretical developments as regards the way in which firms of varying sizes may have different innovative responses as an answer to different economic stimuli even in the same industries.

In what follows, we develop a theoretical model for a change of regime in order to examine the hypothesis on the existence of structural differences in terms of size. It is assumed that there exist two technological regimes depending on whether we are dealing with small or large companies, but that the scope of the change of the regime is unknown. The rationale applied is the following, in terms of the model below:

$$\begin{aligned}
 (1) \quad & et = \beta_0 + \beta_1 A + \beta_2 XR + \beta_3 INVR + \beta_4 E + \beta_5 C4 + \beta_6 C4^2 \\
 & \text{if } E < E(*) \\
 & et = \gamma_0 + \gamma_1 A + \gamma_2 XR + \gamma_3 INVR + \gamma_4 E + \gamma_5 C4 + \gamma_6 C4^2 \\
 & \text{if } E \geq E(*)
 \end{aligned}$$

The value of employment which maximises the combined likelihood of both models may be considered as $E(*)$. Once this value has been obtained, categorical variables are defined on the basis of the value obtained, which capture changes in the intercept of the model and the slopes. In order to do so, we redefined the parameters in the model considering that it may be written as:

$$(2) \quad et = f(E) + f(E)A + f(E)XR + f(E)INVR + f(E)E + f(E)C4 + f(E)C4^2$$

That is, both the intercepts as well as the slope are considered a function of the variable for employment. In this formulation, each coefficient will be β or γ depending on whether employment is lower than or higher than $E(*)$. If we introduce the following notation:

$$(3) \quad \gamma_i = \beta_i + \Delta\beta_i \quad \forall i = 1 \dots 6$$

Defining then $\delta = 1$ if $E > E(*)$ and 0 in another case, we can re-write the model as:

$$(4) \quad et = (\beta_0 + \Delta\beta_0\delta) + (\beta_1 + \Delta\beta_1\delta)A + (\beta_2 + \Delta\beta_2\delta)XR + (\beta_3 + \Delta\beta_3\delta)INVR + \\ + (\beta_4 + \Delta\beta_4\delta)E + (\beta_5 + \Delta\beta_5\delta)C4 + (\beta_6 + \Delta\beta_6\delta)C42$$

It should be borne in mind that a fundamental assumption of this model is that it restricts the variances of both regimes to be equal. This may involve a certain limitation, but we should also remember that it is a standard practice in this type of research. Furthermore, the previous model is estimated through *conditional* maximum likelihood in E^* . This does not invalidate the estimation model but the standard errors obtained will be erroneous, as they do not consider the fact that E^* is an additional parameter to be estimated. The bias of these standard errors will lead to underestimating the true standard errors. However, a suggestion to obtain errors which are closer to the true standard errors has been to develop their empirical distribution by bootstrapping

Accordingly, the steps to be followed in this estimation are the following :

- (1) Estimate the most probably size that separates both regimes
- (2) Estimate the model with categorical variables which discriminate between both regimes
- (3) Compute standard errors through bootstrapping
- (4) Obtain a "parsimonious" model"
- (5) Conduct likelihood ratio tests to validate the reduction.

For the first stage, we developed a program which estimates the model through maximum likelihood creating a categorical variable in a successive manner for each estimation and which then identifies the categorical variable which corresponds to the maximum value of the likelihood. As the model is sensitive to the "increment" which the categorical variable stands for, we repeated the exercise for increments from 1, 5 and 10 workers. In the first case 3500 regressions were estimated, in the second case 700 and in the third case 350 ; in which the maximum results was the same in all cases, and the break-even point obtained corresponds to a plant size of fifty workers.¹⁶

Taking this value as optimal, we estimated the ML \hat{E}^* model conditional to same, and the results are shown in Table N° 4. However, in order to obtain more suitable errors, we proceeded to compute the empirical distribution of each estimator obtained by using a number of 1000 replications of the sample and the estimations to do so. Then the confidence intervals for the significance tests were computed by the percentiles method which is not based on any assumption of theoretical distribution.

¹⁶ As shown in Graph N° 3 at the end of the paper.

TABLE N° 4
ML ESTIMATES WITH ROBUST VARIANCES
(conditional in Employment =50).
STANDARD ERRORS BY BOOTSTRAPPING

(**Significant at 5% and* significant at 10% according to Percentile Method)

Variable	Coefficient	Std.Err.	Empirical Std. Err.
Constant	-0.03989	0.03728	
A	-0.00060	0.00044	0.00041
A*di	0.00269**	0.00079	0.00201
XR	0.00326	0.00605	0.00864
XR*di	0.01308	0.02074	0.05346
INVR	0.06851*	0.01358	0.03879
INVR*di	-0.14065	0.11305	0.22821
C4	-0.00049	0.16990	0.17968
C4*di	1.05184**	0.38197	1.60284
C42	0.01103	0.18376	0.15638
C42*di	-1.29479**	0.47259	2.39370
E	4.59e-06	0.00003	0.00002
E*di	0.00149	0.00127	0.00278
di	-0.35811	0.07909	0.267721
σ	0.09317	0.00602	
Obs	541		
Ch2(14)	137.71		
Prob>Chi2	0.000		

The first estimation shows that the categorical variable which represents the change of regime is statistically significant, as is the variable for age when it interacts with the categorical variable. On the other hand, the variables representing the market structure are also significant when they interact with categorical variables. Finally, the variable for investment is statistically significant, without any interaction. Taking these results as a basis, we proceeded to estimate the model in its restricted form (Table N° 5).

Thus, the hypothesis of the existence of technological regimes is not rejected and it is possible to establish the existence of, at least, two models of accumulation of knowledge in the Chilean manufacturing sector. On the one hand, the one representative of small companies (less than 50 workers). Firms in this group tend to create knowledge primarily on the basis of adapting previous physical investments. It is a sector where the variables related to age (learning) and size do not seem to be relevant. Also, it is a segment of companies where variables related to market structure (which relates to appropriability in our interpretation) are not relevant. They are companies "dominated by the suppliers".¹⁷

¹⁷ See K.Pavitt (1985).

On the other hand, companies with more than 50 workers seem to belong in a set in which the variable related to investment continues to be relevant, but also the accumulated experience of the company plays a significant role. Also the conditions of appropriability seem relevant as in this segment the variable for concentration, both in levels as well as in the squared term, appear as statistically significant. These are plants where endogenous creation of knowledge is more important. Finally, the variable related to exports does not appear to be significant in any case at all.

TABLE N° 5
ML ESTIMATES WITH ROBUST VARIANCES
(conditional at Employment=50).STANDARD ERRORS BY BOOTSTRAPPING
(**Significant at 5% and * significant at 10% according to Percentile Method)

Variable	Coefficient	Std.Err.	Empirical Std. Err.
Constant	-0.05350	0.01378	
Age*di	0.00206*	0.00060	0.00175
INVR	0.06573*	0.01367	0.03799
C4*di	1.15763**	0.31772	1.63020
C42*di	-1.39499**	0.40874	2.55937
di	-0.33240**	0.06403	0.279891
s	0.09174	0.00604	
Obs	498		
Ch2(14)	131.82		
Prob>Chi2	0.00		

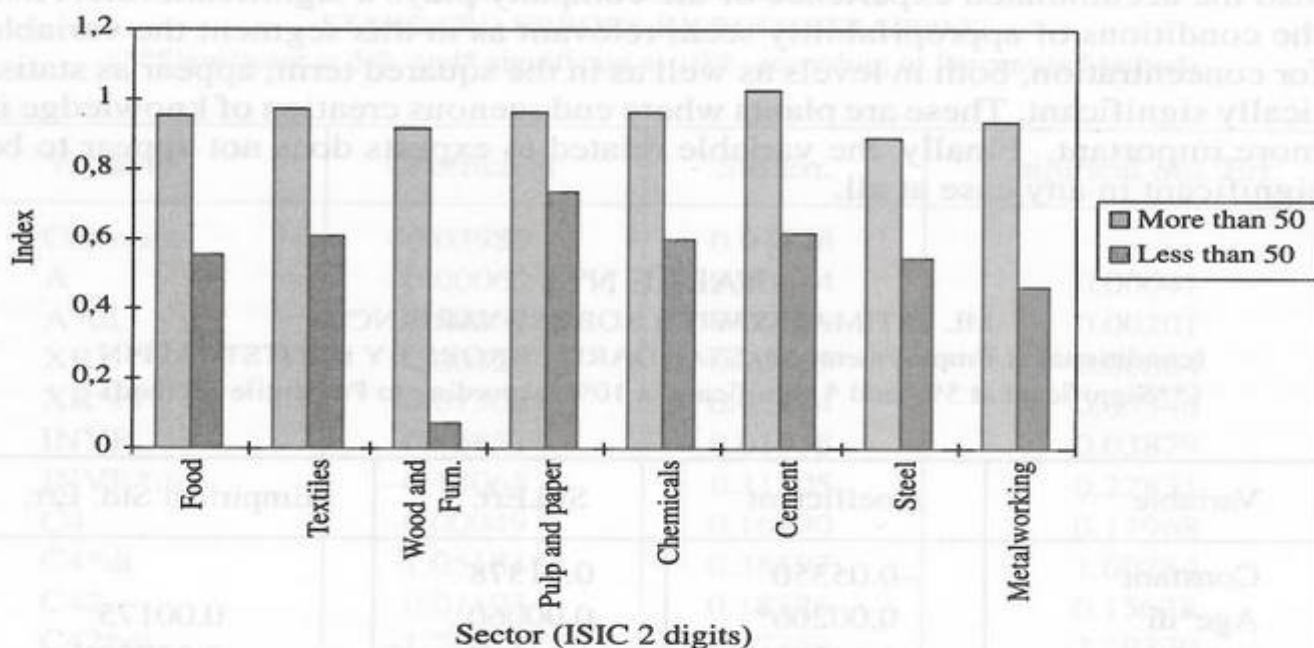
Likelihood ratio test of the reduction:

$$\chi^2_{(d_0-d_1)} = -2(L_1 - L_0) = 5.88 \quad (0.6604)$$

A by-product of this estimate are the interactive fixed effects between the categorical variable for size and the productive sector, these effects being statistically significant (see Graphs N° 2 and 3). A characteristic of these effects is the "dominance" in the R&D expenditure by companies with more than 50 workers in "all" productive sectors. That is, there is no evidence in our data base that in any industry small firms (SMEs) predominate, in terms of R&D expenditure.

The lag of the small company is not, however, the same across sectors, because the heterogeneity of behaviour is important. Thus, while the average gap is of slightly more than 40%, it goes down to 20% in the case of pulp and paper and goes up to 80% in the case of wood and furniture. There is some evidence that the heterogeneity is smaller in scale intensive plants which operate in natural resources and export oriented sectors. Maybe in that branches the relatively high efficient scale produce a reduction of the heterogeneity.

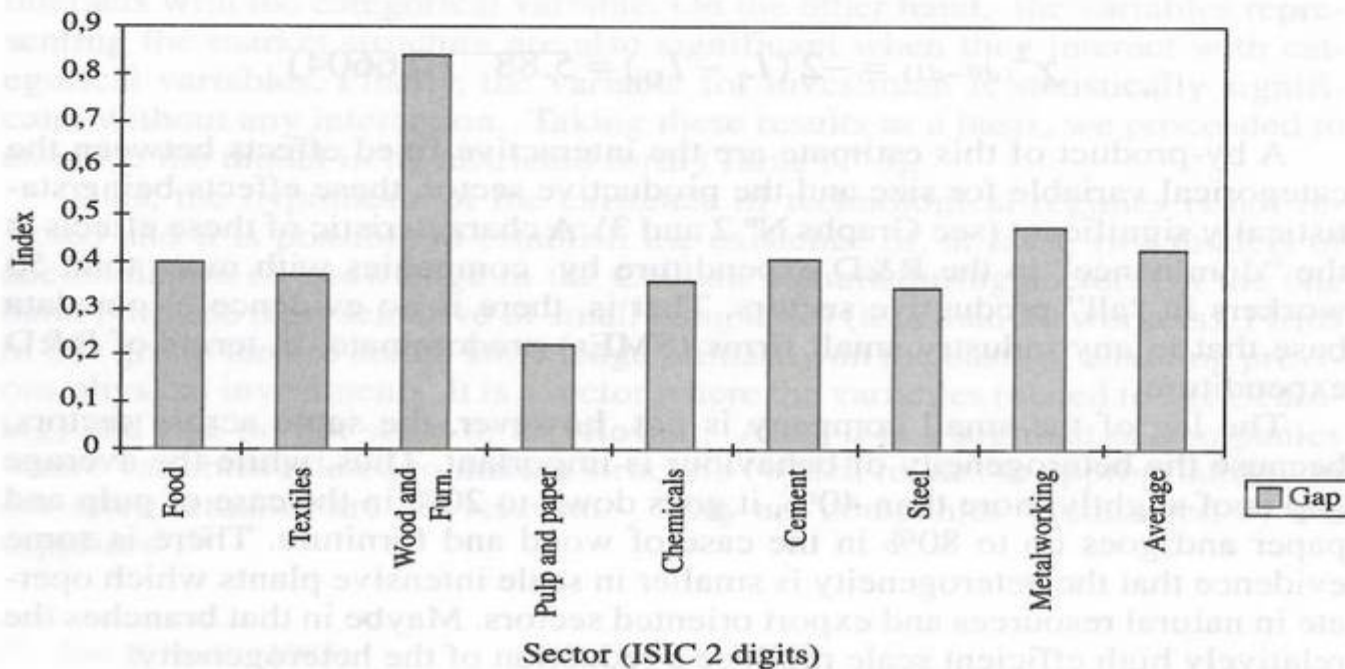
GRAPH Nº 2
INTERACTIVE EFFECTS SIZE-SECTOR



Likelihood ratio test of fixed effects of sector/size are zero :

$$\chi^2_{(d0-d1)} = -2 (L_1 - L_0) = 20.74 \quad (0.04)$$

GRAPH Nº 3
GAP IN R&D EXPENDITURE BETWEEN COMPANIES OF MORE THAN AND LESS THAN 50 EMPLOYEES



4. CONCLUSIONS

The paper started with a review of the empirical evidence available in relation to the determinants of the innovative efforts of firms operating in a market economy. Our revision of the literature allowed us to conclude that most studies show serious shortcomings in the econometric specification of the model and also estimation problems due to the use of unsuitable statistical tools. Among these, models using "non" random samples exhibit the most serious shortcoming. To this, we must add that, except for very few unusual exceptions, the analysis of this phenomenon in developing countries -where capital markets are imperfect and the technological lag vis a vis world's frontier is evident-practically does not exist.

On the basis of the above, we proceeded to specify an empirical model which should take into account those aspects which are more relevant to developing countries, in special the elements related with the particular nature of absorption, imitation and adaptation of foreign technology to local conditions. Concurrently, we incorporate the traditional scale and market structure effects.

The estimation was applied to a new data base, microeconomic in nature, generated from a random sample. The results of the survey revealed that more than 70% of Chilean industrial establishments do not spend resources in R&D activities; which introduces a strong censorship in the distribution of this variable. This needs to be taken into account when estimating statistical models in this field.

The results of the estimations suggest that there are at least two technological "regimes" in the Chilean manufacturing sector, with the stratification threshold close to 50 workers. In the case of firms with less than 50 workers, the accumulation of knowledge is typically adaptive in nature with non-existing capacity to absorb knowledge through exports. This is a stratum of firms that also shows lack of endogenous generation of knowledge by virtue of the fact that variables for appropriability are not important.

The other stratum corresponds to larger firms where the production of knowledge shows greater significance; in addition to be based on adaptation, also the variables related to endogenous learning seem to play an important role in the production of knowledge by the firm. The above is shown by the fact that for the firms in this group there exist "optimal" market structures (from a private standpoint) to innovate.

Although the role of technological opportunity seems to be larger for large firms, its incidence seems to be different across industries. Smaller gaps between large and small firms seem to prevail in the pulp and paper sector, while a larger gap is observed in wood and furniture.

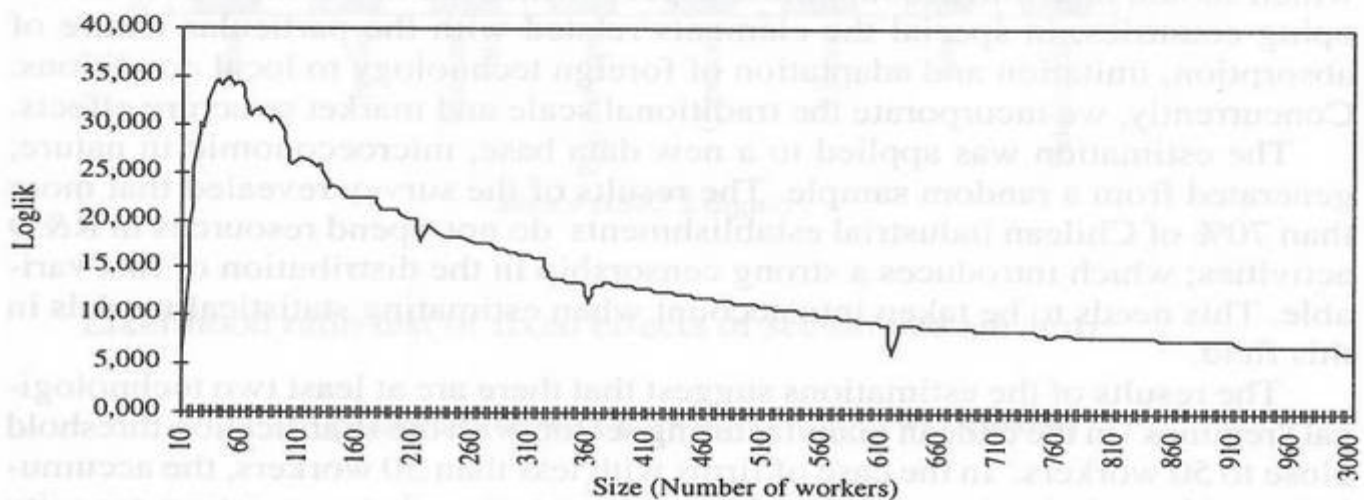
This is the first attempt at exploring technological behaviour among Chilean industrial firms. Further research seem to be needed to determine which is the socially optimum R&D expenditure, as well as the amount of subsidy and tax to be collected. Externalities do exist and it is an argument favouring intervention; but as yet the problem of how to handle it remains unresolved, as competition does bring about a duplication of efforts

It is also necessary to make further progress in terms of arriving at better indicators for both technological appropriability and opportunity so as to re-

duce the bias involved in the use of proxy variables.¹⁸ To the extent that research efforts in this field are carried further it will be possible also to have more and better information at our command so as to adequately address other problems, such as the possible endogenization of some regressors.

Last but not the least, it must be borne in mind that though this study aims only at analysing the innovation decisions through one input (expenditure in R&D), it is still necessary to determine whether these relationships hold out in time for the outputs (the innovations themselves) as they are the ones which ultimately are determinant of the improvements in productivity and welfare. Therefore, a time-series follow-up of these companies would enable us to establish the real "return" on R&D expenditure.

GRAPH N° 4
VALUES OF LIKELIHOOD LOGARITHM



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¹⁸ In any event, the Second Survey on Technological Innovation in the Manufacturing Sector is scheduled for 1998.

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APPENDIX

In this section we developed a specification test of the model estimated in the paper. One way to understand this may be based on the following fact: If the likelihood is appropriate, then the ratio of the maximum likelihood estimates from the Tobit, $\frac{\beta_T}{\hat{\sigma}_T}$, should be the same as the probit coefficients from the same data, treating nonzero values as 1 and 0 values as 0, $\frac{\beta_P}{\hat{\sigma}_P}$.

In the A1 and A2 we reproduced the coefficients reported in the Tables N° 4 and N° 5. In both of them the coefficients in the Tobit have been divided by $\hat{\sigma}_T$. We can conclude that there are not important differences in many parameters. We also reported a Hausman test to the null that the parameters are the same. In both estimations the null hypothesis was not rejected.

TABLE A1
ML PROBIT AND TOBIT ESTIMATES OF TABLE 4

Variable	Probit		Tobit		Differences
	Coeff	StdErr	Coeff	StdErr	
Edad	-0.0023	0.0062	0.0015	0.0047	-0.0037
Xva95	0.3482	0.1409	0.1231	0.0530	0.2251
Invva95	0.0366	0.1177	0.7100	0.3088	-0.6734
c4	5.5747	2.6975	4.6320	2.4736	0.9427
c42	-5.8067	2.4662	-4.8910	2.4254	-0.9157
Empleo	0.0019	0.0005	0.0011	0.0004	0.0008
32	0.6479	0.4896	0.4578	0.3567	0.1901
33	-0.3103	0.4524	-0.1472	0.3939	-0.1631
34	1.1987	0.5961	0.7645	0.4345	0.4342
35	0.7101	0.4167	0.5793	0.3747	0.1308
36	0.1400	0.5688	0.3460	0.4975	-0.2059
37	-0.8810	0.5856	-0.7769	0.5626	-0.1041
38	0.0333	0.4407	0.0962	0.3429	-0.0630
39	0.8930	0.7723	0.5805	0.5241	0.3125
Cons	-2.0933	0.4594	-2.1233	0.8027	0.0300
Hausman	14.25535				
Prob	0.50				

TABLE A2
ML PROBIT AND TOBIT ESTIMATES OF TABLE 5

	Probit		Tobit		
Variable	Coeff	StdErr	Coeff	StdErr	Diff
Edad	-0.0078	0.0064	-0.0066	0.0141	-0.0012
Edaddi	0.0228	0.0152	0.0295	0.0154	-0.0067
Xva95	0.1320	0.1634	0.0357	0.0375	0.0963
Xvadi	0.0952	0.2386	0.1429	0.1475	-0.0477
Invva95	0.0608	0.0907	0.7501	0.2971	-0.6893
Invdi	-0.1142	1.6834	-1.5399	1.1483	1.4257
C4	-1.1359	3.0096	-0.0054	1.7945	-1.1305
c4di	12.5770	3.4107	11.5155	6.2041	1.0615
c42	1.1115	2.6000	0.1208	1.5481	0.9907
c42di	-14.2898	6.0429	-14.1753	7.0253	-0.1144
Empleo	0.0000	0.0004	0.0001	0.0002	0.0000
Di	-4.9261	1.2221	-3.9206	1.4566	-1.0055
Empleodi	0.0347	0.0212	0.0163	0.0178	0.0184
32	0.5409	0.4962	0.3257	0.3094	0.2152
33	-0.7844	0.6028	-0.4767	0.4302	-0.3077
34	1.2655	0.7110	0.9271	0.5184	0.3384
35	0.2603	0.4820	0.2559	0.3248	0.0044
36	0.4322	0.5853	0.6618	0.4699	-0.2296
37	-0.5419	0.4815	-0.6173	0.4838	0.0755
38	-0.4673	0.5279	-0.3571	0.3697	-0.1102
39	0.9985	1.0373	0.8204	0.6921	0.1781
Cons	0.2321	0.7924	-0.4368	0.4813	0.6689
Hausman	25.869				
Prob	0.25				