

Relative R&D intensity for exporters in an oligopolistic industry with spillovers

by

Juan A. Mañez
Rafael Moner-Colonques
Juan A. Sanchis
and
Jose J. Sempere-Monerris

June 2018

Working Papers in Applied Economics

WPAE-2018-07

Relative R&D intensity for exporters in an oligopolistic industry with spillovers*

Juan Mañez,[†] Rafael Moner-Colonques,[‡] Juan A. Sanchis[†]
and Jose J. Sempere-Monerris^{‡§}

Abstract

This paper explores the links between firms R&D investment decisions, and firms decisions on how much to sell at home and abroad in a heterogeneous-firm international oligopoly. The model provides analytical results that yield four testable hypotheses, which are empirically checked with data from the Spanish Survey on Business Strategies (ESEE) for the period 1992-2013. Our results confirm that exporters invest in R&D four times more than non-exporters in relative terms (Hypothesis H1). Our estimates confirm that past R&D intensity has a positive and significantly different effect on domestic and export outputs by exporters and that the effect on the rate of growth of exports is larger (H2). Econometric evidence suggests a positive and significant effect of appropriability on domestic sales, while a positive but non-significant effect on exports; thus partially confirming hypothesis H3. Finally, R&D efficiency measured as the propensity to obtain a patent or utility model is found to have a positive and significant effect on the rate of growth of exports, which confirms H4.

Keywords: International oligopoly, R&D, exports, knowledge spillovers.

*The authors thank the comments and suggestions from seminar participants at the I KIIS Workshop (Valencia 2015), the Centre for Operations Research and Econometrics (CORE, Louvain-la-neuve, Belgium 2016) and the Centre de Recherche en Economie (CEREC, Brussels, Belgium 2016). We also thank the financial support from Fundación BBVA, under I Convocatoria de Ayudas de la Fundación BBVA a Proyectos de Investigación (Área Socioeconomía).

[†]Department of Applied Economics II (Economic Structure) and ERI-CES, University of Valencia. Campus dels Tarongers. E-46022 Valencia, Spain.

[‡]Department of Economic Analysis and ERI-CES, University of Valencia. Campus dels Tarongers, E-46022 Valencia, Spain.

[§]CORE, University of Louvain, Voie du Roman Pays, 34, B-1348 Louvain-la-Neuve, Belgium.

1 Introduction

Innovation is basic for reaching international competitiveness. Recent research has examined the relationship between firms R&D and export decisions pointing out that these ultimately affect productivity levels. The evolution of productivity differences over time may provide firms with further incentives to innovate and/or internationalize thus creating industry dynamics that are worth analyzing. We wish to explore the links between firms R&D investment decisions, and firms decisions on how much to sell at home and abroad. In a setting with heterogeneous firms and the presence of knowledge spillovers attached to such decisions, some natural questions arise: Which type of firm invests more? A firm that remains local or a firm that is an exporter? How do exporters allocate their outputs across markets? How are output choices shaped by spillovers? How does an increase in R&D productivity affect international flows?

To answer these questions, we develop an international oligopoly model with firm heterogeneity in which local firms' output competes with imports. Besides, some local firms may also export. Firms R&D decisions, though costly, allow firms to reduce their production costs. However, the existence of public spillovers means that competitors, whether local or exporters, benefit from own R&D investments in that market. Exporters face a fixed cost linked to their exporting activities. However, we assume that exporters take advantage of international spillovers when they compete outside. The oligopoly approach, followed by some recent researchers, is particularly adequate to study the strategic interactions that arise regarding R&D and export decisions.

The game that we solve unfolds in two stages. Firms, in the first stage, decide on their R&D level to maximize individual profits. These decisions determine the marginal costs of production, which are observed by all firms. Then, in the second stage, firms decide on the level of output to be sold in each of the markets they are present to maximize individual profits. The model provides analytical results that yield some testable hypotheses. In particular, i) exporters invest in R&D, in relative terms, more than non-exporters (hypothesis H1); ii) exporters' own R&D impact on sales differs between domestic sales and exports (H2); iii) an increase in the size of

spillovers reduces exporters output both locally and abroad (H3); and iv) an increase in R&D efficiency makes exports to grow (H4). These hypotheses are empirically checked with data from the Spanish Survey on Business Strategies (ESEE) for the period 1992-2013. Our results confirm that exporters invest in R&D four times more than non-exporters in relative terms (H1). We also estimate the effect of past R&D intensity on the rate of growth of both domestic sales and exports for exporting sales. Our estimates confirm that R&D intensity has a positive and significant effect on these outputs; that those effects are statistically different, and that the effect on the rate of growth of exports is larger, thereby confirming H2. Regarding H3, we use the ratio of the total number of patents and utility models over the total number of firms that assert to have achieved innovations in the firms industrial sector as a measure of appropriability. Then, econometric evidence suggests a positive and significant effect on domestic sales, while a positive but non-significant effect on exports; thus partially confirming H3. Finally, R&D efficiency measured as the propensity to obtain a patent or utility model is found to have a positive and significant effect on the rate of growth of exports, which confirms H4.

Recent empirical analyses have examined a causality relation between export activities and the productivity of exporting firms. It is found that exporters are better than non-exporters in several respects: they are of larger size, pay higher wages, and are more productive. See Greenaway and Kneller (2007) and Wagner (2007) for surveys on the selection of firms into domestic and export markets. Also the relationship between R&D investments and productivity has been extensively analyzed. The literature has found that the average productivity of R&D firms is higher than that of non-R&D firms; once again, this result might be due to some selection process as only the more productive firms can afford the sunk costs associated with R&D activities (see e.g. (Sutton, 1991), and (Máñez et al., 2009)). Certainly, firms decisions about their innovation strategies in a global competitive environment alters the degree of firm heterogeneity. Navas-Ruiz and Sala (2007) and Bustos (2011) suggest that there is a link between exporting and R&D investments: trade liberalization periods raise the incen-

tive of exporters to upgrade technology.

On the theoretical side, contributions by Petit and Sanna-Randaccio (2000) and Petit et al. (2012) have studied the impact of the firms mode of foreign expansion on the incentive to innovate. Market structure is endogenous and these authors show that there is a positive relationship between multinational expansion and R&D investment. In turn, investment in research makes an equilibrium with foreign direct investment more likely to be observed, and spillovers are relevant in the choice of firms international strategy. Theoretical papers that examine innovation and export decisions with heterogeneous firms include Costantini and Melitz (2008), Atkeson and Burstein (2010), and Van Long et al. (2011). These models study how trade liberalization can raise the returns to R&D and thus lead to future endogenous productivity gains. Whether trade liberalization is anticipated in a dynamic setting or innovation investments are taken in advance play a role in finding that trade liberalization increases aggregate R&D when trade costs are rather low. We wish to complement earlier analyses as it is clear that R&D and export decisions are interrelated, and these decisions are influenced by spillovers in competitive settings.

At an empirical level, the works by Aw et al. (2011), for Taiwanese electronic industry, and Máñez et al. (2015), for Spanish manufacturing, merit to be cited. There the linkages between the three factors, R&D, exports and productivity, are investigated. These papers, using different methodologies, find that both exporting and R&D activities have a positive effect on firms future productivity. Therefore, firms productivity levels before they start exporting or investing in R&D should be considered as endogenous as firms past choices about exporting and performing R&D may result in productivity gains, allowing firms to surpass the exporting or R&D productivity thresholds. Further, they find that investing in R&D (exporting) in the past has a positive direct and significant effect on the likelihood of exporting (engaging in R&D), what probably suggests that each decision also affects future returns from the other activity.

The next section describes the model. In Section 3 we describe the data set and provide the empirical analysis. Section 4 concludes.

2 The model

Consider two countries denoted by a and b . There is an oligopoly of n_a firms located in country a , each one denoted by counter i , with $i = 1, 2, \dots, n_a$; and another of n_b firms in country b , each one denoted by j , with $j = 1, 2, \dots, n_b$. There is a market in each country characterized by the following inverse demand expression, $p_k = A_k - Q^k$, where A_k denotes the country k 's market size, p_k is the price and Q^k is total output in country k , for $k = a, b$.

Firms are active in investing in R&D and we assume that there are public R&D spillovers linked to such aggregated activity. Firms in each country may be exporting to the other country and if they do so they enjoy a kind of learning spillovers from the abroad industry that allow them to be more efficient and which are proportional to the number of firms selling in that foreign market. Then, firms located in each country are partitioned in two groups: the exporters and the non-exporters. The firms in the first group are selling in both countries, so they profit from both types of positive externalities, while those that remain local only sell in its home market and only enjoy the R&D externality. Denote the number of firms exporting in country a by n_{ae} and also denote exporters in country a by counter ie , with $ie = 1, 2, \dots, n_{ae}$ and non-exporters by il with $il = 1, 2, \dots, (n_a - n_{ae})$, similarly for country b counters je and jl will be used. Given that, in an environment with trade among both countries, that is for $n_{ae}, n_{be} > 0$, total output in country a will be the sum of three terms. The first one is the sum of output of non-exporters, denoted by Q_{il}^a ; the next one corresponds to the sum of output sold at home by exporters located in country a , denoted by Q_{ie}^a ; and finally, the sum of output sold by foreign exporters, those located in country b , denoted by Q_{je}^a , that is, $Q^a = Q_{il}^a + Q_{ie}^a + Q_{je}^a$. Similarly for country b , $Q^b = Q_{jl}^b + Q_{je}^b + Q_{ie}^b$.

For a given stable market structure in terms of firms profile in each country, that is given n_a, n_{ae}, n_b and n_{be} , the timing of the decisions is as follows. In a first-stage firms decide non-cooperatively and simultaneously on its level of investment in R&D to maximize own profits. This decision together with their profile of exporters or non exporters determines each firm's marginal cost of production. Then, firms decide on

quantities non-cooperatively and simultaneously to maximize profits. Exporters decide both the level of output sold home and that sold abroad. Stability is understood in the sense that no firm, either exporter or non-exporter in both countries, wants to change its profile.

Second-stage: competition in quantities

Each firm selling in a particular market chooses the level of output that maximizes profits. In particular for country a , there are three types of firms operating which add up to a total of $n_a + n_{be}$ firms. All firms $il \in \{1, 2, \dots, (n_a - n_{ae})\}$ choose q_{il}^a , those $ie \in \{1, 2, \dots, n_{ae}\}$ choose q_{ie}^a and finally firms $je \in \{1, 2, \dots, n_{be}\}$ choose q_{je}^a . Similarly, in country b firms choose q_{jl}^b, q_{je}^b and q_{ie}^b . Firms' profits are defined as follows,

$$\pi_{il} = (p_a - c_{il})q_{il}^a - \frac{\gamma}{2}x_{il}^2 \text{ for } il = 1, 2, \dots, (n_a - n_{ae}) \quad (1)$$

$$\pi_{ie} = (p_a - c_{ie})q_{ie}^a + (p_b - c_{ie})q_{ie}^b - \frac{\gamma}{2}x_{ie}^2 - f_{ie} \text{ for } ie = 1, 2, \dots, n_{ae} \quad (2)$$

$$\pi_{je} = (p_a - c_{je})q_{je}^a + (p_b - c_{je})q_{je}^b - \frac{\gamma}{2}x_{je}^2 - f_{je} \text{ for } je = 1, 2, \dots, n_{be} \quad (3)$$

$$\pi_{jl} = (p_b - c_{jl})q_{jl}^b - \frac{\gamma}{2}x_{jl}^2 \text{ for } jl = 1, 2, \dots, (n_b - n_{be}) \quad (4)$$

where $c_s, s = \{il, ie, jl, je\}$ are the marginal cost of production for each firm, and $x_s, s = \{il, ie, jl, je\}$ corresponds to the level of investment in R&D made by each firm in the first-stage of the game. Finally, f_{ie} and f_{je} are fixed costs due to the exporting activities for firms located in country a and b , respectively. Note that there are four groups of firms and within each group firms are heterogeneous in marginal costs. After solving the output stage, the following equilibrium output expressions for market a and market b respectively, read:

MARKET a

$$\begin{aligned}
q_{il}^{a*} &= \frac{a_a - (n_a + n_{be} + 1)c_{il} + \sum_{\forall il} c_{il} + \sum_{\forall ie} c_{ie} + \sum_{\forall je} c_{je}}{n_a + n_{be} + 1} \text{ for } il = 1, 2, \dots, (n_a - n_{ae}) \\
q_{ie}^{a*} &= \frac{a_a - (n_a + n_{be} + 1)c_{ie} + \sum_{\forall il} c_{il} + \sum_{\forall ie} c_{ie} + \sum_{\forall je} c_{je}}{n_a + n_{be} + 1} \text{ for } ie = 1, 2, \dots, n_{ae} \\
q_{je}^{a*} &= \frac{a_a - (n_a + n_{be} + 1)c_{je} + \sum_{\forall il} c_{il} + \sum_{\forall ie} c_{ie} + \sum_{\forall je} c_{je}}{n_a + n_{be} + 1} \text{ for } je = 1, 2, \dots, n_{be} \\
Q^{a*} &= \frac{(n_a + n_{be})a_a - \sum_{\forall il} c_{il} - \sum_{\forall ie} c_{ie} - \sum_{\forall je} c_{je}}{n_a + n_{be} + 1}
\end{aligned}$$

MARKET b

$$\begin{aligned}
q_{jl}^{b*} &= \frac{a_b - (n_b + n_{ae} + 1)c_{jl} + \sum_{\forall jl} c_{jl} + \sum_{\forall je} c_{je} + \sum_{\forall ie} c_{ie}}{n_b + n_{ae} + 1} \text{ for } jl = 1, 2, \dots, (n_b - n_{be}) \\
q_{je}^{b*} &= \frac{a_b - (n_b + n_{ae} + 1)c_{je} + \sum_{\forall jl} c_{jl} + \sum_{\forall je} c_{je} + \sum_{\forall ie} c_{ie}}{n_b + n_{ae} + 1} \text{ for } ie = 1, 2, \dots, n_{ae} \\
q_{ie}^{b*} &= \frac{a_b - (n_b + n_{ae} + 1)c_{ie} + \sum_{\forall jl} c_{jl} + \sum_{\forall je} c_{je} + \sum_{\forall ie} c_{ie}}{n_b + n_{ae} + 1} \text{ for } je = 1, 2, \dots, n_{be} \\
Q^{b*} &= \frac{(n_b + n_{ae})a_b - \sum_{\forall jl} c_{jl} - \sum_{\forall je} c_{je} - \sum_{\forall ie} c_{ie}}{n_b + n_{ae}}
\end{aligned}$$

By making use of the first-order conditions it happens that at equilibrium, $p_a^* = c_s + q_s^{a*}$ for $s = il, ie, je$ and $p_b^* = c_s + q_s^{b*}$ for $s = jl, ie, je$. Then the reduced form expressions for profits are,

$$\pi_{il}^* = (q_{il}^{a*})^2 - \frac{\gamma}{2} x_{il}^2 \text{ for } il = 1, 2, \dots, (n_a - n_{ae}) \quad (5)$$

$$\pi_{ie}^* = (q_{ie}^{a*})^2 + (q_{ie}^{b*})^2 - \frac{\gamma}{2} x_{ie}^2 - f_{ie} \text{ for } ie = 1, 2, \dots, n_{ae} \quad (6)$$

$$\pi_{je}^* = (q_{je}^{a*})^2 + (q_{je}^{b*})^2 - \frac{\gamma}{2} x_{je}^2 - f_{je} \text{ for } je = 1, 2, \dots, n_{be} \quad (7)$$

$$\pi_{jl}^* = (q_{jl}^{b*})^2 - \frac{\gamma}{2} x_{jl}^2 \text{ for } jl = 1, 2, \dots, (n_b - n_{be}) \quad (8)$$

First-stage: competition in R&D

Firms are now deciding on the level of investment in R&D taking into account that each firm's marginal cost is a decreasing function of such level and, since there are public spillovers, also decreasing on a proportion of the aggregate investment of all the firms in their corresponding local market. Also, in case firms are exporters they profit from positive learning externalities which we assume to be proportional to the

number of firms present in the foreign market. In particular, marginal costs for the respective firms read:

$$\begin{aligned}
c_{il} &= A_{il} - (1 - \beta)x_{il} - \beta\left(\sum_{\forall il} x_{il} + \sum_{\forall ie} x_{ie}\right) \text{ for } il = 1, 2, \dots, (n_a - n_{ae}) \\
c_{ie} &= A_{ie} - (1 - \beta)x_{ie} - \beta\left(\sum_{\forall il} x_{il} + \sum_{\forall ie} x_{ie}\right) - \tau(n_b + n_{ae}) \text{ for } ie = 1, 2, \dots, n_{ae} \\
c_{je} &= A_{je} - (1 - \beta)x_{je} - \beta\left(\sum_{\forall jl} x_{jl} + \sum_{\forall je} x_{je}\right) - \tau(n_a + n_{be}) \text{ for } je = 1, 2, \dots, n_{be} \\
c_{jl} &= A_{jl} - (1 - \beta)x_{jl} - \beta\left(\sum_{\forall jl} x_{jl} + \sum_{\forall je} x_{je}\right) \text{ for } jl = 1, 2, \dots, (n_b - n_{be})
\end{aligned}$$

where $A_s, s = \{il, ie, jl, je\}$ are the baseline marginal costs for each firm, i.e. those corresponding to no-R&D activity nor exports. Note that they are possibly different for any firm. Besides, $\beta \in (0, 1)$ is the strength of the public spillovers due to R&D activities and $\tau > 0$ is a parameter measuring the intensity of the learning externality for exporters. Since the equilibrium quantities are also function of aggregates of marginal costs is convenient to present them now,

$$\begin{aligned}
\sum_{\forall il} c_{il} &= \sum_{\forall il} A_{il} - (1 + \beta(n_a - n_{ae} - 1)) \sum_{\forall il} x_{il} - \beta(n_a - n_{ae}) \sum_{\forall ie} x_{ie} \\
\sum_{\forall ie} c_{ie} &= \sum_{\forall ie} A_{ie} - (1 + \beta(n_{ae} - 1)) \sum_{\forall ie} x_{ie} - \beta n_{ae} \sum_{\forall il} x_{il} - \tau n_{ae} (n_b + n_{ae}) \\
\sum_{\forall je} c_{je} &= \sum_{\forall je} A_{je} - (1 + \beta(n_{be} - 1)) \sum_{\forall je} x_{je} - \beta n_{be} \sum_{\forall jl} x_{jl} - \tau n_{be} (n_a + n_{be}) \\
\sum_{\forall jl} c_{jl} &= \sum_{\forall jl} A_{jl} - (1 + \beta(n_b - n_{be} - 1)) \sum_{\forall jl} x_{jl} - \beta(n_b - n_{be}) \sum_{\forall je} x_{je}
\end{aligned}$$

We now obtain the $n_a + n_b$ system of first-order conditions as follows,

$$2q_{il}^{a*} \frac{\partial q_{il}^{a*}}{\partial x_{il}} - \gamma x_{il}^* = 0 \text{ for } il = 1, 2, \dots, (n_a - n_{ae}) \quad (9)$$

$$2q_{ie}^{a*} \frac{\partial q_{ie}^{a*}}{\partial x_{ie}} + 2q_{ie}^{b*} \frac{\partial q_{ie}^{b*}}{\partial x_{ie}} - \gamma x_{ie}^* = 0 \text{ for } ie = 1, 2, \dots, n_{ae} \quad (10)$$

$$2q_{je}^{a*} \frac{\partial q_{je}^{a*}}{\partial x_{je}} + 2q_{je}^{b*} \frac{\partial q_{je}^{b*}}{\partial x_{je}} - \gamma x_{je}^* = 0 \text{ for } je = 1, 2, \dots, n_{be} \quad (11)$$

$$2q_{jl}^{b*} \frac{\partial q_{jl}^{b*}}{\partial x_{jl}} - \gamma x_{jl}^* = 0 \text{ for } jl = 1, 2, \dots, (n_b - n_{be}) \quad (12)$$

It must be noted that the above system implicitly defines the equilibrium level of R&D investment for each firm in the market; and that the fact that there is trade between the two markets supposes that the two markets are connected when firms decide on such R&D investments. That is, the level of investment on R&D made by a non-exporter in market b is affecting the decision on R&D made by a non-exporter in market a although they are not directly competing in output. Then, it is important to give some information, in Lemmas 1 and 2, on the strategic relationship among R&D levels of all different firm's profile.¹ The strategic relationship for non-exporters is the content of Lemma 1.

Lemma 1 *R&D investments undertaken by local non-exporter firms and those made by foreign firms either exporters or non-exporters are strategic substitutes. Besides, the strategic relationship between R&D investments made by firms in the same country (either other non-exporters or exporters) is of strategic complementarity as long as $\beta > \frac{1}{n_{be}+2}$ in market a (similarly, for $\beta > \frac{1}{n_{ae}+2}$ in market b), being of substitutability otherwise.*

Regarding exporters, Lemma 2 reads,

Lemma 2 *R&D investments undertaken by exporters in one market and those made by foreign firms either exporters or non-exporters are strategic substitutes. Besides, the strategic relationship between R&D investments made by firms in the same country can be either of strategic complementarity or substitutability. A sufficient condition for complementarity is $\beta > \frac{1}{n_{be}+2}$ in market a (similarly, for $\beta > \frac{1}{n_{ae}+2}$ in market b), while a sufficient condition for substitutability is $\beta < \frac{1}{n_b+2}$ in market a (similarly, for $\beta < \frac{1}{n_a+2}$ in market b).*

In order to get our main result, we add the set of equations from (9) to (12) for all

¹Also, second order conditions are to be satisfied, this requires a large enough γ , in particular $\gamma > 2 \max\{(\frac{\partial q_{ie}^{a*}}{\partial x_{ie}})^2 + (\frac{\partial q_{ie}^{b*}}{\partial x_{ie}})^2, (\frac{\partial q_{je}^{a*}}{\partial x_{je}})^2 + (\frac{\partial q_{je}^{b*}}{\partial x_{je}})^2\}$.

firms in the same group to get the following four equations,

$$2Q_{il}^{a*} \frac{\partial q_{il}^{a*}}{\partial x_{il}} = \gamma \sum_{\forall il} x_{il}^* \quad (13)$$

$$2Q_{ie}^{a*} \frac{\partial q_{ie}^{a*}}{\partial x_{ie}} + 2Q_{ie}^{b*} \frac{\partial q_{ie}^{b*}}{\partial x_{ie}} = \gamma \sum_{\forall ie} x_{ie}^* \quad (14)$$

$$2Q_{je}^{a*} \frac{\partial q_{je}^{a*}}{\partial x_{je}} + 2Q_{je}^{b*} \frac{\partial q_{je}^{b*}}{\partial x_{je}} = \gamma \sum_{\forall je} x_{je}^* \quad (15)$$

$$2Q_{jl}^{b*} \frac{\partial q_{jl}^{b*}}{\partial x_{jl}} = \gamma \sum_{\forall jl} x_{jl}^* \quad (16)$$

It happens that $\frac{\partial q_{il}^{a*}}{\partial x_{il}} = \frac{\partial q_{ie}^{a*}}{\partial x_{ie}} = 1 - \frac{1+\beta(n_a-1)}{n_a+n_{be}+1}$ and $\frac{\partial q_{jl}^{b*}}{\partial x_{jl}} = \frac{\partial q_{je}^{b*}}{\partial x_{je}} = 1 - \frac{1+\beta(n_b-1)}{n_b+n_{ae}+1}$. By use of expression (9), we know that $\frac{\partial q_{il}^{a*}}{\partial x_{il}} = \frac{\gamma \sum_{\forall il} x_{il}^*}{2Q_{il}^{a*}} = \frac{\partial q_{ie}^{a*}}{\partial x_{ie}}$ which can be substituted in (10) to obtain,

$$\frac{Q_{ie}^{a*}}{Q_{il}^{a*}} \gamma \sum_{\forall il} x_{il}^* + 2Q_{ie}^{b*} \frac{\partial q_{ie}^{b*}}{\partial x_{ie}} = \gamma \sum_{\forall ie} x_{ie}^* \quad (17)$$

Since $\frac{\partial q_{ie}^{b*}}{\partial x_{ie}} > 0$, the above equilibrium condition in (13) implies $\frac{Q_{ie}^{a*}}{Q_{il}^{a*}} \gamma \sum_{\forall il} x_{il}^* < \gamma \sum_{\forall ie} x_{ie}^*$ or put it another way,

$$\frac{\sum_{\forall il} x_{il}^*}{Q_{il}^{a*}} < \frac{\sum_{\forall ie} x_{ie}^*}{Q_{ie}^{a*}} \quad (18)$$

Therefore, the following result is proven:

Proposition 1 *Exporters' R&D intensity relative to output sold in the local market is larger than that of non-exporters in the same market. That is, $\frac{\sum_{\forall il} x_{il}^*}{Q_{il}^{a*}} < \frac{\sum_{\forall ie} x_{ie}^*}{Q_{ie}^{a*}}$ and $\frac{\sum_{\forall jl} x_{jl}^*}{Q_{jl}^{b*}} < \frac{\sum_{\forall je} x_{je}^*}{Q_{je}^{b*}}$.*

Note that this result is obtained considering firms heterogeneity in their initial marginal cost or any possible profile of exporters and non-exporters and just assuming strategic behaviour in the market. Proposition 1 corresponds to our H1 to be tested below.

It is also important to underline that the marginal effect of R&D on local output for an exporter differs from the one on its exports. Notice that, for example for exporters from country a, $\frac{\partial q_{ie}^{b*}}{\partial x_{ie}} = 1 - \frac{1+\beta(n_{ae}-1)}{n_b+n_{ae}+1}$. Then, it is easy to show the following result.

Result 1 *The effect of R&D investments for firms present in both markets is larger on exports than on local sales when foreign markets are more competitive. That is, $\frac{\partial q_{ie}^{a*}}{\partial x_{ie}} < \frac{\partial q_{ie}^{b*}}{\partial x_{ie}}$ if and only if $m_a < (\frac{1+\beta(na-1)}{1+\beta(nae-1)})m_b$ with m_k denoting the total number of firms selling in country k plus one and $k = a, b$.*

Since by definition $n_{ae} \leq n_a$ for a larger marginal effect on exports it is sufficient a more competitive foreign market, considered as more firms selling in such country. This is the content of our H2.

Finally, to complete the empirical part of the paper, it is important to analyse the effect of both the R&D spillovers and the efficiency in doing R&D, on the level of exports and local sales from exporters. After some numerical simulations² the model shows that the higher the level of R&D spillovers, the higher β , the higher both exports and local sales of exporters. Besides, the higher efficiency in doing R&D, that is a lower γ , the higher both exports and local sales of exporters. These latter claims are going to be empirically checked as hypotheses H3 and H4.

3 Data and empirical analysis

The data we use in this study has been drawn from the Spanish Survey on Business Strategies (ESEE, Encuesta de Estrategias Empresariales), for the period 1992-2013. In this sample we have 39,984 observations corresponding to 4,918 firms. The ESEE is an annual survey carried out by the SEPI Foundation that is representative of the Spanish manufacturing firms classified by industry and size. The sampling procedure of the ESEE is as follows. Firms with less than 10 employees are excluded from the sample. Firms that have between 10-200 workers (small firms) are included randomly, accounting for 5% of the population of companies between 10 and 200 workers in 1990. All companies with more than 200 employees (large firms) are requested to participate

²The set of numerical simulations are constructed so that all the technical restrictions are satisfied (non-negativity of equilibrium variables, second order conditions and that final marginal costs are positive). Also the split between exporters and non-exporters is stable. The predictions of these exercises give rise to the statement of H3 and H4.

in the survey, with a participation of about 70% in 1990. To minimize attrition in the initial sample important efforts have been conducted. Thus, annually new firms are incorporated with the same criterion of the base year in order to preserve the representativeness of the sample over time. This data set is remarkably rich in providing firm level information, needed to carry out our empirical analysis. The two variables of interest in this work (exporting and R&D) are obtained from the survey using the following questions. As for the firms exports the relevant question is: *"Indicate the quantity exported by the firm, either directly, or through other firms from the same group, during this year (including exports to the European Union)."* For the R&D expenditure the question we use is: *Indicate the quantity spent by the firm if during this year for undertaking or contracting any R&D activity.*

In what follows, we present the procedure carried out to test the main hypothesis raised in the theoretical section. The first hypothesis proposed in our theoretical section is:

H1: Exporters R&D intensity relative to output sold in the local market is larger than that of non-exporters in the same market.

In order to test whether R&D intensity (defined as R&D expenditure over local sales) of exporters is larger than that on non-exporters, we estimate the following reduced form:

$$RD_{it} = \beta_0 + \beta_1 export_{it} + \beta_2 \log(employment) + \sum_{i=2}^{20} \gamma_i ind_i + \sum_{t=1993}^{2013} \delta_t year_t + u_{it}$$

where, RD_{it} is firm R&D intensity defined as R&D expenditure over local sales in period t , $export_{it}$ is a dummy variable that takes value 1 if the firm exports in period t (and 0 otherwise). Further, we control for firms' size (measured by the log of the number of employees) and introduce in estimation a set of industry and year dummies.

When modelling R&D intensity we find that many firms report a zero value for this ratio. Using a linear regression would imply to ignore the zero lower bound, and therefore it would not properly account the firms decision not to engage in R&D activities. Much of the empirical modellization of R&D intensity has been made using a Tobit

model (a censored regression technique), which combines the Probit likelihood that a zero value will be observed with the linear regression likelihood to explain non-zero values. The Tobit approach certainly improves upon the linear regression by taking into account the existence of a mass-point at zero. However, Papke and Wooldridge (2008) Papke and Wooldridge (2008) have noted that the Tobit model should not be applied where values beyond the censoring point (in our case negative R&D intensity) are unfeasible. Papke and Wooldridge (2008) Papke and Wooldridge (2008) propose to use instead a generalized linear model (GLM) with a binomial distribution and a logit link function.

In Table 1 we report the GLM estimation results for R&D intensity. In these results, we confirm that R&D intensity is higher for exporters than for non exporters, confirming our first hypothesis

	exp (β)
export	4.394*** (0.772)
log(employment)	1.293*** (0.055)
constant	0.0001*** (0.000)
Observations	39,501
The regression includes a full set of year and industry dummies	
*** p < 0.01, ** p < 0.05, * p < 0.10	

Table 1: GLM estimation of R&D intensity on export status

The second hypothesis we test in the empirical work is:

H2: The effect of R&D investments for firm present in both markets is larger on exports than on local sales when foreign markets are more competitive.

It is generally assumed that foreign markets are more competitive than domestic markets. Thus, to test whether the impact of exporters' own R&D is larger on exports than in domestic sales, we estimate the following reduced form:

$$y_{it} = \beta_0 + \beta_1 RD_{it-1} + \beta_2 \log(\text{employment}) + \sum_{i=2}^{20} \gamma_i \text{ind}_i + \sum_{t=1993}^{2013} \delta_t \text{year}_t + u_{it}$$

where, y_{it} is either the rate of growth of domestic sales or the rate of growth of exports, RD_{it-1} is firms R&D intensity in period $t - 1$. As above, we introduce as controls firm size (measured by the log of the number of employees) and a set of industry and year dummies. In these specifications we introduce the R&D intensity variable with one lag as we assume that some time is needed for the investment on R&D to have an effect on firms sales.

	Fixed Effects		OLS	
	Rate of growth of domestic sales	Rate of growth of exports	Rate of growth of domestic sales	Rate of growth of exports
RD intensity t-1	0.312*** (0.034)	1.373** (0.621)	0.283*** (0.032)	1.028*** (0.227)
log(employment)	0.159*** (0.007)	0.112*** (0.019)	0.013*** (0.0016)	0.005 (0.004)
constant	-0.001 (0.158)	-0.003** (0.001)	-0.0916*** (0.0177)	0.160*** (0.050)
Observations	34,468	20,959	34,468	20,959
R-squared	0.164	0.003	0.044	0.013
Test of equality of the estimate of RD intensity t-1				
	χ^2 (1)=3.35	p-value=0.067	χ^2 (1)=6.32	p-value=0.012

Robust standard errors in parentheses. The OLS regression includes a full set of year and industry dummies.

*** p<0.01, ** p<0.05, * p<0.10

Table 2: Impact of R&D intensity on domestic sales and exports

In Table 2 we present two set of estimates for the exports and domestic sales equations. In the first two columns we report the estimates using a panel data fixed effect estimator and in columns 3 and 4 we report the same estimates using OLS. It is possible

observe that both in the fixed effects and OLS estimations, the estimate for lagged export intensity is significantly larger in the exports equation than in the domestic sales one (we reject the null of equality of these coefficients at 7% level in the fixed effect estimation and at almost 1% level in the OLS estimations). Hence, these results suggest that the impact of firms' own R&D is larger on exports than in domestic sales. Therefore, they should be considered as evidence in favour of hypothesis 2.

The third hypothesis we aim to test in this paper is:

H3: An increase in spillovers reduces exporters output both locally and abroad.

In order to test whether spillovers reduce exporters sales in the domestic and in foreign markets, we estimate the following reduced form equation:

$$sales_{it} = \beta_0 + \beta_1 app_{it} + \beta_2 \log(employment) + \sum_{i=2}^{20} \gamma_i ind_i + \sum_{t=1993}^{2013} \delta_t year_t + u_{it}$$

where, $sales_{it}$ is either domestic or foreign sales in period t , app_{it} is a variable capturing firms appropriability from innovation results. We also introduce as controls firms size (measured by the log of the number of employees) and a set industry and year dummies, and control for unobserved firm heterogeneity. In relation to the variable app , many works use the number of patents as a measure of output from the innovative process. Patents are seen as an indicator of firms appropriability of innovation results, against imitation by other firms, for a limited period of time. We consider that the higher the appropriability from the innovations results the lower the spillovers.

The ESEE offers the possibility of using not only patents but also utility models as indicators of appropriability. Appropriability is then calculated as the ratio of the total number of patents and utility models over the total number of firms that assert to have achieved innovations in the firms industrial sector (in %) (20 sectors of the two-digit NACE-93 classification).

In the first column of Table 3 we report the estimation results when we use domestic sales by exporters as the dependent variable. We estimate a sample selection model as

	log(domestic sales)	log(exports)
app	0.096*** (0.028)	0.020 (0.018)
log(employment)	-0.162*** (0.018)	0.762*** (0.037)
constant	3.134*** (0.282)	9.225*** (0.742)
Observations	18468	9749
The regression includes a full set of year and industry dummies		
*** p < 0.01, ** p < 0.05, * p < 0.10		

Table 3: Spillovers, domestic sales and exports

we select for our estimation only those firms exporting. We test for the independence between the main and the selection equation an the LR test of independence of the two equations is rejected, with a $\chi^2(1)$ of 12.10 and a $p - value = 0.00001$. The estimated coefficient for the variable appropriability is positive and statistically significant. If one interprets that more appropriability means less spillovers, then this result gives support for hypothesis 3 raised above.

In the second column of Table 3, we report the estimation results when we use exports as the dependent variable. As before, we start estimating a sample selection model as we select for our estimation only those firms exporting. We test for the independence between the main and the selection equation an the LR test of independence of the two equations cannot be rejected, with a $\chi^2(1)$ of 0.03 and a $p - value = 0.8623$. Therefore, we estimate a linear panel data model using only those observations with a positive value in exports. In order to do so we test for fixed effects versus random effects for firm heterogeneity through a Hausman test. We reject the null that coefficients are equal between these two specification with a $\chi^2(39)$ of 339.11 and $p - value = 0.000$. Therefore in Table 3 we report the fixed effect estimation results. As before, we obtain that the estimated coefficient for the variable appropriability is positive. However, in this case it is not statistically significant.

Finally, we present hypothesis fourth, in which we test the following:

H4: An increase in R&D efficiency makes exports to grow.

In order to test whether R&D efficiency (measured as the propensity to obtain a patent or utility model), we estimate the following reduced form:

$$y_{it} = \beta_0 + \beta_1 \text{propat}_{it} + \beta_2 \log(\text{employment}) + \sum_{i=2}^{20} \gamma_i \text{ind}_i + \sum_{t=1993}^{2013} \delta_t \text{year}_t + u_{it}$$

where, y_{it} is the firms' rate of growth of foreign sales (exports) in period t , propat_{it} is a variable capturing firms propensity to obtain a patent or utility model (this propensity has been predicted in a first stage for all firms using a probit model). We also introduce as controls firms size (measured by the log of the number of employees) and a set industry and year dummies, and control for unobserved firm heterogeneity. In relation to the variable propat , we use the number of patents (or utility models) as a measure of efficiency for the investment in R&D by firms. The ESEE offers the possibility of using not only patents but also utility models as indicators of firms efficiency.

We estimate the propensity to obtain a patent or utility model as there are not many firms patenting or obtaining utility models and due to the fact that this is a dynamic activity. So that firms invest in R&D today and some time in the future might obtain a patent.

In Table 4 we present the estimation results for the fourth hypothesis. As predicted by the theory, the estimate for propat is positive and significant, suggesting that the higher the propensity to patent (that is our measure for R&D efficiency) the higher the firms exports growth, what confirms the results for hypothesis 4.

	β
propat	0.980** (0.451)
log(employment)	0.816*** (0.055)
constant	9.941*** (0.894)
Observations	11,289
The regression includes a full set of year and industry dummies	
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$	

Table 4: Panel data (fixed effect) estimation of domestic sales on R&D efficiency

4 Conclusions

This paper has studied theoretically and empirically the linkages between R&D and output decisions in an international oligopoly setting with heterogeneous firms and the presence of knowledge and learning spillovers. The model has produced a number of testable hypotheses that have been tested for a sample of Spanish manufacturing firms classified by industry and size. Our findings confirm that an exporter invests in R&D more than a non-exporter in relative terms. R&D investments have an effect on the exporters allocation of outputs across markets. We show that the effect of R&D on exports is larger than on local sales. Besides, the size of knowledge spillovers affects negatively the level of both exports and domestic sales made by exporters. Finally, an increase in R&D productivity would positively affect international flows.

A Expressions

Here we show the precise expressions for the derivatives of the equilibrium outputs with respect to the level of investment in R&D of any firm.

MARKET A

	$\frac{\partial q_{il}^{a*}}{\partial x_{il}} = \frac{\partial q_{ie}^{a*}}{\partial x_{ie}} = 1 - \frac{1-\beta+\beta n_a}{n_a+n_{be}+1} > 0$
$\frac{\partial q_{il}^{a*}}{\partial x_{il'}} = \frac{\partial q_{il}^{a*}}{\partial x_{ie}} = \frac{\partial q_{ie}^{a*}}{\partial x_{ie'}} = \frac{\partial q_{ie}^{a*}}{\partial x_{il}} = \beta - \frac{1-\beta+\beta n_a}{n_a+n_{be}+1} > 0$	iff $\beta > \frac{1}{n_{be}+2}$
	$\frac{\partial q_{il}^{a*}}{\partial x_{je}} = \frac{\partial q_{ie}^{a*}}{\partial x_{je}} = -\frac{1-\beta+\beta n_{be}}{n_a+n_{be}+1} < 0$
	$\frac{\partial q_{il}^{a*}}{\partial x_{jl}} = \frac{\partial q_{ie}^{a*}}{\partial x_{jl}} = -\frac{\beta n_{be}}{n_a+n_{be}+1} < 0$
	$\frac{\partial q_{je}^{a*}}{\partial x_{je}} = 1 - \frac{1-\beta+\beta n_{be}}{n_a+n_{be}+1} > 0$
	$\frac{\partial q_{je}^{a*}}{\partial x_{jl}} = \beta - \frac{\beta n_{be}}{n_a+n_{be}+1} > 0$
	$\frac{\partial q_{je}^{a*}}{\partial x_{ie}} = \frac{\partial q_{je}^{a*}}{\partial x_{il}} = -\frac{1-\beta+\beta n_a}{n_a+n_{be}+1} < 0$

MARKET B

$\frac{\partial q_{il}^{b*}}{\partial x_{jl}} = \frac{\partial q_{je}^{b*}}{\partial x_{je}} = 1 - \frac{1-\beta+\beta n_b}{n_b+n_{ae}+1} > 0$
$\frac{\partial q_{il}^{b*}}{\partial x_{je}} = \frac{\partial q_{je}^{b*}}{\partial x_{jl}} = \beta - \frac{1-\beta+\beta n_b}{n_b+n_{ae}+1} > 0$
iff $\beta > \frac{1}{n_{be}+2}$
$\frac{\partial q_{il}^{b*}}{\partial x_{ie}} = \frac{\partial q_{je}^{b*}}{\partial x_{ie}} = -\frac{1-\beta+\beta n_{ae}}{n_b+n_{ae}+1} < 0$
$\frac{\partial q_{il}^{b*}}{\partial x_{il}} = \frac{\partial q_{je}^{b*}}{\partial x_{il}} = -\frac{\beta n_{ae}}{n_b+n_{ae}+1} < 0$
$\frac{\partial q_{ie}^{b*}}{\partial x_{ie}} = 1 - \frac{1-\beta+\beta n_{ae}}{n_b+n_{ae}+1} > 0$
$\frac{\partial q_{ie}^{b*}}{\partial x_{jl}} = \beta - \frac{\beta n_{ae}}{n_b+n_{ae}+1} > 0$
$\frac{\partial q_{ie}^{b*}}{\partial x_{je}} = \frac{\partial q_{ie}^{b*}}{\partial x_{jl}} = -\frac{1-\beta+\beta n_b}{n_b+n_{ae}+1} < 0$

References

- Atkeson, A. and Burstein, A. T. (2010). Innovation, firm dynamics, and international trade. *Journal of Political Economy*, 118(3):433–484.
- Aw, B. Y., Roberts, M. J., and Yi Xu, D. (2011). R&D investment, exporting, and productivity dynamics. *The American Economic Review*, 101(4):1312–1344.
- Bustos, P. (2011). Trade liberalization, exports, and technology upgrading: Evidence on the impact of mercosur on argentinian firms. *The American Economic Review*, 101(1):304–340.
- Costantini, J. and Melitz, M. J. (2008). *The Organization of Firms in a Global Economy*, chapter The Dynamics of Firm Level Adjustment to Trade Liberalization, pages 107–141. Harvard University Press, Cambridge, MA.
- Greenaway, D. and Kneller, R. (2007). Firm heterogeneity, exporting and foreign direct investment. *The Economic Journal*, 117(517):F134–F161.
- Máñez, J. A., Rochina-Barrachina, M. E., Sanchis, A., and Sanchis, J. A. (2009). The role of sunk costs in the decision to invest in R&D. *The Journal of Industrial Economics*, 57(4):712–735.
- Máñez, J. A., Rochina-Barrachina, M. E., and Sanchis-Llopis, J. A. (2015). The dynamic linkages among exports, R&D and productivity. *The World Economy*, 38(4):583–612.
- Navas-Ruiz, A. and Sala, D. (2007). Technology adoption and the selection effect of trade. *Working Paper 2007/58*.
- Papke, L. E. and Wooldridge, J. M. (2008). Panel data methods for fractional response variables with an application to test pass rates. *Journal of Econometrics*, 145(1):121–133.
- Petit, M.-L. and Sanna-Randaccio, F. (2000). Endogenous r&d and foreign direct investment in international oligopolies. *International Journal of Industrial Organization*, 18(2):339–367.
- Petit, M. L., Sanna-Randaccio, F., and Sestini, R. (2012). R&D and foreign direct investment with asymmetric spillovers. *Economics of Innovation and New Technology*,

21(2):125–150.

Sutton, J. (1991). *Sunk costs and market structure: Price competition, advertising, and the evolution of concentration*. MIT press.

Van Long, N., Raff, H., and Stähler, F. (2011). Innovation and trade with heterogeneous firms. *Journal of International Economics*, 84(2):149–159.

Wagner, J. (2007). Exports and productivity: A survey of the evidence from firm-level data. *The World Economy*, 30(1):60–82.