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INNOVATION, EXPORTS AND PRODUCTIVITY: LEARNING AND SELF-SELECTION IN CHILE

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Innovation, Exports and Productivity: Learning and Self-selection in Chile[1]

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Abstract

Both exports and innovation (in particular, research and development) are key factors for the growth of firms and economies, but there has been little study of their combined impact on them, especially in developing countries. This article uses plant-level data from Chile to examine the relationship between productivity, R&D expenditure, and exports. We find that firms that invest in R&D are considerably more likely to export, but the reverse is not true. Even though exporting does not stimulate investment in R&D, both exports and R&D have a joint effect on improving productivity. These results allow us to recover the private return to "learning by exporting" across different sectors.

Keywords: Productivity, Exports, Innovation, R&D.
JEL: O30, F10, O33.

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1. Introduction

This article evaluates the relationship between research and development (R&D), exports and productivity in Chile. During the past fifteen years, the relationship between productivity of firms and their participation in foreign markets has been extensively investigated. Since the seminal work of Bernard and Jensen (1995), most studies have consistently shown that exporters are larger, more productive, and more capital-intensive; they accumulate more human capital, pay higher wages and invest more in technology and research and development (R&D).[5] However, the previous literature has only recently highlighted the importance of innovation and related activities in this virtuous relationship between productivity and export performance. This article contributes evidence of this relationship for the case of a developing country. The study also addresses most of the econometric problems in this type of analysis, such as simultaneity, endogeneity and the discrete nature of some variables.

We find that firms that invest in R&D are considerably more likely to export, but the reverse is not true. However, we observe that R&D and exports have a joint effect on improving productivity in Chilean plants. In other words, although exporting may not stimulate formal investment in R&D, there is still evidence of "learning by exporting." Finally, by addressing endogeneity problems, we reach conclusions contrary to the prevailing view that the same firms self-select for both R&D and export activities. However, we believe that our set of findings is consistent with previous evidence that finds "conscious self-selection," which in our case is operationalized by firms' investment in R&D aimed at increasing productivity in order to be able to export.

We focus on analyzing how firms improve productivity by means of R&D and/or through foreign markets participation. For this purpose, we rely on the rich information available in the Chilean Innovation and Industrial Surveys that cover the period 1997-2004. We address the relationship between export and R&D, controlling for its endogeneity, based on detailed information on exports, expenditure on R&D, and estimates of total factor productivity and added value per worker at a plant level. We are particularly interested in identifying processes of *innovating by exporting* (exports as a determinant of R&D expenditure) and/or *exporting by*

[5] See, for example, Bernard and Jensen ((1998), (1999) and (2004)), Richardson and Rindhal (1995), Bernard and Wagner (1997), Bernard et al. (1997), Clerides et al. (1998), Álvarez and López (2005), Van Biesebroeck (2004), De Loecker (2007), Harris and Li (2009), Pattnayak and Thangavelu (2006), and Diao, Rattso and Stokke (2006), among others.

innovating (R&D as a determinant of exports), together with the well-documented hypothesis of *self-selection* in exporting (high productivity generates exports). We conclude our analysis by addressing the relationship between R&D and productivity and the “learning by exporting” hypothesis as a source of a plant’s productivity growth.

By controlling for the inherent endogeneity in these activities, we can properly identify the relationships between exports, productivity and innovation, and, in particular, R&D as a specific type of innovative activity. This can provide information of great importance for better design of public policy instruments that aim to promote exports and innovation in developing countries, because the causal direction between these variables is not neutral. If firms that invest more in R&D then become exporters, and R&D activities generate improvements in productivity, a subsidy policy addressed to current exporters would focus on the wrong group of firms. However, if firms increase productivity and innovation by exporting, then programs that generate the necessary incentives for firms to export, or reduce barriers to the access of foreign markets, would improve aggregate productivity.

In order to capture these effects and control for endogeneity, we model R&D expenditure, exports and productivity changes at a plant level through a multi-equation system, which is estimated by Asymptotic Least Squares (ALS). This methodology, new in this context, allow us to estimate the system simultaneously, taking into account the discrete nature of some variables and the simultaneity of effects, with statistical properties –as we review later- that are superior to other methods such as GMM or 2SLS.

Our results do not support the innovating by exporting hypothesis, at least with respect to R&D investment, but we do find support for the exporting by innovating hypothesis. After controlling for the inherent endogeneity in this relationship, we find that firms that invest more in R&D tend to become exporters. Furthermore, contrary to an important part of the literature on exports and productivity, we do not find evidence for the self-selection in exports hypothesis, or for the R&D self-selection hypothesis (higher productivity generates R&D investments).

Regarding the productivity equation, after controlling for endogeneity between expenditure on R&D and exports, we conclude that both variables are important determinants of productivity. As well as evidence that R&D is an important source of productivity improvements, we find there is learning by exporting even without formal R&D investment.

Our contribution is threefold. First, we review an important part of the literature on exports, R&D and productivity highlighting its weaknesses to contextualize the contribution of this study. Second, we address the endogeneity and selection problem by estimating the joint relationship between R&D, exports and productivity using ALS, a new methodology in this context. Finally, we provide estimates of the private returns to learning by exporting.

The paper is structured as follows. The following section summarizes the empirical literature that examines the links between R&D, exports and productivity. Section 3 presents the data. Section 4 presents the model to be estimated. The estimation results are presented in Section 5. Then we proceed to discuss our results and estimate the private returns to R&D and export learning in Section 6. Finally, Section 7 concludes.

2. Literature Review

2.1 Analysis of the Causality Hypothesis

As previously suggested by the literature, there is a close link between productivity and trade and other variables that affect both, such as R&D and innovation. Until recently, these relationships had been studied mostly as bilateral relations, for example, R&D-productivity, exports-productivity or R&D-exports. Moreover, only some studies have recognized the endogeneity in these relationships, and hence implemented appropriated econometric techniques. Few studies have addressed the relationships among these three variables simultaneously. A major and successful effort was developed just recently by Aw et al. (2011), which we review below.

In the next subsections, we summarize the findings of the literature that has dealt with the relationship between exports and productivity, and the relationship between exports and innovation. We omit the discussion between R&D and productivity, as there has been a very long series of studies whose results are widely known and accepted.

2.1.1 Self-selection: High Productivity as Requisite to Export

The self- selection hypothesis comes from the idea that, to start exporting, firms must incur fixed and sunk costs. They are generally market research costs, marketing, training, permits and licenses. Other costs faced, which are not always so explicit, are the increase in competition, adaptation of products to foreign consumers' tastes, or the legal regulations of the destination country. For this reason, "bigger" or more "efficient" companies can afford or successfully bear these entry costs. Therefore, companies are self-selected to participate in global markets.

From an empirical point of view, Bernard and Jensen (1995, 1999), pioneering the work with U.S. data, find evidence that firms who become exporters are more productive prior to entry.

Today, there is considerable consensus on the existence of self-selection of the most efficient firms into international markets. The evidence is overwhelmingly in favour. It has been found in countries such as Canada, Colombia, Chile, the US, the UK, Denmark, Taiwan, and others, with different methodologies and samples. The most common empirical strategy used in many of those studies was to estimate the “export premium” along different firms’ performance dimensions and to estimate the probability of exporting conditional on productivity and other firm characteristics.

Worldwide evidence can be found in Bernard and Jensen (1995), (1998), (1999) and (2004), Richardson and Rindhal (1995) for the US; Bernard and Wagner (1997) and Bernard et al. (1997) for Germany; Clerides et al. (1998) for México, Marruecos and Colombia and Álvarez y López (2005) for Chile; Van Biesebroeck (2004) for sub-Saharan Africa; De Loecker (2007) for Slovenia; Harris and Li (2009) and Greenaway and Kneller (2004) for the UK; Pattnayak and Thangavelu (2006) for India.

From a theoretical point of view, until the beginning of the last decade, traditional models of trade were not able to explain the self-selection of exporters. In a seminal work, Melitz (2003) develops the first of the dynamic general equilibrium models with exogenous productivity for the firm consistent with the evidence of self-selection. His work has spurred a long list of studies that have taken his model as the cornerstone from which to study other dimensions of firms’ participation in foreign markets.

2.1.2. Learning by Exporting: Exports increase Productivity

This hypothesis is probably the one that comes to mind when we mention the relationship between exports and productivity. However, in comparison to the alternative hypothesis, it has less supporting evidence. According to Greenaway and Kneller (2007), the label of "learning by exporting" contains at least three channels: 1) The interaction with foreign competitors and customers provides information on products and processes, thereby reducing costs and improving quality; 2) Exports allow scaling up production because of access to larger markets; 3) Increased competition in foreign markets may force firms to be more efficient and increase their investments in innovation. These three factors are discussed in most of the literature of endogenous growth and trade.[6]

The first pieces of evidence in this regard were contributed by Clerides et al. (1998) and Bernard and Jensen (1999), who do not find robust evidence that productivity increases faster after entrance into exporting. Since then, different countries, with a variety of methodologies, have been studied. Nevertheless, the most used methodology has been propensity score matching, whereby for each exporter there is found a non-exporter “twin” to whom productivity after entrance into exporting is compared. Wagner (2002), with data from Germany, pioneered this approach, finding that labor productivity for newcomers is higher than for the "twin" non-newcomers, but the result is not statistically significant. Girma and coauthors follow this approach for firms that enter or exit into exporting. Regarding entering into exporting, Girma et al. (2004), with UK data, find significant effects of *learning by exporting*. De Loecker (2007) also uses matching techniques with a sample of data for Slovenia. He finds positive effects on productivity of newcomers after beginning to export, which increase over time. Regarding evidence from developing countries, Clerides et al. (1998) do not find learning effects in Mexico, Morocco or Colombia. On the other hand, Alvarez and Lopez (2005) find evidence of *learning by exporting* in the case of Chilean firms, and Fernandez and Isgut (2005) find the same evidence for Colombian firms.

For a thorough analysis and summary of the evidence on the relationship between exports and productivity, see also Wagner (2007).

2.1.3 Exporting by Innovating: R&D as Determinant of Exports

The study of the relationship between innovation and exports dates back to the early nineties. One of the first articles that studied the relationship between exports and R&D is Ito and Pucik (1993). They find positive effects of the level of R&D on the level and share of exports for the case of Japanese firms. Lefebvre et al. (1998), with data for small manufacturing firms in Canada, find that the efforts in R&D, either in basic research or improved products and cooperation with competitors, positively differentiate exporters from non-exporters.

More recently, there have been two main approaches to this question. One is to estimate an IV export probability model; the second is to implement matching estimators. The use of IV and matching estimators addresses the possibility that the export decision could affect R&D

[6] Rivera and Romer (1990), Grossman and Helpman (1990), (1991) and (1994), Aghion and Howitt (1992), Aghion and Howitt (1997, chapter. 11), Ericson and Pakes (1995), Klette and Griliches (2000), Atkeson and Berstein (2007) among others.

investments prior to export. Cassiman, Golovko and Martinez-Ros (2010), using probits and instrumental variables, find that product innovation increases the probability of exporting. Caldera (2009) finds similar results using similar methodology. Van Beveren et al. (2010), using IV estimations, find that firms self-select into innovation before exporting. Becker and Egger (2013) and Damijan et al. (2008) tackle endogeneity using matching. Damijan et al. (2008) do not find any impact of innovation on export propensity. Becker et al. (2007), on the other hand, find that product innovation increases the propensity to export.

Aw et al. (2011) take a sample for electronic companies in Taiwan and estimate a structural model, finding that R&D does not affect the probability of exporting.

In conclusion, the empirical evidence shows that, in general, investment in R&D affects the export behavior of firms, generating a greater likelihood of exporting or a greater export share in the output of a firm.

Other articles dealing with this hypothesis both for innovation in general and for investment in R&D, and getting results in the same direction, are: Hirsch and Bijaouni (1985), Sriram, Neelankavil and Moore (1989), Brower and Kleinknecht (1993), Kumar and Siddharthan (1994) and Sterlacchini (1999).

From a theoretical point of view, until recently, traditional models took as given the levels of productivity previous to exports. Yeaple (2005) and Constantini and Melitz (2007) allow investments from firms previous to exporting, which is a view consistent with the findings of this section.

2.1.4 Innovating by Exporting

The impact of export orientation on investments in R&D has been less treated by the empirical literature. Some recent empirical studies on this issue are those of Salomon and Shaver (2005), Girma et al. (2008), Damijan et al. (2008) and Aw et al. (2011).

Salomon and Shaver (2005) test the presence of *innovating by exporting* for firms in Spain by means of non-linear GMM estimations, finding that exporting is positively related to subsequent increases in innovation. Girma et al. (2008), using a bivariate probit, find positive evidence of exporter status on the decision to invest in R&D for Irish firms. Damijan et al. (2008), using matching techniques to control for endogeneity, find that past exporting experience increases innovation. On the other hand, Aw et al. (2011), in their structural model, find that export experience and R&D are an important source of productivity growth for the electronics industry but that past exporting experience is not important for R&D.

2.2 Literature Review Epilogue

With the exception of the work of Aw et al. (2011) there have been few attempts to deal with simultaneity and endogeneity between export decisions, innovation and productivity. An important attempt was developed by Damijan et al. (2008); however, they do not estimate a simultaneous productivity equation in their model. Thus, the work we present below helps answer questions that have been left unanswered in the literature. Indeed, in our model we account for simultaneous export self-selection, learning by exporting, innovating by exporting and exporting by innovating, and the traditional impact of R&D on productivity. Moreover, we do this with data from a developing country with a sample that includes an important number of small and medium enterprises (SME's).

3. Data

We use several rounds of the National Innovation Survey and the National Industrial Survey of Chile, covering the years 1997-2004. The industrial survey is taken yearly but the innovation survey is taken each two years, but collects R&D data for the years in between two surveys. Moreover, while the industrial survey has census characteristics for firms with 10 or more workers from the manufacturing sector, the innovation survey corresponds to a random sub sample of the corresponding yearly census, unfortunately this sample does not have panel characteristics and changes each two years. Moreover, all firms that represent more than 2% of manufacturing added value enter compulsory in the innovation survey.

Table 1 shows the main statistics of our database. R&D investment increases from 20 thousand pesos to 82 thousand pesos between the years 1997 and 2004 (all figures in constant year 2000 pesos). That's between 40 and 164 dollars, approximately, per plant in the whole sample. Taking the average of those firms that actually invest in R&D, this increases from 48 to 139 thousand pesos, i.e., between 96 and 278 dollars, approximately.

The share of plants that carry out R&D increases from 42% to 59% between 1997 and 2004. The size of the plants also increases from 295 employees to 444 employees. Exports also increase from 10 million to 84 million pesos (between 20 thousand and 168 thousand dollars). Investment in machinery increases from 3 million (six thousand dollars) to 10 million (20 thousand dollars). By the same token the share of R&D funded with public resources increased from 5% to 13%.

Table 2 shows a preliminary exercise in which we compute the export premiums in small, medium and large firms in our sample. We investigate the percentage points over non- exporters that characterize the exporter firms along several dimensions–employment, R&D, added capital, value added, TFP, skilled labor share and average wage. We find that along all dimension exporters show a premium. That is, exporters are larger firms, invest more in R&D, add more capital, have greater value added per worker, show higher productivity, have a larger share of skilled workers and pay higher wages.

Table 1. Summary Statistics.

(constant year 2000, pesos)

Variable	1997	1998	2000	2001	2003	2004
R&D investment (total sample, thousand pesos)	20	24	78	48	42	82
R&D investment (firms with non zero R&D, thousand pesos)	48	54	150	108	80	139
Probability that a plant make R&D investment	42	44	52	44	53	59
Employment (units)	295	299	446	292	264	444
Qualified employment (average percentage)	20	18	33	24	28	32
Exports (thousand pesos)**	10	8	25	22	27	84
Machinery investment (thousand pesos)**	3	2	8	4	3	10
Patents ** (firms with non zero R&D, pesos)	155	217	171	169	351	673
Public R&D support (percentage over total R&D investment)	5	6	8	11	12	13

Table 2: Export premiums.

(percentage difference between exporters and non-exporters companies; main variables)

Variable	(1) Small	(1) Medium (percentage)	(1) Big	(1) All firms	(2) Small	(2) Medium (percentage)	(2) Big	(2) All firms
Total Employment	21.2	10.4	18.8	79.9	-	-	-	-
R&D investment	201.8	68.8	53.5	76.3	219.8	70.8	54.6	80.8
Added Capital/total workers	72.6	92.9	38.1	75.3	63.6	85.5	34.6	56.1
Added value/total workers	84.7	35.3	21.9	39.5	78.7	30.5	21.4	33.7
TFP	76.2	17.5	20.3	47.6	65.6	11.0	15.7	23.2
Skill labor (%)	20.2	22.0	15.9	7.2	26.3	23.9	14.8	14.7
Average wage	49.1	38.3	6.8	33.6	45.8	36.1	7.0	24.7

(*) Estimator of the export dummy in a OLS estimation, with the specific variable as dependent variable.

(1)Equation: $\text{Variable} = b_0 \text{Export} + \text{SectorDumm}$

(2) Equation: $\text{Variable} = b_0 \text{Export} + b_1 \textit{Employment} + \text{SectorDumm}$

4. **The Empirical Model**

Both endogenous growth models and the "new" literature of international trade have generated hypotheses about the relationship between productivity, R&D performance in our case, and export status. As discussed in the literature, there are both theoretical and empirical models that support the bicausal relationship between these variables. There is evidence of a positive impact on a firm's productivity stemming from participation in international markets, and, on the other hand, the belief that more productive firms self-select into the international market. We need a model that captures the causal relationships in both directions while adjusting for the endogeneity problems of the relationship. Additionally, we are interested in the causal relationship in both directions between R&D and exports, which complicates things further. Indeed, export status may have effects on investment in R&D and also directly on productivity. Because there is a link between exports and R&D, the export variable should be included when analyzing the relationship between R&D and productivity.

The proposed model aims to describe three processes and obtain the structural relationships of its variables. The first is the decision to invest in R&D and the amount of investment. The second process is the decision of a firm to export and the amount exported. The third reflects the determinants of the firm's productivity.

4.1 Research Equations

Most of the literature on the behavior of R&D is based on a generalized Tobit model. This consists of two equations that in turn reflect two separate decisions. One is related to the decision to invest in R&D and the other to the amount of resources devoted to this activity.

It is assumed that there is a latent dependent variable drd_i^*, for firm i, given by the following equation:

(1) $drd_i^* = x_{i0}b_0 + x_i^*\alpha_G + u_{i0}$

where x_{i0} is a set of explanatory variables, b_0 is the associated parameter and u_{i0} is an error term. drd_i^* represents some decision criterion as the present value (PV) of benefits of the investment project. That is, we will observe investment in R&D if the value of the PV, namely drd_i^*, is positive or greater than an arbitrary threshold.

Furthermore, to be consistent with the process above, we establish that the decision to innovate depends on the export status. In particular, we say that it depends on the export intensity, reflected by x_i^*. Therefore, α_G is the correlation coefficient between exports and the probability to invest in R&D.

Consequently, we assume that the intensity of R&D expenditure is determined by the second equation:

(2) $rd_i^* = x_{i1}b_1 + u_{i1}$

where $rd_i^* = rd_i$ is expenditure on R&D per worker of firm i when it carries out innovation activities, that is, when drd_i^* is greater than the minimum defined threshold. Here rd_i^* and rd_i are expressed in logarithms, x_{i1} is the vector of explanatory variables, b_1 is the vector of coefficients and u_{i1} is an error term that captures stochastic, omitted or unobservable variables.

Given that we observe rd_i^* when drd_i^* is greater than zero, we must specify the joint distribution to estimate the model. In order to use the generalized Tobit estimation methodology (Tobit type II), we assume that equations (1) and (2) are normally distributed, which can be tested later.

For this specification, we use the logarithm of expenditure on R&D in Chilean year 2000 constant pesos per worker. The explanatory variables considered are size variables, market share, features of innovation, export status and lag productivity. To include these variables, we rely primarily on the literature of R&D and applications in Chile. More precisely, for each equation the set of variables is:

$$x_{i0} = (\mathrm{l_i}, \mathrm{Imit}, \mathrm{Coop}, \mathrm{A_{i,-1}}, \mathrm{ma}, \mathrm{quality}, \mathrm{msh}, \mathrm{learn}, \mathrm{FDI_i}, \mathrm{pub_i}, \mathrm{Med}, \mathrm{Gre}, \mathrm{S_i^1}, ..., \mathrm{S_i^7})$$

$$x_{i1} = (\mathrm{l_i}, \mathrm{Imit}, \mathrm{Coop}, \mathrm{A_{i,-1}}, \mathrm{ma}, \mathrm{quality}, \mathrm{msh}, \mathrm{learn}, FDI_i, \mathrm{pub_i}, \mathrm{Med}, \mathrm{Gre}, \mathrm{S_i^1}, ..., \mathrm{S_i^7})$$

where l_i is employment; *Imit* is a *dummy* if imitation is considered an obstacle to innovation; *Coop* is a dummy which take the value of 1 if the innovation ideas come from cooperation with other industry actors; $\mathrm{A_{i,-1}}$ is the lagged total factor productivity of the firm; *ma* and *quality* are dummies that reflect whether innovations are oriented to the environment and the product quality, respectively; *Msh* is the market share of the firm, obtained by its share of sales, out of the total sales of the industry; *learn* is a dummy which is equal to 1 if the company recognizes that innovation is generated from an ongoing internal process; FDI_i is a dummy variable for the presence of foreign capital; *pub* is a dummy which take the value of 1 if the company receive grants from the public sector. We include a set of 7 sectoral *dummies*, which reflect the productive sectors: Machinery, Textiles, Chemicals, Wood, Paper, Metal and Non Metallic. The control is the *dummy* “Other sectors.” Finally, we add three size dummies, Med or Gra*,* if the firm are medium or large, respectively, leaving the small companies as a control.

In order to reflect the export intensity, we used the logarithm of the value of export sales per worker only in equation (1).

4.2 Export Equations

The export equation has a similar structure to the research equation. It is assumed that the dynamics of the exporting firm can also be represented by a generalized Tobit process. That is, we separate the decision to export from the size of exports, as explained above.

We therefore have two equations: The first comprises a latent variable reflecting the decision to export. It can be understood, as is the case for innovation, as the PV of the decision to export or participate in international markets:

(3) $dx_i^* = x_{i2}b_2 + rd_i^*\alpha_E + u_{i2}$

where x_{i2} is a vector of variables explaining the decision to participate and is u_{i2} an error term. As the decision to invest in R&D is influenced by the size of exports, the reverse also occurs. Here is where we complete the inclusion of endogeneity, or bicausality of the relationship. That is why we add the term rd_i^*, which is the logarithm of investment in R&D per worker, where α_E reflects the relationship between R&D and the probability of exporting.

On the other hand, we have an equation for the size of the exports, which is active for those who have decided to export, that is, when x_i^* is above the threshold that makes it profitable to participate:

(4) $x_i^* = x_{i3}b_3 + u_{i3}$

where $x_i^* = x_i$ is the logarithm of sales from exports of the company i which decides to export, x_{i3} is a set of explanatory variables and u_{i3} is an error term.

We also assume that the joint distribution of both equations is normal, to represent the process as a Tobit Type II.

In the model setup, we use as explanatory variables those which define the company, some related to innovation and others that reflect market conditions. This is because there are no variables that describe the destination of exports, institutions or facilities to undertake an international business, among others. In any case, we include a set of explanatory variables, such as determinants of exports, excluding investment in R&D, in the following variables:

$$x_{i2} = x_{i3}(\mathrm{l_i}, \mathrm{Coop}, \mathrm{pub}, \mathrm{quality}, FDI_i, \mathrm{Lic_i}, \mathrm{Med}, \mathrm{Gra}, \mathrm{Inv_{i,-1}}, \mathrm{Skill}, \mathrm{A_{i,-1}}, \mathrm{S_i^1}, ..., \mathrm{S_i^7})$$

Most of the variables were described above. We also add Skill, which is the percentage of qualified workers over the total workers, and $\mathrm{Lic_i}$, which reflects the number of licenses that the firm has.

4.3 Productivity Equation

The last equation of the system corresponds to productivity. From here, we analyze the impact of investment on R&D and export intensity on productivity. For this, we regress productivity on both variables and on a control group (x_{i4}), using OLS.

Therefore:

(5) $\mathrm{A}_i = x_{i4}b_4 + x_i^*\alpha_E + rd_i^*\alpha_I + u_{i4}$

where pi is a productivity index and the vector of factors other than R&D and exports is as follows:

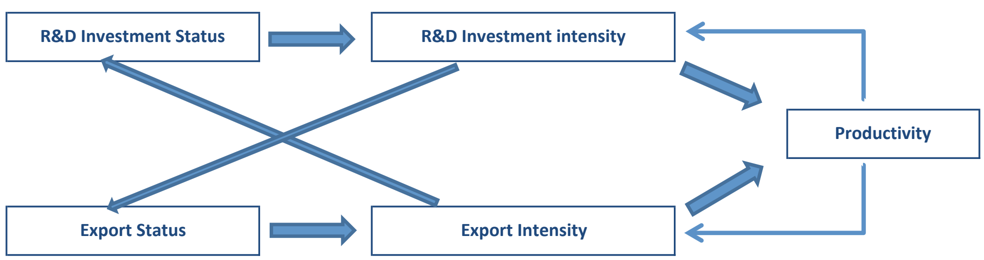
$$x_{i4} = (\mathrm{l_i}, \mathrm{msh}, \mathrm{pub}, \mathrm{A_{i,-1}}, FDI_i, \mathrm{Lic_i}, \mathrm{Inv}, \mathrm{Med}, \mathrm{Gra}, \mathrm{Inv}, \mathrm{Skill}, \mathrm{S_i^1}, \ldots, \mathrm{S_i^7})$$

Letter b_4 in (5) is the vector of coefficients of this variable, while α_E is the elasticity of productivity with respect to the quantity exported, represented by x_i^*, and α_I is the elasticity with respect to investment in R&D, denoted by rd_i^*.

Following the literature, to calculate productivity, we use the methodology described by Levinson and Petrin (2002). They calculate productivity by controlling for unobservables. We therefore assume a Cobb-Douglas production function, with capital and labor, skilled and unskilled, obtaining productivity as a residual.[7] Additionally, and as a robustness check, we use the added value per worker as proxy of productivity in a second set of estimations.[8]

Estimation of the Complete Model

Figure 1: Estimation Model



As described at the beginning of the section, the five equations form a system where exports and investment in R&D interact, and both determine the productivity of the firm (*see Figure 1*):

Decision and expenditure on R&D

(1) $drd_i^* = x_{i0}b_0 + x_i^*\alpha_G + u_{i0}$ (2) $rd_i^* = x_{i1}b_1 + u_{i1}$

Decision and size of Exports

(3) $dx_i^* = x_{i2}b_2 + rd_i^*\alpha_E + u_{i2}$ (4) $x_i^* = x_{i3}b_3 + u_{i3}$

Finally, the productivity equation

[7] See Appendix A for details on the estimation and its results.
[8] We attempted to improve our TFP estimations by using De Loecker (2011) and Ackerbertg et al. (2006) methodologies, but the authors were not available to provide the codes to run these estimations.

(5) $A_i = x_{i4}b_4 + x_i^*\alpha_X + rd_i^*\alpha_I + u_{i4}$.

Considering the characteristics of our set of equations and sample size the most efficient way to estimate this system is by Asymptotic Least Squares (ALS). As suggested by Crepon et al. (1998), Maximum Likelihood would be impractical due to the non-closed form of the joint distribution, while ALS can be easily generalized to complex systems - which could include limited dependent variables as in our case- in a tractable manner.[9] Moreover, maximum likelihood approached by numerical integration is likely to fail considering the large number of integrals and the large size of our sample. For the case of large samples this estimator is relatively more efficient and its computational costs lower compared with alternative estimators such as the GMM or 2SLS (Lee, 1981). Finally, this estimator imposes restrictions between the equations that, together with the nonlinearity functional form, help to identify exogenous variations.[10]

This system, similar to Indirect Least Squares, consists of estimating each equation individually in a way that best fits the data. In our case, that is by Generalized Tobit for the first two systems and equation (5) by OLS, without neglecting the endogeneity relationship of the equations.[11]

In fact, we estimate different specifications in their reduced forms, that is, without endogenous variables, and then we estimate the parameters of the structural system by GLS (Generalized Least Squares), minimizing the distance between the first, so-called "auxiliary," and the seconds. The key step is to obtain estimates of the variance-covariance matrix necessary for the estimation of the structural parameters, which corrects for the relationships between variables imposed in our specification.

5. **Estimation Results**

In this section, we present the results of our estimates and analyze the relationship between exporting behavior and R&D investment and the relationship of both to productivity. To present the results of the estimation by ALS, which controls for endogeneity, we must keep in mind that the equations of interest are those of selection of export and investment in R&D and productivity.

5.1 R&D, Exports and Productivity

[9] See Gourieroux and Monfort (1996) and Gourieroux, Monfort and Trognon (1984)
[10] Other applications of ALS in the context of innovation and productivity can be found in Galia and Legros (2012) and Benavente (2006).
[11] The results of this first stage estimations are available from the authors upon request.

In order to analyze parameter sensibility for our system of equations between R&D, exports and productivity, we estimate four specifications that we replicate and present in Table 3, 4, 5 and 6. Tables 3 and 4 show the ALS estimations for two measures of productivity: TFP estimated by the Levhinson and Petrin technique and the most traditional added value per worker. Tables 5 and 6 use these measures but, as a second robustness check, the equations are estimated by TSLS. Estimation (1) corresponds to a parsimonious model with few controls and a complete set of dummies. In (1) we test the relationship between exports and R&D and their impact on productivity as way to test a raw set of correlations. Estimations (2) and (3) include a larger set of control variables, which are based on the literature on R&D, exports and productivity. Additionally, equations (2), (3) and (4) differ from equation (1) in the inclusion of lagged productivity as a regressor. In other words, we allow productivity to be endogenous to investment in R&D and exports. Moreover, in equation (3) we add to this possibility the inclusion of lagged productivity in the productivity equation. Finally, equation (4) also add time dummies to equation (3). Thus, for the case of TFP as productivity measure and from equations (3) and (4) we will be able to recover export returns, similarly to the work of Griliches (1998) and Bravo-Ortega and Garcia (2011) for R&D returns.

In tables 3, 4, 5 and 6 we report coefficients from R&D per worker, export per worker and productivity included in the export and R&D tobits and the productivity equation. For the sake of brevity of exposition and given space constraints, we omit the coefficients of the control variables; however we do report whether they are significant at 10 percent, by filling the table cell with an S, or not significant with NS. Thus, we first discuss the impact of the variables of interest and then we present a summarized and general discussion of the control variables.

R&D Status and R&D Level

In relation to export intensity, included in estimations (1)-(4), the results show that in general exporting effort decreases the probability that a firm invests in R&D. This result is statistically significant for the ALS estimations of Table 4 (added value per worker set) and for both sets of estimations of Tables 5 and 6, which are estimated by TSLS. Thus, results suggest that firms more involved in trade efforts tend to set aside R&D efforts, rejecting an *innovating by exporting* process for the Chilean firms.

Once we control for those firms investing in R&D, we can discuss the determinants of the amount of resources invested in these activities. Results presented in Table 3-6 clearly show, that once a firm has decided to invest, those firms with better productivity invest a larger amount of resources in research activities. This result is significant for both productivity variables and the two estimation techniques. It is interesting to note that, despite the fact that TFP is not related to the probability of investing in R&D, productivity does matter as to the amount of resources involved for the subsample of R&D performers.

Export Status and Level of Exports

We now move to the export dimension. In tables 3-6, when we look at the probability that some of a firm's production is sold in foreign markets, we find the first interesting result concerned with the impact of lagged TFP. In our ALS estimations of Tables 3 and 4, we find that firms with previous poor performance in TFP have a greater probability of exporting once other effects are controlled. In our TSLS, although we recover the same coefficients' signs when controlling by TFP, we do not obtain statistical significance for this variable.

Regarding the impact of R&D on export status, we find that, in our ALS estimations of Tables 3 and 4, this increases the probability of exporting. This is an interesting finding consistent with the conscious self-selection hypothesis, as we have discussed previously and has also been found by Alvarez at al. (2005) for Chilean firms. The difference between this previous work and ours is that, instead of this effect materializing through investments, it materializes through R&D investment. This result also helps to explain the absence of self-selection in the decision to export. Thus, firms first will invest in R&D to increase productivity and then will export.

Once we consider only firms that export, our results show that those with better productivity performance tend to export more, as this variable has a positive and significant coefficient for the TFP estimations with both estimations techniques–shown in Tables 3 and 5. This variable is not significant for the added value per worker estimations set of Tables 4 and 6. Results of Tables 3 and 5 are partially consistent with previous literature.

Productivity Equation

In our productivity equation, the estimations (2), (3) and (4) include the same set of control variables, except by the time dummies of equation (4), while these are maintained at a minimum in equation (1). Moreover, in (3) and (4) we include lagged TFP in the productivity equation.

Table 3. R&D, Exports and Productivity (Levinson and Petrin, TFP).

Asymptotic Least Squares.

ALS Estimation (Levinson and Petrin)

ALS Estimation (Standard errors between parentesis)		R&D (log R&D per worker)	Exports (log value of Exports per worker)	TFP (t-1)(2)	Imitation	Cooperation	Public Resources	Environment	Quality	Market share	Employment	Foreign Property	Licenses	Skill Labor	Investment (-1)	Size Dummies	Time Dummies
R&D decision	(1)		-0.004				S			S		S				Yes	No
			(0.017)														
Dependent Variable: Dummy R&D	(2)		-0.111	0.064	S	NS	S	S	NS	S	S					No	No
			(0.086)	(0.093)													
	(3)		-0.111	0.064	S	NS	S	S	NS	S	S					No	No
			(0.086)	(0.093)													
	(4)		0.078	-0.142	S	NS	S	S	NS	S	NS					No	Yes
			(0.091)	(0.091)													
R&D Intensity	(1)					NS		NS	S							Yes	No
Dependent Variable: Logarithm of Research and Development	(2)			0.516 ***	NS	NS	S	NS	NS		S					No	No
				(0.054)													
	(3)			0.516 ***	NS	NS	S	NS	NS		S					No	No
				(0.054)													
	(4)			0.524 ***	NS	NS	S	NS	NS		S					No	Yes
				(0.056)													
Export decision	(1)	-0.159 *										NS			NS	Yes	No
		(0.081)															
Dependent Variable: Export Dummy	(2)	10.085 ***		-5.132 ***		S	S		S		S	NS	NS	NS	NS	No	No
		(2.100)		(1.102)													
	(3)	10.085 ***		-5.132 ***		S	S		S		S	NS	NS	NS	NS	No	No
		(2.100)		(1.102)													
	(4)	8.264 ***		-4.245 ***		S	S		NS		S	NS	NS	NS	NS	No	Yes
		(2.178)		(1.165)													
Export Intensity	(1)											NS			NS	Yes	No
Dependent Variable: Logarithm of Export value	(2)			0.794 ***		NS	NS		S		NS	NS	NS	S	S	No	No
				(0.076)													
	(3)			0.794 ***		NS	NS		S		NS	NS	NS	S	S	No	No
				(0.076)													
	(4)			0.697 ***		NS	NS		S		NS	NS	NS	S	S	No	Yes
				(0.075)													
Productivity Equation	(1)	1.537 ***	0.371 **												NS	Yes	No
		(0.181)	(0.155)														
Dependent Variable: Total Factor Productivity (1)	(2)	0.239 **	0.794 ***				NS			NS		S	S	S	S	Yes	No
		(0.102)	(0.049)														
	(3)	-0.094	0.254 **	0.746 ***			NS			NS		NS	NS	NS	S	Yes	No
		(0.102)	(0.100)	(0.132)													
	(4)	-0.080	0.239 ***	0.753 ***			NS			NS		NS	NS	NS	NS	Yes	Yes*
		(0.098)	(0.088)	(0.113)													

(1) Total Factor Productivity by a Levinson y Petrin estimation.
* Includes all possible time dummies but one. Our attempt to include all generated a non invertible matrix in our estimations.

Table 4. R&D, Exports and Productivity (Added Value per Worker).

Asymptotic Least Squares.

ALS Estimation (Added Value per Worker)

ALS Estimation (Standard errors between parentesis)		R&D (log R&D per worker)	Exports (log value of Exports per worker)	TFP (t-1)(2)	Imitation	Cooperation	Public Resources	Environment	Quality	Market share	Employment	Foreign Property	Licenses	Skill Labor	Investment (-1)	Size Dummies	Time Dummies
R&D decision	(1)		-0.004				S			S		S				Yes	No
			(0.017)														
Dependent Variable: Dummy R&D	(2)		-0.099 ***	0.008	S	NS	S	S	NS	S	S					No	No
			(0.035)	(0.010)													
	(3)		-0.099 ***	0.008	S	NS	S	S	NS	S	S					No	No
			(0.035)	(0.010)													
	(4)		-0.029	0.015	S	NS	S	NS	NS	S	NS					No	Yes
			(0.039)	(0.012)													
R&D Intensity	(1)					NS		NS	S							Yes	No
Dependent Variable: Logarithm of Research and Development	(2)			0.036 ***	S	NS	S	NS	S		S					No	No
				(0.019)													
	(3)			0.036 ***	S	NS	S	NS	S		S					No	No
				(0.019)													
	(4)			-0.003	S	NS	S	NS	S		S					No	Yes
				(0.022)													
Export decision	(1)	-0.159 *										NS			NS	Yes	No
		(0.081)															
Dependent Variable: Export Dummy	(2)	1.468 ***		-5.132 ***		NS	S		S		S	NS	NS	NS	NS	No	No
		(0.465)		(1.102)													
	(3)	1.468 ***		-5.132 ***		NS	S		S		S	NS	NS	NS	NS	No	No
		(0.465)		(1.102)													
	(4)	0.524 *		0.002		NS	NS		S		NS	NS	NS	NS	NS	No	Yes
		(0.297)		(0.015)													
Export Intensity	(1)											S			S	Yes	No
Dependent Variable: Logarithm of Export value	(2)			-0.009		NS	NS		S		S	S	NS	S	S	No	No
				(0.019)													
	(3)			-0.009		NS	NS		S		S	S	NS	S	S	No	No
				(0.019)													
	(4)			0.000		NS	NS		S		S	S	NS	S	S	No	Yes
				(0.021)													
Productivity Equation	(1)	1.228 ***	0.426 ***												NS	Yes	No
		(0.147)	(0.163)														
Dependent Variable: Total Factor Productivity (1)	(2)	0.872 ***	0.187 ***				S			NS		S	NS	S	S	Yes	No
		(0.160)	(0.100)														
	(3)	0.895 ***	0.183 *	-0.017			S			NS		S	NS	S	S	Yes	No
		(0.163)	(0.100)	(0.022)													
	(4)	0.839 ***	0.215 **	0.018			S			NS		S	NS	S	S	Yes	Yes*
		(0.154)	(0.093)	(0.023)													

(1) Added value per worker.

* Includes all possible time dummies but one. Our attempt to include all generated a non invertible matrix in our estimations.

Table 5. R&D, Exports and Productivity (Levinson and Petrin, TFP). Two Stages Least Squares.

2SLS Estimation (Levinson and Petrin)

2SLS Estimation

(Standard errors between parentesis)		R&D (log R&D per worker)	Exports (log value of Exports per worker)	TFP (t-1)(2)	Imitation	Cooperation	Public Resources	Environment	Quality	Market share	Employment	Foreign Property	Licenses	Skill Labor	Investment (-1)	Size Dummies	Time Dummies
R&D decision	(1)		-0.0537				S			NS		S				Yes	No
			(0.0570)														
Dependent Variable: Dummy R&D	(2)		-0.210 **	0.106	S	NS	S	NS	NS	NS	S					No	No
			(0.0833)	(0.0710)													
	(3)		-0.210 **	0.106	S	NS	S	NS	NS	NS	S					No	No
			(0.0833)	(0.0710)													
	(4)		(0.104) *	-(0.110) **	S	NS	S	NS	NS	S	NS					No	Yes
			(0.0572)	(0.0549)													
R&D Intensity	(1)					NS		NS	NS							Yes	No
Dependent Variable: Logarithm of Research and Development	(2)			0.543 ***	NS	NS	S	NS	S		S					No	No
				(0.0956)													
	(3)			0.543 ***	NS	NS	S	NS	S		S					No	No
				(0.0956)													
	(4)			(0.586) ***	S	NS	NS	NS	S		S					No	Yes
				(0.104)													
Export decision	(1)	-0.150										S			S	Yes	No
		(0.406)															
Dependent Variable: Export Dummy	(2)	0.0809		-0.0993		S	S		NS		NS	NS	NS	NS	NS	No	No
		(0.326)		(0.181)													
	(3)	0.0809		-0.0993		S	S		NS		NS	NS	NS	NS	NS	No	No
		(0.326)		(0.181)													
	(4)	-0.0758		-0.00148		S	NS		NS		NS	S	NS	NS	NS	No	Yes
		(0.283)		(0.180)													
Export Intensity	(1)											NS			S	Yes	No
Dependent Variable: Logarithm of Export value	(2)			0.281 **		NS	NS		NS		NS	NS	NS	NS	S	No	No
				(0.135)													
	(3)			0.281 **		NS	NS		NS		NS	NS	NS	NS	S	No	No
				(0.135)													
	(4)			0.110		NS	NS		NS		S	NS	NS	NS	S	No	Yes
				(0.128)													
Productivity Equation	(1)	0.228	-0.706 **												S	Yes	No
		(0.306)	(0.327)														
Dependent Variable: Total Factor Productivity (1)	(2)	0.509 ***	1.281 ***				S			S		S	S	S	S	Yes	No
		(0.0529)	(0.102)														
	(3)	0.137	0.455 *	0.463 ***			NS			S		NS	NS	NS	S	Yes	No
		(0.109)	(0.236)	(0.120)													
	(4)	0.0169	0.0218	0.602 ***			NS			S		NS	NS	NS	NS	Yes	Yes
		(0.105)	(0.207)	(0.0942)													

(1) Total Factor Productivity by a Levinson y Petrin estimation.

Table 6. R&D, Exports and Productivity (Added Value per Worker).

Two Stages Least Squares.

2SLS Estimation (Added Value per Worker)

2SLS Estimation (Standard errors between parentesis)		R&D (log R&D per worker)	Exports (log value of Exports per worker)	TFP (t-1)(2)	Imitation	Cooperation	Public Resources	Environment	Quality	Market share	Employment	Foreign Property	Licenses	Skill Labor	Investment (-1)	Size Dummies	Time Dummies
R&D decision	(1)		-0.0254				S			S		S				Yes	No
			(0.0585)														
Dependent Variable:	(2)		-0.218 ***	0.0134	S	NS	S	NS	NS	NS	S					No	No
Dummy R&D			(0.0710)	(0.0122)													
	(3)		-0.218 ***	0.0134	S	NS	S	NS	NS	NS	S					No	No
			(0.0710)	(0.0122)													
	(4)		(0.113) **	0.0148	S	NS	S	NS	NS	S	S					No	Yes
			(0.0521)	(0.0123)													
R&D Intensity	(1)					NS		NS	NS							Yes	No
Dependent Variable:	(2)			0.048 **	NS	NS	S	NS	S		S					No	No
Logarithm of Research				(0.0195)													
and Development	(3)			0.048 **	NS	NS	S	NS	S		S					No	No
				(0.0195)													
	(4)			-0.0219	S	NS	NS	NS	NS		S					No	Yes
				(0.0258)													
Export decision	(1)	-0.206 *										S			S	Yes	No
		(0.433)															
Dependent Variable:	(2)	-0.0162 ***		0.000		S	NS		NS		NS	NS	NS	S	NS	No	No
Export Dummy		(0.309)		(0.0175)													
	(3)	-0.0162 ***		0.000		S	NS		NS		NS	NS	NS	S	NS	No	No
		(0.309)		(0.0175)													
	(4)	0.828		-0.00894		S	NS		NS		S	S	NS	NS	NS	No	Yes
		(0.622)		(0.0160)													
Export Intensity	(1)											NS			S	Yes	No
Dependent Variable:	(2)			-0.005		NS	NS		NS		S	NS	NS	NS	S	No	No
Logarithm of Export				(0.023)													
value	(3)			-0.005		NS	NS		NS		S	NS	NS	NS	S	No	No
				(0.023)													
	(4)			0.0198		NS	NS		NS		S	NS	NS	S	S	No	Yes
				(0.0263)													
Productivity Equation	(1)	0.519	-0.853 ***												S	Yes	No
		(0.331)	(0.329)														
Dependent Variable:	(2)	0.361 ***	0.222				NS			S		NS	NS	NS	NS	Yes	No
Total Factor		(0.126)	(0.233)														
Productivity (1)	(3)	0.203	0.0101	0.038 ***			NS			S		NS	NS	NS	S	Yes	No
		(0.130)	(0.235)	(0.00978)													
	(4)	0.0460	-0.467 **	0.046 ***			NS			S		NS	NS	S	S	Yes	Yes
		(0.171)	(0.234)	(0.0120)													

(1) Added value per worker.

The most important result from Tables 3 and 4 (ALS estimations) is that R&D and exports increase both measures of productivity in most specifications. Indeed, exporting is significant in all eight specifications and R&D in six of them. Thus, these tables report evidence of learning by exporting and the traditional R&D channel for increasing a firm's productivity. Regarding the TSLS estimations of Tables 5 and 6, we find that exports are significant in five specifications and R&D in two of them. However, export coefficients are highly unstable, change signs and significance. There is also significant evidence of R&D impact on productivity in two estimations. The unstability of these coefficients and lower significance make worth it to compute these estimations by ALS, a method that is generally more efficient than TSLS as discussed previously.

5.2 General Discussion: Other Controls

In the discussion that follows, we discuss only the results that are robust in either estimations techniques and/or measure of productivity.

R&D Status

In the ALS estimations, market share is positively associated with the probability of performing R&D, consistent with most previous empirical studies. This positive effect reinforces the notion that firms with greater participation, or, in the extreme case, with higher monopoly power, have greater incentives to conduct research activities because they are more likely to appropriate the results from this investment.

Concerning firm size –measured by employment- results show that in eight of twelve estimations, larger firms have a greater probability of being involved in R&D investments. This result, consistent with previous theoretical as well as empirical work, shows that there exists a scale effect similar to market power.

Firms that see imitation as a potential obstacle to innovation invest more in R&D. The interpretation of this result is based on the distinction we make between R&D and innovation, where the first is an input for the second. Therefore, a higher risk of imitation would force firms to invest in new and original ideas that have more tacit and plant-specific knowledge, which makes imitation more difficult.

Finally, firms that have been involved in innovation projects with partial public funding have a larger probability of investing resources in R&D.

R&D Level

Consistent with previous work, we found that R&D investments have decreasing economies of scale. The negative sign of the coefficients related to employment show that larger firms tend to invest proportionally less in R&D. Given that the dependent variable is R&D per worker, larger firms tend to have a higher probability of performing R&D activities, but the amount of resources grows at a slower rate than the size of the firm.

The positive sign associated with public funding – in ten of twelve cases- shows that public resources linked to innovation indeed complement private resources in R&D, which is good news.

Export Status

An interesting result of our ALS estimations is related to the negative effect that public support for innovation has on the probability that the firm exports –in five cases of six possible-. This negative effect of public funding might be related to the firm's focus. It seems that there is a trade-off between innovation and exporting efforts. If we consider that those firms already exporting are less likely to engage in R&D – as shown previously – but that those receiving public funds for R&D do not export, the results are consistent with the idea that firms concentrate on either exporting or investing in R&D. But they cannot do both at the same time.[12]

We also find in our ALS estimations that employment is also positively related with the probability of exporting, as has been found in the previous literature –in five cases of six possible-. Finally, in our TSLS estimations, we find that cooperation affects negatively the likelihood of exporting.

Export Intensity

We find that investment increases the level of exports across estimation techniques and specifications. Additionally, we find that quality concerns increase exports in our ALS estimations.

Productivity

In our ALS estimations, we find that foreign-owned firms have higher productivity for both measures –in four cases of six possible- and in our TSLS estimations we find that those with larger market shares tend to have higher productivity, also for both measures of productivity

6. Discussion

Our estimations deal–among other issues–with the simultaneous effects of R&D, export learning and export selection on productivity, measured as TFP. Our main finding is that there is no evidence of exporter selection, but positive evidence for export learning, together with the

[12] We are talking about the decision to export or to perform R&D activities and not the amount invested in them once decided.

traditional positive R&D impact on productivity. Moreover, we find evidence of exporting by innovating. Thus, the effect of R&D on productivity is twofold: directly and, through exports, indirectly. This should be taken into consideration in the discussion that follows.

Given these results, we now can estimate the return to learning by exporting, a relevant issue for a small and export oriented less-developed country like Chile. However, no estimates in this regard have been previously documented for Chile. For this purpose, we adapt the framework presented in Griliches (1998).

Returns to export learning can be computed as:

$$\rho = \frac{\beta}{(X/Y)}$$

where β corresponds to the estimated coefficient multiplying the logarithm of exports per worker in our estimations of equations (3) and (4) in Table 3, and (X/Y) corresponds to the exports share on the output measure used to compute TFP.

The latter result is derived from the assumption that the stock of exports plays a role similar to R&D stock in the production function of firms, an assumption that has been used in the literature to relate productivity to learning by doing processes. Table 7 shows that the return to export learning fluctuates between 30% and 36%.

Table 7. Returns to Learning by Exporting using TFP.

Estimated by ALS.

Return to Exports	0.30	0.36

Note: Authors' calculations, based on statistically significant export coefficients in specifications (3) and (4).

One major finding of our results is that exporting, provides higher return than capital investments, thereby providing a rationale for public intervention as a way to increase firms' productivity. Thus, our results can be complemented by the literature on the evaluation of export promotion agencies. Indeed, Lederman, Olearraga and Payton (2010) find positive effects of these agencies across the world as a way to boost exports.

7. **Conclusions**

In this study, we contrast the hypothesis of *self-selection* and *learning by exporting* and the linkages between export activity and R&D investments with productivity, using firm-level data for Chile. We also aim to answer the question of whether the firms with innovative activities and R&D investments are more likely to export or whether it is the export experience that determines their greater propensity to invest in R&D.

These hypotheses have been extensively studied in the literature on exports and productivity, but only recently have they been linked with other firm efforts such as R&D and innovation. This paper follows the literature on exports and innovation-generally tested for developed countries-and tests theses hypotheses in the context of a developing country characterized by low barriers to trade, and where innovation presents a growing public and private concern.

For this purpose, we develop and implement an original econometric model for this context that includes the relationship between innovation and exports and the linkages of both with the productivity of the firm. Given the complex relationships among variables such as nonlinearities, simultaneity and endogeneity, together with some features of the information available, such as censorship and truncation, we use an Asymptotic Least Squares (ALS) estimation procedure that perform better in these circumstances than traditional methods such as GMM or Two-Stage Least Squares (Gourieroux and Monfort, 1989; Crepon, Duguet and Mairesse, 1998).

Our results are not consistent with the hypothesis of *self-selection* in exports, nor with innovating by exporting, the idea that firms which export more are also more likely to engage in R&D. However, our results show exporting by innovating, which implies that firms that invest more in R&D have a greater tendency to become exporters. This finding seems to be consistent with the conscious self-selection hypothesis corroborated by Alvarez et al. (2005) for Chilean plants, whereby plants invest in order to increase productivity before they become exporters. This result is consistent with the findings of Van Beveren et al (2010), Cassiman et al (2010) among others.

We find an interesting feedback loop between R&D productivity and exports. In particular, we find that, in half of our ALS estimations, R&D results in an increase of productivity, but also that exports increase productivity ,that is, learning by exporting. Our results therefore imply that R&D affects productivity by two channels–directly and indirectly through export levels. The second loop is the export-productivity virtuous circle. While greater exports increase productivity, this greater productivity induces larger exports. The identification of these loops made it worth the effort to implement ALS. Unlike previous research, our method simultaneously controlled for endogeneity and the interaction of exports, R&D and productivity.

Finally, this study opens a new set of questions on the importance of R&D and related activities to the productive performance of firms. Our analysis of the causal links between R&D and exporting is a major breakthrough. We still have many questions regarding not only the determinants of investment in these activities, but also their complementarity with other investments, including physical capital, and more important still, human capital. These are certainly challenges for future studies, which may now be possible due to the existence of detailed information on innovative activities, production and investment by Chilean firms, as well as the development of estimation methods that account for the particularities of this information. The challenge is open.

7. References

Ackerberg, Daniel & Caves, Kevin & Frazer, Garth, 2006. "Structural identification of production functions,"MPRA Paper 38349, University Library of Munich, Germany.

Aghion, Philippe & Howitt, Peter. 1992. "A Model of Growth through Creative Destruction". Econometrica, Econometric Society, vol. 60(2), pages 323-51, March.

Aghion, Philippe & Howitt, Peter. 1997. "Endogenous Growth Theory,"MIT Press Books, The MIT Press, edition 1, volume 1, number 0262011662.

Alvarez, Roberto and López, Ricardo. 2005. "Exporting and Performance: Evidence from Chilean Plants.". Canadian Journal of Economics, Canadian Economics Association, vol. 38(4), pages 1384-1400, November.

Atkeson, Andrew and Burstein, Ariel Tomás. 2010. "Innovation, Firm Dynamics, and International Trade". Journal of Political Economy, University of Chicago Press, vol. 118(3), pages 433-484, 06.

Aw, Bee Yan; Roberts, Mark J. and Yi Xu, Daniel. 2011. "R&D Investment, Exporting, and Productivity Dynamics". American Economic Review, American Economic Association, vol. 101(4), pages 1312-44, June.

Becker, Sascha and Egger, Peter. 2013. "Endogenous product versus process innovation and a firm's propensity to export,"Empirical Economics, Springer, vol. 44(1), pages 329-354, February.

Benavente, José Miguel. (2006) "The Role of Research and Innovation in Promoting Productivity in Chile". *Economics of Innovation and New Technology* 15 (4-5) : 301- 315. June.

Bernard, Andrew and Jensen, Bradford. 1995. "Exporters, Jobs and Wages in U.S. Manufacturing: 1976-1987". Brookings Papers on Economic Activity. Microeconomics, Vol. 1995.pp. 67-119.

Bernard, Andrew and Wagner, Joachim. 1997. "Exports and Success in German Manufacturing", Review of World Economics, Volume 133, Issue 1, March 1997. pp. 134-157.

Bernard, Andrew; Jensen, Bradford and Wagner, Joachim. 1997. “The Good Go Abroad: Evidence from Longitudinal Micro Data on German and U.S. Exporters”. in S. Laaksonen (ed.), The Evolution of Firms and Industries. International Perspectives (Helsinki: Statistics Finland), 489–500.

Bernard, Andrew and Jensen, Bradford. 1998. “Understanding the U.S. Export Boom”. National Bureau of Economic Research. Working Paper No 6438.

Bernard, Andrew and Jensen, Bradford. 1999. “Exceptional exporter performance: cause, effect, or both?” Journal of International Economics, N°. 47, pp.1-25.

Bernard, Andrew; Eaton, Jonathan; Jensen, Bradford and Kortum, Samuel. 2003. “Plants and Productivity in International Trade’, American Economic Review, Vol. 93, N°. 4, pp.1268-1290.

Bernard, Andrew and Jensen, Bradford. 2004. “Why some firms export”. The Review of Economics and Statistics, Vol. 86, No. 2 (May, 2004), pp. 561-569.

Bravo-Ortega, Claudio and García, Álvaro (2011) “R&D and Productivity: A Two Way Avenue?” World Development Volume 39, Issue 7, July 2011, Pages 1090‑1107

Cassiman, Bruno; Golovko, Elena & Martínez-Ros, Ester, 2010. "Innovation, Exports and Productivity,"International Journal of Industrial Organization, Elsevier, vol. 28(4), pages 372-376, July.

Clerides, Sofronis., Lach, Saul and Tybout, James. 1998 “Is learning by exporting important? Micro-Dynamic evidence from Colombia, Mexico, and Morocco. The Quarterly Journal of Economics. (1998) 113 (3), pp. 903-947.

Crepon, Bruno; Duguet, Emmanuel and Mairessec, Jacques. 1998. "Research, Innovation And Productivi[Ty: An Econometric Analysis At The Firm Level,"Economics of Innovation and New Technology, Taylor and Francis Journals, vol. 7(2), pages 115-158.

Constantini, J.A. and Melitz, M.J. 2007. “The Dynamics of Firm-Level Adjustment to Trade Liberalization.” Princeton University, Mimeo.

Damijan, Jože, Črt Kostevc and Sašo Polanec. 2008. “From innovation to exporting or vice versa? Causal link between innovation activity and exporting in Slovenian microdata.” LICOS Discussion Paper Series, Discussion Paper 204/2008, Katholieke Universiteit Leuven.

De Loecker, Jan. 2007. "Do exports generate higher productivity? Evidence from Slovenia,"Journal of International Economics, Elsevier, vol. 73(1), pages 69-98, September.

De Loecker, Jan. 2011. "Product Differentiation, Multiproduct Firms, and Estimating the Impact of Trade Liberalization on Productivity". Econometrica,Econometric Society, vol. 79(5), pages 1407-1451, 09.

Diao, Xinshen; Rattso, Jorn and Stokke, Hildegunn Ekroll. 2005. "International spillovers, productivity growth and openness in Thailand: an intertemporal general equilibrium analysis,"Journal of Development Economics, Elsevier, vol. 76(2), pages 429-450, April.

Ericson, Richard and Pakes, Ariel. 1995 “Markov-Perfect Industry Dynamics: A Framework for Empirical Work”. Review of Economic Studies (1995) 62 (1) pp. 53-82.

Fernandes, Ana M. & Isgut, Alberto E., 2005. "Learning-by-doing, Learning-by-exporting, and Productivity : Evidence from Colombia,"Policy Research Working Paper Series 3544, The World Bank.

Girma, Sourafel; Görg, Holger. and Strobl, Eric. 2004. "Exports, International Investment, and Plant Performance: Evidence from a Non-parametric test" Economics Letters. Nº 83, pp. 317–324

Girma, Sourafel; Görg, Holger and Hanley, Aoife. 2008. "R&D and Exporting: A comparison of British and Irish firms". Review of World Economics, Volume 144, Issue 4, pp 750-773.

Gourieroux, Christian; Monfort, Alain and Trognon, Alain. (1984), Pseudo Maximum Likelihood Estimation Methods : Application to Poisson Models. *Econometrica*, 52(3), pp. 701-720.

Gourieroux, Christian and Monfort, Alain. 1989. Statistics and Econometric Models. Translated by Q. Vuong, Cambridge University Press, Cambridge, UK.

Greenaway, David. and Kneller, Richard . 2004. "Industry Differences in the Effect of Export Market Entry: Learning by Exporting?" Review of World Economics October 2007, Volume 143, Issue 3, pp 416-432

Greenaway, David and Kneller, Richard. 2007. "Firm Heterogeneity, Exporting and Foreign Direct Investment: A Survey". The Economic Journal Volume 117, Issue 517, pp. F134–F161.

Griliches, Zvi. 1998. *R&D and Productivity. The Econometric Evidence.* The University of Chicago Press, Chicago and London

Grossman, Gene and Helpman, Elhanan. 1990. "Trade, Innovation, and Growth". The American Economic Review, Vol. 80. No. 2, pp. 86-91.

Grossman, Gene M. & Helpman, Elhanan, 1991. "Trade, knowledge spillovers, and growth,"European Economic Review, Elsevier, vol. 35(2-3), pages 517-526, April.

Grossman, Gene and Helpman, Elhanan .1994. "Endogenous Innovation in the Theory of Growth". The Journal of Economic Perspectives, Vol. 8, No. 1. pp. 23-44.

Harris, Richard and Li, Qian Cher. 2009. "Exporting, R&D and Absorptive Capacity in UK Establishments". Oxford Economic Papers. (2009) 61 (1). Pp. 74-103.

Hirsch, Seev and Bijaoui, Ilan. 1985. "R&D Intensity and Export Performance: A Micro View". Weltwirtschaftliches Archi, 121, pp. 238-251.

Ito, Kiyohiko and Pucik, Vladimir. 1993. " R&D Spending, Domestic Competition, and Export Performance of Japanese Manufacturing Firms". Strategic Management Journal, Vol. 14, pp. 61-75.

Klette, Tor Jakob & Griliches, Zvi, 2000. "Empirical Patterns of Firm Growth and R&D Investment: A Quality Ladder Model Interpretation,"Economic Journal, Royal Economic Society, vol. 110(463), pages 363-87, April.

Kumar, Nagesh. and Siddharthan, N. S. 1994. "Technology, Firm Size and Export Behvior in Developing Countries". Journal of Developing Studies. 32, pp.288-309.

Lederman, Daniel; Olarreaga, Marcelo. and Payton, Lucy. 2010. ”Export promotion agencies: Do they work?” Journal of Development Economics Volume 91, Issue 2, March 2010, Pages 257–265

Lee, Lung-Fei. 1981. Simultaneous Equations Models with Discrete and Censored dependent Variable. In C. Manski and D. McFadden eds. Structural Analysis of Discrete Data with Econometric Applications, Boston : MIT Press, pp. 346-364.

Lefebvre, Elisabeth; Lefebvre, Louis A and Bourgault, Mario. 1998. “R&D-Related Capabilities as Determinants of Export Performance”. Small Business Economics, June 1998, Volume 10, Issue 4, pp 365-377

Legros Diego and Fabrice, Galia. 2012. "Are Innovation and R&D the Only Sources of Firms’ Knowledge that Increase Productivity? An Empirical Investigation of French Manufacturing Firms," *Journal of Productivity Analysis*, Springer, vol. 38(2), pages 167-181, October.

Levinsohn, James and Petrin, Amil. 2003. "Estimating Production Functions Using Inputs to Control for Unobservables". Review of Economic Studies, Wiley Blackwell, vol. 70(2), pages 317-341, 04.

Melitz, Marc J. 2003. “The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity”. Econométrica. Vol. 71 No 6. pp. 1695-1725.

Richardson, David., Rindal, Karin, 1995. “Why Exports Really Matter!”. The Institute for International Economics and the Manufacturing Institute. Washington D.C.

Rivera-Batiz, Luis A & Romer, Paul M, 1991. "Economic Integration and Endogenous Growth,"The Quarterly Journal of Economics, MIT Press, vol. 106(2), pages 531-55, May.

Romer, Paul. 1990. “Endogenous Technological Change." Journal of Political Economy, XCXXVUI, pp.71—102.

Pattnayak, Sanja Samirana and Thangavelu, Shandre M. 2009. “Economic Liberalization in India: Productivity and Learning by Export”. Center for Contemporary Asian Studies, Doshisha University, Working Paper N° 21.

Salomon, Robert and Shaver, J. Myles. 2005. “Learning by Exporting: New Insights from Examining Firm Innovation” Journal of Economic and Management Strategy. 14. pp. 431-460.

Sriram, Ven., Neelankavil James. and Moore, Russell. (1990) “Export Policy and Strategy Implications for Small-to-Medium Sized Firms” Journal of Global Marketing, Volume 3, Issue 2, pp. 43-60

Sterlacchini, Alessandro. 1999. “Do Innovative activities matter to small firms in non R&D-intensive Industries? An application to Export Performance”. Research Policy, 28, pp.819-832.

Van Beveren, Ilke and Hylke Vandenbussche. 2010. “Product and process innovation and firms’ decision to export.“ Journal of Economic Policy Reform, Vol. 13, No. 1, 3–24, March.

Van Biesebroeck, Johannes. 2005.“Exporting raises productivity in sub-Saharan African manufacturing firms”. Journal of International Economics. N° 67, pp. 373–391

Wagner, Joachim. 2002. "The Causal Effects of Exports on Firm Size and Labor Productivity: First Evidence from a Matching approach". Economics Letters. Nº 77, pp. 287–292

Wagner, Joachim . 2007. "Exports and Productivity: A Survey of the Evidence from Firm Level Data". The World Economy Volume 30, Issue 1, pages 60–82, January.

Yeaple, Stephen Ross. 2005. "A Simple Model of Firm Heterogeneity, International Trade, and Wages". Journal of International Economics. Nº65, pp. 1– 20.

Appendix A.

We estimate the Total Factor Productivity (TFP) for the whole sample by the Levinsohn and Petrin method (Levinsohn and Petrin (2003)). This methodology allows us to control by the potential correlation between the input levels and the unobserved firm-specific productivity shocks, present in a common Ordinary Least Squares estimation of production functions parameters. This methodology is an improvement of the Oalley and Packes (1996) approach and use intermediate inputs to control for this aforementioned correlation, instead of the investment variable.

For the TFP estimation, we use the Chilean Annual National Survey of Industry (ENIA[13]), the same database as Levinsohn and Petrin (2003), between 1997 and 2004[14]. The estimation includes the added value as an output index, the capital stock of the firm measured as in Levinsohn and Petrin (2003)[15] and presented by Lui (1991), and the number of skilled and unskilled workers as labor input index. We took as reference, for the estimation of the TFP, the previous work of Bergoeing and Repetto (2006), Benavente (2006), Alvarez and Fuentes (2009) and Bergoeing et. al (2010), with the particularities set forth below.

Additionally, we include the electricity consumption as intermediate input and instrument or proxy necessary for the methodology. The electricity consumption it is measured in thousands of KW per hour, as in the previous work of Bergoeing and Repetto (2006).

All the former variables measured in pesos are deflated by the Producer Price Index (IPP) of the manufacturing industry[16] and measured in real 2000 chilean pesos. We did not control by different industries to estimate the TFP and only estimate one general equation.

In particular, the capital stock variable is constructed by the sum of the real peso value of buildings, machinery and vehicles, assuming a depreciation of 5, 10 and 20% respectively. The capital evolves in the following manner:

$$K_{it} = (1 - \delta_i)K_{i,t-1} + i_{it}$$

Where i_{it}, is the investment of the firm i at period t. We use annual gross fixed capital added by the firm as the investment of the firm. Then, the capital index at time t it is equal to: $K_t = \sum_i^N K_{it}$

Particularly we estimate the following equation:

[13] The ENIA is an annual survey of manufacturing firms conducted by the National Institute of Statistics (INE), the chilean national statistics agency. The ENIA covers all manufacturing plants that have more than ten employees. This survey collects information of plant characteristics such as sales, employment, investment, intermediate inputs among others. The ENIA covers the manufacturing sectors at a 4-digit ISIC level.

[14] We only include the firms that are present in our sample, used in the main model and estimation of the Paper.

[15] See Levinsohn and Petrin (2003) p. 324.

[16] We use the Production Price Index (IPP) provided by the INE.

$$\ln(av_i) = \beta_0 + \beta_1 ln(Skill_i) + \beta_2\ ln(Uskill_i) + \beta_3 ln\ (\ K_i) + u_i$$

Where av_i is the added value (expressed in thousand pesos), $Skill_i$ and $Uskill_i$ are the number of qualified workers (skill labor) and non qualified workers (unskilled labor) of every firms respectively, and K_i is capital stock of the firm (expressed in thousand pesos), previously described. As the equation shows and the methodology requires, all the covariates are expressed in logs. The log of the electric consumption is included as intermediate input. The results of the estimation are showed in the next table:

Table A1 Production Function estimation by Levinsohn and Petrin (2003) (1)

VARIABLES	ln(av)
ln(Skill)	0.282***
	(0.0165)
ln(Uskill)	0.325***
	(0.0260)
ln(gfka)	0.147***
	(0.0143)
Observations	1,321
Wald test of constant return to scale (p value)	58.76 (0.000)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

(1) The table above correspond to the *levpet* Stata program output which we used to estimate the TFP by Levinsohn and Petrin (2003).