SYNERGIES BETWEEN R&D AND EXPORTING STRATEGIES AND THE IMPACT OF THE FINANCIAL AND ECONOMIC CRISES

by

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DECLARATION

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This thesis is submitted to the University of Warwick in support of my application for the degree of Doctor of Philosophy. It has been composed by myself and has not been submitted in any previous application for any degree. All the work presented was carried out by me.

A former version of Chapter 1: "The decision to invest in export and R&D: Adoption sequence and the impact of the financial and the economic crisis" was presented at the 6th Network of Industrial Economist Doctoral Colloquium at Nottingham University, II Workshop KIIS (Knowledge, Innovation and Internationalisation Strategies) at University of Valencia, 41 Simposio de la Asociación Española de Economía-Spanish Economic Association (SAEe) in Bilbao, DRUID Academy Conference 2017 at University of Southern Denmark (Odense) and Academy of Management Annual Meeting in Atlanta. A version of this Chapter is also under review in the journal *Research Policy.*

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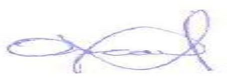
Signature of student: 

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ABSTRACT

The positive effects of export and R&D strategies upon productivity, firm profits, economic growth or innovation have been extensively studied in the economics literature (Bernard and Jensen, 1999; Greenaway and Kneller, 2007; Wagner, 2007; Girma, Görg and Strobl, 2004; Becheikh, Landry and Amara, 2006; Greenaway and Kneller, 2004). Moreover, a positive correlation between the two strategies has also been found in some studies, suggesting positive synergies if jointly adopted (Golovko and Valentini, 2011; Aw, Roberts and Winston, 2007). Therefore, adopting both strategies should be one of the priority goals for any firm. However, very little is known about the adoption dynamics behind the achievement of this target. Sunk costs, learning effects and likely decreasing marginal performance associated with diseconomies of scope from simultaneous adoption, would make it rational for any strategy to be adopted at different points in time rather than simultaneously (Battisti, Colombo and Rabbiosi, 2015; Astebro, Battisti and Colombo, 2016). Nevertheless, to the best of my knowledge, no study has looked to the most likely adoption path and to their drivers. Literature is also limited on the impact that liquidity and demand conditions, associated to both the financial and the economic crisis that started in 2008, may have had upon export and R&D adoption decisions and the depth of their adoption.

To address these research gaps I studied a sample of Spanish manufacturing firms from the period 2000-2014. Interestingly, to the study, the sample covers an entire business cycle as well as the 2008 world financial and economic crisis. Drawing upon the econometric analysis, I provide new insight into the research field through three separate contributions. In the first Chapter, I examine whether sequential is more likely than simultaneous adoption for export and R&D and also whether the sequential adoption order matters. I also investigate the crisis effects upon this sequentiality. In the second Chapter, I analyse the factors that have driven the adoption of these strategies during the crisis, disentangling the effects of the dropping demand and credit crunch. Finally, in Chapter three, to observe the whole picture about the consequences of the crisis upon export and R&D strategies, I extend the analysis started in Chapter 1 to the intensive margin. Findings from these three chapters shed light on the relationship between export and R&D with important industrial policy implications.

Keywords: export, R&D, sequential adoption, simultaneous adoption, asymmetry, crisis, intensity, credit crunch, demand

Introduction

Background

Both export and R&D strategies have an important role in driving economic growth as they foster innovation, increase productivity and generate wealth (De Jong and Vermeulen, 2007; Cohen and Levinthal, 1989; Peters, Roberts and Vuong, 2015; Bernard and Jensen, 1999; Greenaway and Kneller, 2007; among others).[1] As highlighted by the Economic Outlook (November19, 2013) the OECD has pointed out that '*Improving growth in export markets...will help to foster a weak recovery in 2014 and 2015'* in the Spanish economy. Moreover, to build a sustainable comparative advantage in the long run, firms should increase R&D investments that result in new process and product innovations, which will allow them to be competitive in international markets. Therefore, exporter and R&D status are characteristics of the most innovative and productive firms that will drive the economy. That is why it is important to understand how firms engage in R&D and exporting, how the two are related and the channels through which these two strategies are affected.

Although previous studies have generally focused on the impact of innovation (R&D) and exports as if they had independent effects (Wakelin, 1998; Roper and Love, 2002; Cassiman, Golovko and Martínez-Ros, 2010; Cassiman and Golovko, 2011), since Aw et al. (2007), a growing number of works have analysed the impact of joint adoption acknowledging some complementarities between the two strategies (Golovko and Valentini, 2011; Peters et al., 2015). The theoretical literature on the relationship between R&D and export has mainly focused on three arguments to defend a positive effect from R&D to export. First, investment in R&D increases the likelihood of developing a novel (or better quality) product, generating a competitive advantage (Vernon, 1966; Krugman, 1979) that could increase foreign demand (Mowery and Rosenberg, 1979), pushing the firm to internationalise by selling this commodity abroad (Hitt, Hoskisson and Kim, 1997; Girma, Görg and Hanley, 2008). Second,

[1] See Greenaway and Kneller (2007) and Wagner (2007, 2012) for a thorough review of the relationship between export and productivity. In terms of the relationship between R&D and productivity, we can highlight at least three theoretical models that predict a positive effect of investment in R&D on productivity growth. The first is the "R&D capital stock model" of Griliches (1979). The second is the "Active Learning Model" by Ericson and Pakes (1995) and Pakes and Ericson (1998); and, finally, the endogenous growth theory of Romer (1990) and Aghion and Howitt (1992).

investment in R&D also increases the propensity to export (Aw, Roberts and Yi Xu, 2011; Becker and Egger, 2013; Roper and Love, 2002) as the introduction of successful innovation may boost productivity growth (Gu and Tang, 2004; Parisi, Schiantarelli and Sembenelli, 2006; Rochina-Barrachina, Máñez and Sanchis-Llopis, 2010; Máñez, Rochina-Barrachina, Sanchis and Sanchis, 2009), and this improvement in productivity allows firms to *self-select* into international markets (Greenaway and Kneller, 2007; Wagner, 2007). Finally, as suggested by Cohen and Levinthal (1989, 1990), the expansion of organisational knowledge and learning capabilities generated by R&D investments may be also used to foster internationalisation (Dunning, 1993; Kotha, Rindova and Rothaermel, 2001; Lu and Beamish, 2001). Regarding the effects from export to R&D, to meet the needs of a more sophisticated demand, exporters have to invest in new technology in order to be competitive in international markets (Girma et al., 2008). Furthermore, exporting firms are in touch with new technologies, processes or techniques not available in their home markets, expanding firms' capabilities (Álvarez and Robertson, 2004). This new knowledge promotes firms' learning and, thus, increases their innovative capacity, being able to create innovations of better quality (Golovko and Valentini, 2011). Finally, the larger market for exporters when compared with home-based firms allows international firms to spread out the costs associated with R&D investment and, therefore, make R&D investment more profitable (Lileeva and Trefler, 2010; Bustos, 2011). Summarising, export and R&D share some synergies that have to be taken into account in any study of R&D (Export) strategy adoption to avoid misleading results. At the same time, export and R&D share some features which make them more likely to be adopted sequentially rather than simultaneously (Battisti et al., 2015; Astebro et al., 2016). The presence of high sunk costs associated to these activities (Arrow, 1962; Stiglitz, McFadden and Peltzman, 1987; Roberts and Tybout, 1997), jointly with the knowledge base needed to start any of these activities (Cohen and Levinthal, 1989, 1990; Clerides, Lach and Tybout 1998), makes it very difficult for firms to overcome the entry barriers simultaneously. However, research in the field has failed to account for the fact that the strategy adoption sequence and the adoption order matters. It therefore follows that a deeper understanding of the adoption sequence, the order of this adoption, the mechanisms through which export and R&D adoption are affected and the relationship between them would help in boosting the exploitation of the potential complementarities between the two strategies.

Research gap

Despite their importance, very little is known about the adoption dynamics behind export and R&D strategies. Both activities involve important start-up costs that need to be paid in advance, which are largely sunk (Roberts and Tybout, 1997; Arrow, 1962). Beside sunk costs, learning effects and likely decreasing marginal performance associated with diseconomies of scope from simultaneous adoption would make it rational for any strategy to be adopted at different points in time rather than simultaneously (Battisti et al., 2015; Astebro et al., 2016). Hence, *sequential* adoption is often more likely than *simultaneous* adoption. However, while most of the existing studies are based on the observation of joint adoption of the two strategies (Cassiman and Veugelers, 2006; Miravete and Pernias, 2006; Kretschmer, Miravete and Pernias, 2012; among others) our knowledge of their adoption sequence remains very limited. Moreover, even if two strategies share some important synergies, symmetry between them is not implied. That is, when sequential adoption between export and R&D is evaluated, it is important to take into account that adding R&D when the firm was already exporting is not the same as adding exporting when the firm was already performing R&D. The learning process involved in any of the strategies may be behind both the explanation of the sequential adoption and the asymmetries in this sequentiality. In addition, given the importance of financial constraints and demand conditions in explaining export and R&D behaviour (Chaney, 2016; Muûls, 2008; Manova, 2013; Brealey, Leland and Pyle, 1977; Arrow, 1962; Lev, 2000; Belke, Oeking and Setzer, 2014; Esteves and Rua, 2015; Hall, 1991; Aghion, Askenazy, Berman, Cette and Eymard, 2012) the last world financial and economic crisis, which started in 2008, may have had some consequences upon the dynamics of the two strategies evaluated and their symmetries/asymmetries. Finally, in order to observe the whole picture concerning the consequences of the crisis upon export and R&D, not only should the extensive margins (percentage of exporting/R&D firms) be evaluated but, also, their intensity (amount exported/invested in R&D). In their study about the trade collapse during 2008/2009, Behrens, Corcos and Mion (2013) conclude that 97% of the Belgium change in exports was due to changes in the intensive margin. In the same vein, Battisti and Stoneman (2003) and Pulkki and Stoneman (2013) works show the importance of the intensive margin in the diffusion of new technologies.[2] Thus, it is important for any study related with export and R&D to analyse both the extensive and intensive margin.

Research questions

In the light of the research gaps highlighted above, this thesis pursues three main objectives:

1. *What is the adoption sequence of R&D and export decision?*
2. *What are the impacts of the 2008 financial and the economic crises upon the R&D and export decision?*
3. *What is the relationship between R&D and export intensive and extensive margins of adoption and how they were affected by the 2008 financial and economic crises?*

To answer the first research question, the first contribution explores whether export and R&D are strategies adopted simultaneously or sequentially and the direction of their adoption sequence. The second contribution focuses on the two exogenous shocks suffered from 2008, namely, the credit crunch and the dramatic drop in internal demand and channels through which they affected export and R&D adoption. Finally, in order to observe the whole picture of the adoption dynamics as well as the effects of the crises the study shall analyse the crisis effects, not only in the adoption of the strategies (extensive margin) but, also, in the intensity of them and their synergies.

The main hypotheses put forward to answer the first question is that learning entry barriers are the main drivers of the timing of the adoption decision, making sequential adoption more likely than simultaneous adoption. The different learning processes involved in export and R&D should also explain the asymmetries in the direction of the adoption sequence. Regarding the second question, I argue that during the crisis firms were affected by liquidity constraints as well as the recession that significantly affected consumer demand. In particular, firms were liquidity constrained and had no funds for

[2] Battisti and Stoneman (2003) conclude that (in the case of CNC technology in the UK metalworking and engineering industry) after 30 years of first usage, although the inter-firm diffusion (extensive margin) was nearing 82%, the overall diffusion was only 22%.

their investments, which forced them to choose between different investments plans. Due to the long term nature of R&D when compared with the short term nature of exports it is more likely that firms have chosen to adopt export rather than R&D. Moreover, the drop in internal demand has also had different effects upon export and R&D. On the one hand, excess capacity (below optimal level of production) pushed firms to sell abroad. On the other hand, even if the opportunity cost theory predicts that during downturns R&D investments should increase, the lack of internal funds made it impossible to do so. Finally, to answer the third question I argue that the above effects did affect not only the extensive (decision to adopt) but, also, the intensive margins (depth of use) of both exports and R&D.

Contributions and thesis overview

This study addresses the need for a better understanding of the relationship between export and R&D. In doing so, it intends to fully contribute to the understanding of how firms can exploit the potential synergies that research in the field have extensively confirmed between the two strategies (Golovko and Valentini, 2011; Peters et al., 2015).

In Chapter 1, using a probabilistic, a survival and a performance based approach, I analyse whether export and R&D are adopted simultaneously or sequentially and, in the latter case, the direction of their adoption sequence; in other words, whether the effect of adding R&D when the firm was already exporting is the same as adding export when the firm was already performing R&D. I also test whether the world financial and economic crisis had any impact upon the sequential adoption. The research questions addressed here are – *is it more likely that export and R&D are adopted sequentially or simultaneously; does the adoption order matter; has the crisis affected sequential adoption?*

Building on the results of the first Chapter, Chapter 2 sheds more light on the factors driving the adoption of export and R&D during the crisis period. Given that during the crisis economies were hit by two unambiguous exogenous shocks with possible consequences upon export and R&D, here the attempt is to disentangle the effects of the dropping demand and credit crunch upon the adoption of these activities. Conversely, when the economy is hit by a negative demand shock and firms are producing at very low capacities, the free resources may be used to increase their efforts towards international markets (Belke et al., 2014; Esteves and Rua, 2015). After the negative shock, more firms will be willing to pay the sunk costs and substitute domestic sales by exports, since the costs of excess capacity would be higher than the entry costs and the low expectations for the domestic demand may push firms to export as the only way to survive. Furthermore, as suggested by the opportunity cost theory (Hall, 1991; Aghion and Saint-Paul, 1998), firms can allocate their resources to current production or to productivity-enhancing activities (R&D). Therefore, during expansive cycles (characterised by a strong demand) devoting resources to R&D activities would mean detracting resources from current production, implying high opportunity costs for firms. That is why during growth periods it will be optimal for firms to use their resources for current production. Meanwhile, during recessions and the resulting decrease in the opportunity costs of R&D, it would be optimal to allocate resources to R&D activities. On the other hand, given the important sunk costs involved in export and R&D activities (Roberts and Tybout, 1997; Arrow, 1962), the credit crunch suffered by the Spanish economy from 2008 onwards may have had some consequences upon export and R&D adoption. Therefore, the aim of the second Chapter it is to find an answer for the questions – *have the two exogenous shocks suffered by the Spanish economy affected export and R&D adoption? Have they equally affected both strategies? Are the effects of internal and external liquidity constraints equal for export and R&D?*

Finally, Chapter 3 expands the analysis completed in Chapter 1 to the intensity of export and R&D. When analysing the synergies between export and R&D, undertaking the evaluation for only the extensive margin and ignoring the intensity of these strategies may, riskily, lead to misleading results. Thus, this final chapter sheds more light on the effects of export intensity upon R&D intensity and vice versa. Again, special attention will be paid to the effects of the world financial and economic crisis upon the relationship between the two strategies. The research questions followed here are: *does the export intensity affect R&D intensity? Does the R&D intensity affect export intensity? Has this relationship changed because of the crisis? Are these effects different depending on the type of goods exported?*

CHAPTER 1: THE DECISION TO INVEST IN EXPORT AND R&D: ADOPTION SEQUENCE AND THE IMPACT OF THE FINANCIAL AND THE ECONOMIC CRISIS

Abstract

Exports and R&D strategies, when jointly adopted generate important synergies; however, little is known about their adoption sequence. This chapter aims to shed more light on whether they are adopted simultaneously or sequentially and, in the latter case, on the direction of their adoption sequence. The empirical evidence is based on manufacturing firms drawn from the Spanish Technological Innovation Panel from 2004 to 2013. By using both a probabilistic- and a performance-based approach, it is found that: sequential adoption is more frequent than simultaneous adoption and the adoption sequence is not symmetric. The 2008 crisis has increased, more, the likelihood of joint adoption for firms already performing R&D than for those companies already exporting reinforcing the asymmetry in the adoption strategy with important industrial policy implications. It is also found that adopting one strategy when the other is already in place is more likely than adopting this strategy in isolation. The higher likelihood of sequential adoption and the asymmetries in this sequence can be explained through the different learning effects involved in both activities.

Introduction

Both internationalisation and innovative activities (R&D) are strategies that could improve firms' performance and, therefore, economic growth. If jointly adopted, R&D and export strategies should allow firms to successfully compete in international markets (Becker and Egger, 2013; Roper and Love, 2002) and a positive association between R&D and internationalisation has, indeed, been found in the literature, suggesting the presence of clear benefits from their joint adoption (Golovko and Valentini, 2011; Aw et al., 2007; Peters et al., 2015). However, despite their importance, very little is known about their adoption dynamics. Typical of any strategies, sunk costs,[3] learning effects and likely decreasing marginal performance associated with diseconomies of scope from simultaneous adoption would make it rational for any strategies to be adopted at different points in time rather than simultaneously (Battisti et al., 2015; Astebro et al., 2016). Hence, *sequential* adoption is often more likely than *simultaneous* adoption. While most of the existing studies are based on the observation of the joint adoption of two strategies (see for example Cassiman and Veugelers 2006; Miravete and Pernias 2006; Kretschmer et al., 2012),

[3] Das, Roberts and Tybout (2007) estimate average sunk costs for foreign market entry of more than 400,000 US$ for Colombian industries.

knowledge of their adoption sequence remains very limited. Battisti et al. (2015) is one of the first papers that tests and empirically distinguishes sequential from simultaneous adoption. Using a probability approach, they define "*simultaneous adoption when the likelihood of the simultaneous adoption of two innovations is greater than the likelihood of adopting each of them in isolation and… sequential adoption when a prior adoption decision of one innovation leads to a posterior increase in the likelihood of the adoption of the other innovation*" (Astebro et al., 2016, p.3). They also demonstrate that in the presence of sequential adoption, the adoption order matters and should be taken into account. That is, when sequential adoption between export and R&D is evaluated, it is important to keep in mind that adding R&D when the firm was already exporting is not the same as adding exporting when the firm was already performing R&D. In this study, it is claimed that it is the experience and knowledge derived from pre- and post-entry of a strategy that explains both sequential adoption and any asymmetries in the sequentiality of adoption. This also suggests that any study of R&D (Export) strategy adoption in isolation could be highly misleading if the export (R&D) strategy decision was ignored. The initial adoption of any one strategy might make the adoption of the other strategy more likely.

To fill this gap in the understanding of the R&D and export adoption dynamics, I first follow the *probability approach* to the study of sequential adoption strategies proposed by Battisti et al. (2015). I then extend it to the traditional *profitability approach* based upon the investigation of the gains derived from the various adoption strategies. As a robustness test, individual probit and survival models are also used. The probability approach relies on transition probabilities and discrete choice models for dynamic panel data to identify the direction of the adoption decision. While these models can handle both simultaneous and sequential adoption, the Wooldridge (2005) approach is used to correct for unobserved heterogeneity and initial conditions problems. Further to using probability models, I use a *profitability approach* based on the growth regressions via the panel-corrected standard error model to assess the expected gains associated with the various adoption strategies. The survival analysis is carried out by estimating a complementary log-log model.

The evidence is based on Spanish panel data for the period 2004-2013, containing information on the R&D and export strategy of around 6,300 manufacturing firms leading to almost 41,000 observations. The sample is drawn from the *Spanish Technological Innovation Panel* (PITEC, hereafter). PITEC represents the Spanish contribution to the Europe-wide Community Innovation Survey. Differently from the vast majority of other European countries, the Spanish CIS is a longitudinal unbalanced panel dataset enabling me to carry out analysis of the adoption timing and adoption sequence of the various strategies while controlling for internal and external environmental factors. Of interest to the study, the sample includes the years of a whole business cycle as well as the 2008 financial and the economic crisis, allowing me to explore the sensitivity of the adoption sequence not only to internal conditions but also to external shocks and changes in the external environment.

Overall, the findings contribute to the understanding of the synergies between internationalisation and R&D strategies with important implications for public policy.

The rest of the chapter is organised as follows. Section 2 summarises the related literature and introduces the main hypotheses. In Section 3, the data and some preliminary evidence of the firms' adoption strategies are detailed. Section 4 is devoted to the methodology and variables used in the study. Section 5 presents and discusses the results. Finally, Section 6 concludes.

Related literature and main hypotheses

Export and R&D activities are regarded as strategies that may reinforce one another and empirical evidence corroborates their positive association (Hallward-Dreimeier, Iarossi and Sokoloff, 2002; Baldwin and Gu, 2003; Iacovone and Javorcik, 2012). On the one hand, investment in R&D increases the propensity to export (Aw et al., 2011; Becker and Egger, 2013; Roper and Love, 2002) as the introduction of a successful innovation may boost productivity growth (Gu and Tang, 2004; Parisi et al., 2006; Rochina-Barrachina et al., 2010; Máñez et al., 2009), and this improvement in productivity allows firms to enter into international markets (Greenaway and Kneller, 2007; Wagner, 2007). Similarly, and independent of the increase in productivity, the development of a novel (or better quality) product could increase foreign demand pushing the firm to internationalise by selling its goods abroad (Hitt et al., 1997). Finally, as suggested by Cohen and Levinthal (1989, 1990), the expansion of organisational knowledge and learning capabilities generated by R&D investments may also be used to foster internationalisation (Dunning, 1993; Kotha et al., 2001; Lu and Beamish, 2001). On the other hand, international trade allows firms to discover new technologies, processes or techniques not available in their home markets, expanding firms' capabilities (Álvarez and Robertson, 2004). This new knowledge promotes firms' learning and, thus, positively contributes to the performance of R&D investment.[4] Moreover, the larger market for exporters when compared with home-based firms allows international firms to spread the costs associated with R&D investment and, therefore, make R&D investment more profitable (Lileeva and Trefler, 2010; Bustos, 2011). Within this literature, Bustos (2011), Aw, Roberts and Xu (2008), Atkeson and Burstein (2010) and Costantini and Melitz (2008) are some of the studies showing the positive impact of export on R&D. In particular, Bustos (2011) predicts that during periods of liberalisation of trade, (both new and the oldest) exporting firms improve their technology faster than those that do not export. In the same vein, Atkeson and Burstein (2010) and Constantini and Melitz (2008) argue that trade liberalisation can increase the amount of R&D performed.

Golovko and Valentini (2011), Aw et al. (2007) and Peters et al. (2015) explicitly analyse the complementarities between these two strategies.[5] Golovko and Valentini (2011) define complementarity as in Milgrom and Roberts (1990). That is, adding an activity while the other activity is already being performed has a higher incremental effect on performance than adding the same activity in isolation. They conclude that firms that invest in both activities (joint adoption) are characterised by higher growth rates than those that do only one or none of them, and that the performance from any one activity increases as the level of the other increases. Aw et al. (2007) and Peters et al. (2015) study the effects of different combinations of export and innovation across productivity improvements. Aw et al. (2007) find a positive relationship between exports and future productivity. They also find that exporters that also invest in R&D have higher future productivity than firms that only export. Finally, Peters et al. (2015), for a sample of five high-tech German industries, conclude that exporting firms have a

[4] This new knowledge acquired by the firm because of its export activity has been labelled "learning-by-exporting" and it has been widely studied in the applied industrial organisation research. See for example Golovko and Valentini (2014), Love, Roper and Vahter (2014) or Álvarez and Robertson (2004).

[5] Contrary to the studies analysing the synergies between internal and external innovation activities (Battisti and Iona, 2009; Berchicci, 2013; Hagedoorn and Wang, 2012; Schmiedeberg, 2008; Veugelers and Cassiman, 1999) the synergies between export and R&D have received little attention.

higher payoff from R&D investment, invest in R&D more frequently than firms that only sell in the domestic market and, subsequently, have higher rates of productivity growth which means that expenditure on R&D facilitates a firm's ability to benefit from exporting. Overall, the literature consistently indicates that when analysing the probability of exporting or performing R&D a virtuous circle is associated with their joint adoption. Therefore, the two strategies cannot be treated in isolation as this could lead to biased conclusions and also to overestimating the impact of individual adoption. When the probability of carrying out R&D is analysed, export status should be taken into account and vice versa for exports. However, the majority of studies tend to focus on the evidence based on joint adoption and/or on only one adoption sequence, e.g., R&D first and export second, lacking clarity on the most frequently observed adoption sequence and on whether these strategies are simultaneously or sequentially adopted. Battisti et al. (2015) and Astebro et al. (2016) argue that strategies are generally more likely to be adopted sequentially rather than simultaneously. [6] In the case of export and R&D this sequentiality may be explained through the effects of experience and knowledge on pre- and post-entry. Exporting firms, due to interactions with foreign agents, have access to information not available within their borders. These firms are, therefore, exposed to higher knowledge inputs that allow them to accumulate market and technological information (Grossman and Helpman, 1991, 1993). This new knowledge expands firms' capabilities (Álvarez and Robertson, 2004) that can be used to foster innovation (Salomon and Shaver, 2005). Likewise, investment in R&D is an important process that expands organisational knowledge and learning capabilities over time (Cohen and Levinthal, 1989, 1990). Therefore, internationalisation may be driven by the firm's efforts to leverage its improvements in organisational knowledge and learning capabilities (Dunning, 1993; Kotha et al., 2001; Lu and Beamish, 2001). Arguably, learning associated to both R&D and export strategies can constitute potentially high and risky entry barriers to overcome simultaneously, stretching the organisational capabilities and generating

[6] They argue, although they do not directly test, that this can be due to a number of reasons such as diseconomies of scope, managerial and organisational complexity, convex adjustment costs, high sunk costs associated with investment in human capital, internal reorganisation and infrastructure (see Battisti et al., 2015 and Astebro et al., 2016).

significant diseconomies of scope and diminishing returns (Aw at al. 2011). Hence, it is posited that:

HYPOTHESIS 1. Learning barriers associated with each strategy can generate diseconomies of scope from their simultaneous adoption, making export and R&D strategies more likely to be adopted sequentially, from R&D/export to both, rather than simultaneously from none to both *(sequential versus simultaneous adoption)*.

Moreover, the presence of a higher knowledge base generated by either R&D or export activities provides a greater absorptive capacity and organisational flexibility (Cohen and Levinthal, 1989, 1990; Clerides et al., 1998) than in their absence. Therefore, not only should sequential adoption be more likely than simultaneous adoption, but also adding one strategy when the other is already in place should be more likely than adopting each in isolation. Hence, aligned with the previous hypothesis it is postulated:

HYPOTHESIS 2. The spillovers and learning generated by the previous adoption of a strategy make the adoption of the other strategy more likely than in its absence *(sequential versus individual adoption).*

Regarding the adoption sequence, the literature has argued in favour of both export firms being highly likely to engage in R&D and also for R&D firms being highly likely to also engage in exports, but has never looked at any asymmetries in the direction of the adoption sequence. Arguably, the (fixed and sunk) cost of undertaking R&D is higher than the cost of exporting (Aw et al. 2011). The scale of the investments in intangibles, human capital and capital assets generated by the complexity of R&D, alongside the associated risk and sunk costs, can make investments in R&D significantly higher than for export. On the other hand, the absorptive capacity and knowledge base generated by post-entry R&D firms makes them better positioned to overcome the export knowledge entry barriers than the learning by exporting generated by post-entry exposure to international markets. The largest absorptive capacity is likely to be called for to assimilate scientific knowledge (Leiponen, 2001) and, therefore, this type of knowledge should have the largest impact on the internal capabilities. Moreover, as pointed out by Griffith, Redding and Reenan (2004) and Cohen and Levinthal (1990), a key aspect which will allow firms to take advantage of the positive learning by exporting effects is that firms must possess sufficiently advanced internal R&D

allowing them to absorb the new knowledge. If this is not the case, the positive effects may either not arise or be more moderated. Hence, I posit that whether R&D is adopted first and export second or export first and R&D second is of consequence; and, it is not necessarily symmetric. In particular:

HYPOTHESIS 3. The absorptive capacity and the knowledge base generated by post-entry R&D make the adoption of export - by firms already engaging in R&D - more likely than the opposite (*direction of sequential adoption).*

To corroborate previous hypotheses, given that the complexity of R&D is higher and requires high investments in knowledge base, creating higher barriers to entry than for exporting, firms should be more likely to engage in exports than in R&D. Hence:

HYPOTHESIS 4. Export strategy is more likely to be adopted than R&D for firms without any pre-entry knowledge (*individual adoption*).

Lastly, the 2008 financial crisis caused a major shock across developed and developing economies and it is acknowledged this can have affected both exports and R&D adoption decisions via a number of channels (Máñez, Rochina-Barrachina, Sanchis-Llopis and Vicente-Chirivella, 2014; Bricongne et al., 2012; Chor and Manova, 2012), although with different intensity. Exports may be motivated not only by firm internal conditions and the opportunity to gain access to global market demand for own products, but it might also be the result of domestic crisis and a reduction in domestic demand (Greenaway and Kneller, 2007). Hence, sales in international markets may act as a substitute for sales in a national internal market. Belke et al. (2014) have recently corroborated this idea. Using firm-level data for Spain, Portugal, Italy, France, Ireland and Greece, they conclude that domestic demand is relevant for the dynamics of exports, especially for Spain, Portugal and Italy, and more significant during more extreme stages of the business cycle. Secondly, uncertainty of outcome (Brealey et al.,1977), as well as asymmetric information and reluctance to full disclosure (Bhattacharya and Ritter, 1983) associated to new projects and hence new strategies, can make it difficult for prospective funders to calculate the probability of success and future profits, hence creating moral hazard and adverse selection problems (Jensen and Meckling, 1976; Stiglitz and Weiss 1981). Investment in new R&D strategies can generate a large number of intangible assets and higher sunk costs that cannot be used as collateral to the lender (Lev, 2000).[7] The 2008 financial and economic crisis is likely to have exacerbated those factors. Campello, Graham and Harvey (2010) surveyed 1,050 Chief Financial Officers in the US, Europe and Asia to evaluate the effects of the crisis on corporate spending plans. They conclude that due to the credit tightening constrained firms planned deeper cuts in R&D spending. Similarly, Aghion, Angeletos, Banerjee and Manova (2010) for a sample of 21 OECD countries argue that tighter credit constraints contribute to a more pro-cyclical share of long term investment. As later demonstrated by Aghion et al. (2012), López-García, Montero and, Moral-Benito (2013) and Beneito, Rochina-Barrachina and Sanchis-Llopis (2015) when firms are credit constrained the counter cyclicality of R&D is reversed. Beneito et al. (2015) and López García et al. (2013) found that firms' R&D spending is countercyclical for Spanish firms but that credit constraints may reverse this counter cyclicality. Garicano and Steinwender (2016), indeed, corroborate that shocks can reduce the value of long term investments relative to short term ones and that firms are willing to give up some future expected payoffs in order to increase the probability of surviving another day. With regards to this study it would, therefore, imply that during the crisis firms might have been more likely to favour the short term nature of the export, hence selling their products under decreasing domestic demand rather than the long term and more uncertain and intangible nature of the R&D in their investment decision. If export and R&D are activities which reinforce one another, and during credit shocks the value of long term investment is reduced relative to short term, adding export when the firm is already performing R&D may be worthy, but not vice versa. Therefore, the following hypothesis about the presence of asymmetry in sequential adoption during the financial crisis (*asymmetric sequential adoption*) is formulated:

HYPOTHESIS 5. The crisis has reduced the probability that exporting firms embark on R&D strategies (*sequential adoption from export to both*), but not the probability that R&D firms embark on export strategies (*sequential adoption from R&D to both*).

Finally, empirical work analysing the relationship between firms' activities has generally followed two different approaches. The first approach detects synergies and adoption dynamics through the likelihood of adoption of various combinations of

[7] Fifty per cent, or more, of expenditures on R&D are wages and salaries of highly skilled workers, and they generate some intangible assets which in the future will bring benefits to the company (Hall, 2002).

strategies (e.g. Battisti et al., 2015; Astebro et al., 2016; Cassiman and Veugelers, 2006). This is the approach used to define hypotheses 1 to 5. The second approach uses performance (either profitability or productivity) associated with the adoption status of two strategies (e.g. Kretschmer et al., 2012 or Golovko and Valentini, 2011), although with no attention paid to the adoption sequence, e.g., adopting export before R&D or R&D before export. An exception is the work of Peters et al. (2015) who find that, in the case of Germany, exporting firms have a higher payoff from R&D investment and invest in R&D more frequently than firms that only sell in the domestic market. However, the opposite adoption sequence, and hence the causal direction, is not tested. In line with the probability based approach and to corroborate the research hypotheses, the effects of different combinations of export and R&D strategies and their adoption order also on the firm's performance are explored.

Data and descriptive

The dataset used in this study is the Spanish Technological Innovation Panel (PITEC). It represents the contribution of Spain to the Europe-wide Community Innovation Survey (hereafter, CIS) and is the result of the collaboration between the Spanish National Statistics Institute and COTEC Foundation, with the aim of providing data to the CIS.[8] Different from many European Community Innovation Surveys, the Spanish CIS is a panel data covering the period 2003- 2013. The 2003 sample is made of firms with 200 or more employees and a representative sample of firms undertaking intramural R&D. However, in 2004, to increase the representativeness of the survey as well as that of innovative firms, the sample was enlarged to include firms with less than 200 employees undertaking external R&D and no intramural R&D, plus a representative sample of small non-innovative firms (with less than 200 employees). For this reason, I concentrate on the period 2004-2013. [9,10]

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[8] See http://icono.fecyt.es/PITEC/Paginas/por_que.aspx for further details.

[9] The downside of this is that contrary to the small non-innovative firms, small firms receiving any form of public support for R&D or reporting R&D expenses are not randomly chosen. Hence, while the 2004 survey introduced greater sample representativeness of the population of small firms, the representativeness of firms with less than 200 employees could be slightly biased towards firms having internal and/or external R&D (Añón, 2016).

[10] Similar to other innovation surveys, large firms are slightly overrepresented due to the panel nature of the longitudinal sample that sees old firms being more likely to be large. Furthermore, the representativeness of small firms since the 2004 sample was introduced could be biased towards firms having internal or external R&D. Hence, I control for firm size and due care should be taken into account

The longitudinal dimension covers not only an entire business cycle but, of particular interest, also the years of the 2008 crisis. PITEC contains detailed firm-level information on a number of firm characteristics such as ownership, number of employees and turnover. Importantly to this study, PITEC contains information on R&D and export behaviour over time. Firm level data on export and R&D is notoriously difficult to find. Datasets such as FAME, AMADEUS or ORBIS contain some information on exports, but very limited information on R&D. Hence, PITEC is deemed to be the best database for observing the adoption dynamics of R&D and export strategies over time (Barge-Gil, 2010).[11] The final working sample is an unbalanced longitudinal panel of 5,304 firms in 2004 reducing to 4,549 firms in 2013.[12]

To gain a better insight into the adoption sequence Table 1, 2 and 3 report the transition probability matrixes for the whole observation period (2004-2013) and for the period before and after the 2008 financial crisis. For each period the transition probability matrix shows the probability that a firm adopts a strategy in t (reported in the top row), given its adoption status in t-1 (reported in the first column).

Table 1. Transition Probabilities (whole period)

	None$_t$	**Export only$_t$**	**R&D only$_t$**	**Both$_t$**
None$_{t-1}$	78.32	14.11	5.70	1.87
Export only $_{t-1}$	10.60	76.45	1.42	11.53
R&D only $_{t-1}$	14.23	3.88	57.96	23.93
Both$_{t-1}$	1.42	8.38	6.64	83.57

Source: PITEC Survey, 2004-2013

Table 2. Transition Probabilities (2004-2007)

	None$_t$	**Export only$_t$**	**R&D only$_t$**	**Both$_t$**
None$_{t-1}$	84.87	5.31	7.89	1.93
Export only $_{t-1}$	19.63	61.93	3.98	14.46
R&D only $_{t-1}$	15.15	2.16	69.89	12.79
Both$_{t-1}$	2.39	5.31	7.89	78.37

Source: PITEC Survey, 2004-2013

in assessing the potential impact that the sample composition might have on the interpretation of the findings.

[11] PITEC contains information on both manufacturing and services companies. However, this study is concentrated on the sample of manufacturing firms. Exporting services may be completely different from exporting manufacturing goods since not all services are tradable, tangible or durable. Also, the underlying innovation processes can vary substantially between manufacturing and service firms (Hoffman, Parejo, Bessant and Perren, 1998) with limited scope and applicability of formal R&D in some services (Battisti, Gallego, Rubalcaba and Windrum, 2015b).

[12] See Appendix IV for the results with a balanced panel.

Table 3. Transition Probabilities (2008-2013)

	None$_t$	**Export only$_t$**	**R&D only$_t$**	**Both$_t$**
None$_{t-1}$	76.62	17.06	4.97	1.85
Export only $_{t-1}$	8.57	79.70	0.85	10.88
R&D only $_{t-1}$	13.72	4.82	51.42	30.03
Both$_{t-1}$	1.05	9.15	4.27	85.53

Source: PITEC Survey, 2004-2013

Table 1 shows that it is far more likely that firms adopt 'export only' (E_t|None$_{t-1}$= 14.11) rather than 'R&D only' strategies (R&D$_t$|None$_{t-1}$ = 5.7). Moreover, as shown in column 'Both$_t$', the likelihood to adopt R&D after export (Both$_t$|E_{t-1}= 11.53) or export after R&D (Both$_t$|R&D$_{t-1}$=23.93) is significantly higher than the likelihood to adopt both in time t (Both$_t$|None$_{t-1}$= 1.87). Hence, sequential adoption is more likely than simultaneous adoption. With regard to sequential versus individual adoption, results in the transition matrix indicate that sequential adoption is also more likely than individual adoption both for export and R&D. As shown in column 'Both$_t$', the likelihood to adopt R&D after export (Both$_t$|E_{t-1}= 11.53) or export after R&D (Both$_t$|R&D$_{t-1}$=23.93) is significantly higher than the likelihood to adopt R&D in isolation (R&D only$_t$|None$_{t-1}$= 5.7) or export in isolation (Export only$_t$|None$_{t-1}$= 14.11). Finally, the results show an asymmetry in the sequential adoption; the likelihood of adding export when the firm was already performing R&D (Both$_t$|R&D$_{t-1}$=23.93) is significantly higher than the likelihood to adopt R&D when the firm was already exporting (Both$_t$|E_{t-1}= 11.53).

Overall the transition matrix suggests that export is more likely to be adopted than R&D, simultaneous adoption of two strategies is less likely than sequential adoption of any single strategy, and also that the adoption sequence matters and it is not symmetric.

The transition matrixes in Tables 2 and 3 indicate that, since the crisis, more firms have engaged in export rather than in R&D activities irrespective of the state of the firm in t-1 (None$_{t-1}$, Export only $_{t-1}$ or R&D only $_{t-1}$). As shown in the first row of the column 'Export only$_t$', the probability to adopt an 'Export only' strategy post-2008 is significantly higher than pre-2008 (E_t|None$_{t-1}^{POST}$ =17.06 and E_t|None$_{t-1}^{PRE}$ = 5.31). The same applies to the decision to adopt an export strategy by R&D firms as shown in the 'R&D only' row of column 'Both$_t$' (Both $_t$|R&D$_{t-1}^{POST}$ = 30.03 and Both $_t$|R&D$_{t-1}^{PRE}$=12.79). The opposite happens for R&D. Post-2008 the likelihood to adopt an 'R&D

only' strategy by firms that in time t-1 adopted neither strategy is lower than pre-2008 ($R\&D_t|None_{t-1}^{POST}$=4.97 and $E_t|None_{t-1}^{PRE}$=7.89, see 'R&D only'$_t$ column). A similar contraction can be observed in the probability that 'Export only' firms in time t-1, also adopt an R&D strategy in time t ($Both_t|E_{t-1}^{POST}$ =10.88 and $Both_t|E_{t-1}^{PRE}$ = 14.46). Contrary to the probability of sequential adoption, the likelihood to adopt both export and R&D simultaneously remains low and almost unchanged before ($Both_t|None_{t-1}^{PRE}$ = 1.93) and after ($Both_t|None_{t-1}^{AFTER}$=1.85) the crisis.

Table 4 reports the preliminary analysis of the differences in firm performance, measured as sales per worker (in euros), for the various adoption strategies and also depending on their adoption sequence.

Table 4. Test of the differences in the performance (sales per worker) for export and R&D strategies undertaken by firms

	Difference (€)		
Individual adoption	Whole period	2004-2007	2008-2013
Export only vs None	66,800.44***	64,833.31***	68,418.51***
R&D only vs None	29,392.34***	20,301.35***	41,872.77***
Export only vs R&D only	37,408.10***	44,531.96***	26,545.75***
Joint adoption			
Both vs None	84,031.2***	67,274.28***	97,589.87***
Sequential adoption			
Both vs Export only	17,230.76***	2,440.971	29,171.36***
Both vs. R&D only	54,638.86***	46,972.94***	55,717.11***

*Source: PITEC Survey, 2004-2013*** Significant at 1% level*

The results suggest that firms performing 'R&D only', 'Export only' or 'Both', have a significantly higher performance than firms that engage in neither strategy with 'Both' being clearly the most rewarding. They also suggest that embarking on 'Export only' generates higher performance than embarking on 'R&D only'. The greater impact of the export strategy is also visible when comparing individual versus sequential adoption. The performance associated with the adoption of export strategies by R&D companies (Both vs R&D only) is higher than the performance generated by the adoption of R&D strategies by export companies (Both vs Export only) indicating a clear asymmetry in the performance from the adoption sequence. Indeed, the joint adoption of both strategies (Both vs None), is the most rewarding strategy irrespective of the adoption sequence (whether sequential or simultaneous). After the crisis, the returns from the adoption of export strategies are consistently higher across the board.

Modelling and variables

Methodology

To test the first four hypotheses concerning the decision to embark on R&D and/or export strategies by firm i in time t, I use discrete choice models for panel data of the type:

$$Y_{it}^{*j} = \beta X_{it-1}' + u_{it}^{j} \qquad (1)$$

where the dependent variable (Y_{it}^{*j}) is a latent (unobservable) variable representing the increase in the relative discounted utility derived from adopting each one strategy j = Export, R&D and X_{it-1}' is a vector of explanatory factors. As this variable is unobservable the dependent variable is proxied by a binary variable (y_{it}^{j}) that takes value one if the relative utility associated with the strategy is positive, namely:

$$y_{it}^{j} = 1 \; if \; Y_{it}^{*j} > 0$$

$$y_{it}^{j} = 0 \; if \; Y_{it}^{*j} < 0$$

By using a probabilistic approach it is tested if the prior adoption decision of any one strategy leads to a posterior increase in the likelihood of adoption of the strategy under consideration. In particular, to test the hypotheses concerning individual adoption, the presence of sequential adoption and the direction of the adoption sequence I introduced in the regression equation a lagged term (y_{it-1}^{r}), aimed at modelling any increase in the likelihood of adoption of any one strategy j associated with the previous adoption of strategy r, r≠j, e.g., if the prior adoption of R&D (Export) increases the probability of adoption of an export (R&D) strategy. The significance of the pre-entry learning effects (if any) associated to each strategy j can be captured via its adoption status in t-1, y_{it-1}^{j}.

To take into account the potential simultaneity in the firms' decisions to export and/or to perform R&D, a bivariate probit is estimated. This specification accommodates both R&D and export adoption dynamics by including past R&D and export status when explaining the current probability to export (perform R&D).

The bivariate probit model is estimated by maximum likelihood assuming a normal non-linear cumulative distribution function as well as random effects. Although the fixed effect model would have had the advantage of allowing the explanatory variables to be correlated with the individual effects, it would have had the shortcoming of eliminating a large number of observations. To allow the individual effect to be correlated with the regressors and to solve the 'initial conditions problem', the Wooldridge (2005) approach is applied.[13] Following this method, the unobserved individual effect (α_i) is conditioned on the initial values of the dependent variable (y_{i1}) and the individual mean of the time-varying covariates ($\bar{x}_i$), allowing for correlation between the individual effect and the observed characteristics:

$$\alpha_i = \alpha_0 + \alpha_1 y_{i1} + \alpha_2 \bar{x}_i + a_i \qquad (2)$$

and therefore:

$$y_{i,t}^{j} \begin{cases} 1\ if\ \theta_0^j y_{it-1}^J + \theta_1^j y_{it-1}^r + \beta^j X_{it-1} + \\ \alpha_0 + \alpha_1 y_{i1} + \alpha_2 \bar{x}_i + a_i + S_i + z_t + u_{it}^j \geq 0 \\ 0\ Otherwise \end{cases} \qquad (3)$$

where θ_0 identifies the significance of *learning from previous use of strategy j*, $\theta_1$accounts for firms' expected profits from exporting to be affected by firms' R&D decisions and vice versa, X_{it-1} is a vector of control variables, plus the usual vector of industry (S_i) and year (z_t) dummies and u_{it} is the error term. Moreover, as mentioned earlier, due to interdependences in the export and R&D decisions the error terms of the two equations are likely to be correlated. Hence, following Battisti et al. (2015) the resulting latent bivariate model is specified as:

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[13] The initial conditions problem arises when the first observation for each firm in a panel does not coincide with the first year of this firm; that is, when we do not have information about firms from the very beginning. Since the first observation for each firm is affected by the same process that will affect the variable from the first year of the observation period, this variable would be endogenous.

$$\begin{cases} y_{i,t}^{Export} = \theta_0^{Export} y_{i,t-1}^{Export} + \theta_1^{Export} y_{i,t-1}^{R\&D} + \beta^{Export} X_{it-1} + \\ \qquad \alpha_i + S_i + z_t + u_{it}^{Export} \quad (4a) \\ y_{i,t}^{R\&D} = \theta_0^{R\&D} y_{i,t-1}^{Export} + \theta_1^{R\&D} y_{i,t-1}^{R\&D} + \beta^{R\&D} X_{it-1} + \\ \qquad \alpha_i + S_i + z_t + u_{it}^{R\&D} \quad (4b) \end{cases}$$

Because one of the purposes of the study is to analyse the impact of learning and spillovers upon the adoption dynamics, special attention will be paid to the significance of the learning effect generated by the previous adoption ($\theta_1^{R\&D}$ in the R&D equation and θ_0^{Export} in the export equation) as well as the spillovers generated by the previous adoption upon the adoption probability of the other strategy (θ_1^{Export} in the export equation and $\theta_0^{R\&D}$ in the R&D equation).

This model allows me not only to test for the presence of sequential adoption and the direction of the adoption sequence but, also, the presence of simultaneous adoption by checking the significance of the correlation coefficient between the residuals of the export and R&D equations (ρ). Another advantage of this model is that it allows me to make straightforward comparisons among the likelihoods of the various strategies by running tests of differences in the predicted probabilities.[14]

The presence of any significant shift in the adoption strategy before and after the crisis (H5) is tested via the partition of the sample before and after the crisis and a test of differences in the predicted probabilities of the various combination strategies.

As a further test, each adoption strategy j is modelled via five separate survival random effects *complementary log-log* regressions estimated via maximum likelihood, one for each of the five transitions to the states of individual (none to R&D; none to Export), sequential (R&D to Both; Export to Both) and simultaneous adoption (none to Both).[15,16] An advantage of these models is that they allow me to directly model the likelihood of simultaneous adoption, from any previous adoption status. Crucially and most importantly, they allow me to model the cumulative effect of the learning and spillovers via the impact of the duration - the (log) of the number of years the firm has been in a specific status - on the probability of changing status.

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[14] See Appendix I for a robustness check of the bivariate probit model.

[15] See Jenkins (2005) for an overview of complementary log-log models.

[16] Differently from the bivariate probit model, survival models are as such that once changed status the firm leaves the sample and does not contribute to the information set of the following period.

The complementary log-log model is specified as:

$$h(j,X) = 1 - exp\left[-exp\left(\theta_0^j y_t^J + \beta^j X_t + S_i + z_t + \gamma_j\right)\right] \qquad (5)$$

where θ_0 identifies the significance of export/R&D duration, X_t is a vector of control variables, plus the usual vector of industry (S_i) and year (z_t) dummies and γ_j represent the differences in values of the integrated hazard function for the different durations.

The main interest lies in identification of the θ_0^j parameter, which shows the effect of the export and R&D duration upon the probability of survival. Positives estimates suggest that the larger values of the export duration (R&D duration) decrease the probability of survival, and hence the likelihood not to change status.[17]

To corroborate the results obtained through the nonlinear specifications of the probabilistic and survival models, a performance-based approach is used to explore the effects of the various combinations of strategies on firms' growth.[18] Hence, the estimating equation:

$$Growth_{it} = \theta_0^{Export} y_{i,t}^{Export} + \theta_1^{R\&D} y_{i,t}^{R\&D} + \theta_2^{Both} y_{i,t}^{Both} + X_{it}\beta + u_t + s_i + \epsilon_{it} \quad (6)$$

where $\theta_0^{R\&D}$, θ_1^{Export} and θ_2^{Both} identify the effects of the strategic status in time *t* on the firms' growth where 'None' is the baseline case,[19] X_{it} is a vector of control variables that might affect firms' growth, u_t is a vector of year dummies, s_i is a vector of industry dummies and ϵ_{it} is a disturbance that may be autocorrelated along *t* or contemporaneously correlated across *i*.

Variables

In the probabilistic models the dependent variable $y_{i,t}^j$ is a dummy variable taking value one if the firm engages in strategy j = 'Export', 'R&D', in time t and zero otherwise.

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[17] See Appendix II for a robustness check of the survival models.

[18] See Appendix V for a robustness check of this regression.

[19] In the bivariate probit model the dependent variable for export (R&D) include those that export only (do R&D only) and those that do both. In the growth model, the strategies are singled out as Export only, R&D only, Both, None.

In the case of the survival models, I ran five different specifications, one for each adoption strategy it embarks upon in time t, given the adoption status in time t-1. In the first three models the dependent variable $y_{i,t}^{j}$ is a dummy variable taking value one if at time t the firm decides to change status and adopt both strategies (export and R&D), and zero if the firm decides to continue only exporting (for the first specification), only performing R&D (for the second specification) or neither exporting nor performing R&D (for the third specification). In the fourth specification, the dependent variable takes value one if at time t the firm decides to export (only), and zero if deciding to continue neither exporting nor performing R&D. In the last specification, the dependent variable takes value one if at time t the firm decides to engage in R&D (only), and zero if the firm decides to continue neither exporting nor performing R&D.

In performance models, following, Golovko and Valentini (2011) the dependent variable is the firm's real sales growth in time *t* with respect to *t-1* *($Growth_{it}$)*.[20]

I include as controls a series of variables commonly used in the related literature, such as *Size* measured as the logarithm of the number of employees.[21] Large firms usually have larger internal funds than SMEs and have better access to financial markets (Damijan and Kostevc, 2011). SMEs are usually more risk-averse, which may make them more reluctant to take on external debt in order to finance exporting or innovation ventures.[22] Finally, large firms may enjoy economies of scale, which would allow them to increase the profitability of export and innovative activities. Hence, a positive effect of size on the probability of export and/or performing R&D is expected. *Foreign* participation is also included, as it is expected to facilitate the internationalisation strategy. The costs to enter foreign markets might be lower for foreign-owned firms due to the benefits from networks and other resources of the parent company (Kneller and Pisu, 2007), while leaving open the R&D strategy. The demand condition of the industry the firms belong to is also included via the variable

[20] As a deflator, the producer price index from Instituto Nacional de Estadística (www.ine.es) is used.

[21] The control variables used in the *Growth* regressions are the same than those used in the nonlinear models.

[22] As can be seen in Bernard, Jensen, Redding and Schott (2007), Eaton, Eslava, Kugler and Tybout (2008), and Damijan, Kostevc and Polanec (2010), while large firms usually export to many countries and a large number of products, small firms usually only export to one or two countries and a small number of products, being then more vulnerable to foreign market failure.

Industry conditions. Two variables that reflect internal and external financial constraints are also included as controls, *"Lack of internal funds"* and *"Lack of external funds".* Performing export activities carries a higher risk - compared to domestic sales - associated with fluctuations in exchange rates or the reinforcement of contracts (Wagner, 2014). In the case of R&D, the existence of imperfect capital markets hinders the uptake of funding by companies to carry out investments, especially if it comes to investment in R&D (Lev, 2000; Berger and Udell, 1990). Conversely, a contraction in demand could lead the firm to look overseas to place its products (Esteves and Rua, 2015). Industry and year dummies are used in all regressions. Table 5 provides detailed information on all the variables involved in the estimations. Following, among others, Girma et al. (2008), Aw et al. (2007) and Máñez et al. (2014) I use the same explanatory variables for both the export and R&D adoption decision, the only difference being that in the bivariate model (1) they are specified with a lag, t-1, while in the survival models (5) they are in time t. This is done not to superimpose any ex ante restrictions to their significance and it is left to the empirics to determine which control plays a significant role in the decision to adopt each strategy.[23]

Table 5. Variables definition

DEPENDENT VARIABLES	
<u>Bivariate Probit Model</u>	
Y^{Export}_t	Dummy variable that takes value 1 if the firm export in t.
$Y^{R\&D}_t$	Dummy variable that takes the value 1 if the firm has any expenses on internal or external R&D in t.
<u>Complementary Log-Log Model</u>	
$Both_t$	Dummy variable that takes value 1 if the firm export and perform R&D in t.
Only $Export_t$	Dummy variable that takes value 1 if the firm only export in t.
Only $R\&D_t$	Dummy variable that takes value 1

[23] In the robustness check used in Appendix I the dependent variables instead of being Export and R&D the strategies are singled out as Export only, R&D only, Both, None.

	if the firm only perform R&D in t.
<u>Growth Model</u> Growth$_t$	Log (sales$_t$/sales$_{t-1}$)
EXPLANATORY VARIABLES	
Size$_{t/t-1}$	Logarithm of the number of employees.
Foreign$_{t/t-1}$	Dummy variable equal to 1 if a firm has a foreign participation lower than 50%
Internal$_{t/t-1}$	Internal financial constraints. It takes the value 1 if the answer to the question "*asses the importance of lack of internal funds hampering innovation*" is high.
External$_{t/t-1}$	External financial constraints. It takes the value 1 if the answer to the question "*asses the importance of lack of external funds hampering innovation*" is high.
Industry conditions$_{t/t-1}$	Log of the mean turnover by industry and year.
Duration Export$_{t-1}$	Log of the number of years the firm has been 'only exporting'.
Duration R&D$_{t-1}$	Log of the number of years the firm has been 'only performing R&D'.
Duration None$_{t-1}$	Log of the number of years the firm has been 'neither exporting nor performing R&D'.

Source: PITEC Survey, 2004-2013

Results

Simultaneous versus sequential adoption and adoption sequence

In table 6 the results of the bivariate model (1), used to model the likelihood of the various combinations of R&D and export strategies, are reported.

Column 1 in Table 6 reports the presence of significant spillovers from the previous adoption of R&D on the decision to export (θ_1^{Export}= 0.266), while the effect of spillovers generated by exporting on the likelihood of performing R&D can be found in column 2 ($\theta_0^{R\&D}$ = 0.283). Jointly the two results confirm the significance of sequential adoption in the likelihood to adopt either R&D or export strategies and suggest that performing R&D (export) significantly increases in the presence of the previous adoption of export (R&D). They also indicate that there is persistence in the adoption strategy. The presence of learning effects from previous use of a same strategy is indicated by the significance of their own lag in the R&D ($\theta_1^{R\&D} = 2.248$) and in the export equation ($\theta_0^{Export} = 2.051$). The estimated correlations (ρ) between the residuals of export and R&D equations is positive and significant suggesting that the decision of adopting the two strategies is not independent and can be take place simultaneously.

As to the other explanatory variables, size is a significant factor in the adoption decision of either strategy, with large firms being more likely to embark in R&D and/or export strategies (Bernard et al., 2007, Damijan and Kostevc, 2011). The significance of internal constraints in the R&D equation confirms that R&D is a costly strategy (Aw et al. 2011) requiring significantly and continuously expensive investments in both human capital and capital goods. It also signals the higher difficulty in obtaining external funds, due to potential sunk costs and information asymmetries (Brealey et al., 1977). No evidence of financial constraints upon the decision to export is found.

Table 6. Biprobit model estimations for export and R&D decisions

	Model 1		Model 2 Wooldridge correction	
	(1)	(2)	(3)	(4)
VARIABLES	Export	R&D	Export	R&D
$Export_{t-1}$	2.051***	0.283***	1.746***	0.167***
	(0.000)	(0.000)	(0.000)	(0.000)
$R\&D_{t-1}$	0.266***	2.248***	0.176***	2.178***
	(0.000)	(0.000)	(0.000)	(0.000)
$Size_{t-1}$	0.139***	0.155***	0.131***	0.038
	(0.000)	(0.000)	(0.000)	(0.231)
$Foreign_{t-1}$	0.098	0.071	-0.040	-0.046
	(0.139)	(0.207)	(0.611)	(0.517)
$Internal_{t-1}$	-0.006	-0.081***	0.029	-0.074**
	(0.767)	(0.000)	(0.303)	(0.014)
$External_{t-1}$	0.002	0.041	-0.057**	-0.080***
	(0.927)	(0.055)	(0.046)	(0.008)
Industry conditions $_{t-1}$	-0.060	-0.047	0.005	-0.002
	(0.146)	(0.229)	(0.906)	(0.962)
Initial conditions				

Export Status$_1$			0.814***	0.127***
			(0.000)	(0.000)
R&D Status$_1$			0.117***	0.519***
			(0.000)	(0.000)
Mean Size			-0.027	0.136***
			(0.349)	(0.000)
Mean Foreign			0.366***	0.291**
			(0.006)	(0.045)
Mean Internal			-0.078	-0.054
			(0.116)	(0.287)
Mean External			0.132**	0.231***
			(0.012)	(0.000)
Mean Industry conditions			-0.142***	-0.187***
			(0.009)	(0.003)
Constant	-0.759	-1.237*	0.414	0.628
	(0.271)	(0.057)	(0.687)	(0.533)
Mean values explanatory variables[a] (Wooldridge 2005)			Chi2 (10) = 74.69 Prob > chi2 = 0.000	
Industry dummies[b]	Chi2 (42) =1942.93 Prob > chi2 = 0.000		Chi2 (42) =972.79 Prob > chi2 = 0.000	
Year dummies[c]	Chi2 (16) = 1652.30 Prob > chi2 = 0.000		Chi2 (14) = 1295.25 Prob > chi2 = 0.000	
Residual. Correlation	ρ=0.14 (s.e. = 0.013)		ρ=0.121 (s.e. = 0.014)	
LR test $\rho = 0$	$\chi^2(1) = 122.038$		$\chi^2(1) = 65.041$	
Log-likelihood	-32371.619		-26406.223	
Nº observations	46,370		40,328	

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the 1%, 5% and 10% level of significance, respectively
[a] F test of joint significance of the mean values of the time varying explanatory variables
[b] F test of joint significance of the industry dummies
[c] F test of joint significance of the year dummies

To control for unobserved heterogeneity, to solve the initial conditions problem and as a robustness check, following Wooldridge (2005), the export and R&D status for the first year of the observation period and the individual mean of the time-varying covariates (see Model 2 in table 6) are included as explanatory variables. This technique was proposed as a way to relax the assumption that the observed variables are uncorrelated with the unobserved variables. The results are consistent across the two models, with the exception of *Size* and *External liquidity.* While the significance of size in the R&D equation is now picked up by the average size effect of the Wooldridge correction, the external liquidity constraint turns out to be significant for both strategies, suggesting that the heterogeneity of external financial constraint (beyond the mean level) is a significant factor in the ability to adopt either R&D or export.[24]

In order to quantify how likely a firm is to engage in simultaneous versus sequential adoption, and also to compare the likelihood of the various adoption strategies, the predicted probabilities of performing both activities in t depending on the export and R&D strategies undertaken by firms in t-1 is calculated. Then, a test of differences in the predicted probabilities for baseline firms is run.[25] That is, how the probability of performing both activities in t changes when a firm was 'only exporting' in t-1 compared with those that were 'only performing R&D' in t-1; or how the probability of performing both activities in t change when the firm was 'only exporting' in t-1 compared with those that were neither exporting nor performing R&D in t-1, etc. This is equivalent to testing the significance of the parameters indicating the presence of learning from previous adoption of strategy j in j equation $\theta_0^j$and spillovers from learning derived from the previous adoption of the other strategy r≠j θ_0^j.

The results of the test of the differences for the bivariate model are reported in the first column of Table 7.

Firstly, the probability of performing both activities in time t by firms that were either 'only exporting' or 'only performing R&D' in t-1 (θ_0^j=0) and, hence, with learning accumulated from previous adoption, is higher than the probability of performing both activities when the firm had no pre-entry knowledge of performing neither R&D nor exporting, hence in the absence of both learning and spillovers from previous adoption (θ_0^j and θ_1^j =0).

As shown in Table 7, the previous adoption makes joint adoption between 10 and 21 percent more likely than simultaneous adoption (Export only$_{t-1}$ vs None$_{t-1}$=10.49% and R&D only$_{t-1}$ vs None$_{t-1}$=21.67%). Hence, important spillovers exist from learning associated with the adoption of either strategy and that makes sequential adoption more likely than simultaneous adoption (H1).

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[24] To further explore the impact of firm size I also experimented testing the model over the sample of SMEs and large firms separately. The results show that the adoption dynamic is not substantially different in the two groups; the only difference being that liquidity constraints are significant for SME firms but not for large firms. See results in Appendix III.

[25] In nonlinear models the estimated coefficients are not the marginal effects and the interpretation of marginal effects of dummy variables is not very meaningful. That is why it is more appropriate explaining the difference in probabilities of performing both activities in t depending on the firm status in t-1 in terms of probabilities rather than through the marginal effects.

The results also indicate that it is nearly twice as likely that R&D firms start engaging in export activities than the opposite (R&D only$_{t-1}$ vs Export only$_{t-1}$=11.11% in Table 7). The volume of spillovers and learning generated by the previous adoption of R&D (θ_1^j) makes the adoption of export more likely than the opposite, confirming not only the importance of sequential adoption but also that the adoption order is not symmetric (H3).

Table 7. Test of differences in the probability of performing both activities in t by export and R&D strategies undertaken by firms in t-1 (percentage points)

Sequential Vs Simultaneous adoption	**Bivariate model**	**Duration model**
Export only$_{t-1}$ vs None $_{t-1}$	10.49***	6.06***
R&D only $_{t-1}$ vs None $_{t-1}$	21.67***	18.45***
Sequential adoption order		
R&D only $_{t-1}$ vs Export only $_{t-1}$	11.11***	12.38***
Nº observations	40,328	38,285

Note: *** Significant at 1% level

To further explore that the spillover and *learning effects* (either from export or R&D) have an effect on the likelihood of export/R&D adoption, the test of differences in the predicted probabilities is repeated. In this case, the probability of performing both R&D and export in t for firms that were either exporting or performing R&D in t-1 ($\theta_0^j \neq 0$) is compared with the probability of starting export/R&D in t for firms that were neither exporting nor performing R&D in t-1 and, hence, with any pre-entry knowledge from previous adoption (θ_0^j and θ_1^j =0) (H2). If *spillover effects* exist, the former should be higher than the latter. The results presented in column 1 in Table 8 confirm the importance of the learning process. The probability of embarking on R&D when the firm was already exporting is 7.05 percentage points higher than the probability to start performing R&D when the firm was neither exporting nor performing R&D in t-1. In the case of firms that were only performing R&D in t-1, the likelihood to start exporting is 8.59 percentage points higher than the probability of starting exports for firms that were performing none of the strategies in t-1.

These findings confirm hypothesis 2. There are significant spillovers from learning generated by the previous adoption of either export or R&D, making the adoption of the other strategy more likely than in its absence *(sequential more likely than individual adoption).*

Table 8. Test of differences in the probability of performing both activities in t by export and R&D strategies undertaken by firms in t-1 (percentage points) with respect to start export/R&D in isolation

Sequential Vs Individual adoption	**Bivariate model**	**Duration model**
Export only$_{t-1}$ vs None $_{t-1}$	7.05***	5.45***
R&D only $_{t-1}$ vs None $_{t-1}$	8.59***	7.69***
Nº observations	40,328	38,285

Note: *** Significant at 1% level

Due to the nature of R&D requiring high investments in knowledge-base and, hence, creating higher barriers to entry than for export, it is also expected that firms without any pre-entry knowledge are more likely to adopt export strategies rather than R&D strategies (H4). To test this hypothesis, the predicted probabilities of exporting (performing R&D) for firms that were neither exporting nor performing R&D in t-1 are calculated. This is equivalent to setting the parameters of learning from previous adoption ($\theta_0^{R\&D}$ and $\theta_1^{R\&D}$ in the R&D equation and $\theta_0^{Export}$and θ_1^{Export} in the export equation) equal to zero. The results presented in the first column of Table 9 confirm the higher likelihood of exporting in comparison to performing R&D when firms have no previous experience in any of these activities. Aligned with previous findings, evidence of higher difficulties for applying R&D rather than export is found also for the individual adoption.

Table 9. Probability of exporting/performing R&D in t by firms that were neither exporting nor performing R&D in t-1 (percentage points)

Individual adoption	**Bivariate model**	**Duration model**
Export only$_t$	14.97	11.64
R&D only$_t$	5.33	1.5
Nº observations	40,328	38,285

Intensity of learning effects

In order to explore the intensity - and not just the presence - of the learning effects of export and R&D, and also as a robustness check, five survival models are performed. In the first three specifications the dependent variable takes value 1 if the firm starts to perform both activities. In specification 4 the dependent variable takes value 1 for firms that were neither exporting nor performing R&D in t-1 and start to ‘only export’ in t. The same applies to specification 5 but for firms starting to perform ‘only R&D’.

In the survival models the variables *Duration Export*, *Duration R&D*, *Duration None*, *Duration None* $_{to\ only\ export}$ and *Duration None* $_{to\ only\ R\&D}$ measure the logarithm of the number of years the firm has been only exporting, only performing R&D and neither exporting nor performing R&D, respectively. It is through the duration, and hence the cumulative effect of learning that the intensity of the spillover effects from the previous adoption of a strategy are captured. This is equivalent to testing the significance of θ_0^j in equation 5 where positive estimates suggest that larger values of the duration decrease the probability of survival and, hence, the likelihood not to change status.

Table 10. Complementary Log-Log model estimations

VARIABLES	(1) From only export to both	(2) From only R&D to both	(3) From none to both	(4) From none to only export	(5) From none to only R&D
Duration Export	1.933***				
	(0.000)				
Duration R&D		3.788***			
		(0.000)			
Duration None$_{to\ both}$			0.272		
			(0.398)		
Duration None$_{to\ only\ export}$				3.148***	
				(0.000)	
Duration None$_{to\ only\ R\&D}$					5.615***
					(0.000)
Size	0.293***	0.485***	0.398***	0.554***	0.620***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Foreign	-0.339	0.587*	-0.162	0.584	0.333
	(0.242)	(0.087)	(0.833)	(0.130)	(0.673)
Internal	-0.008	-0.012	0.075	-0.114	0.063

	(0.944)	(0.923)	(0.767)	(0.440)	(0.815)
External	0.243**	0.275**	0.208	0.229	0.829***
	(0.034)	(0.029)	(0.410)	(0.128)	(0.002)
Industry conditions	-0.460	-0.038	1.195	1.308**	-0.538
	(0.239)	(0.917)	(0.136)	(0.011)	(0.604)
Constant	1.120	-8.094	-38.716	-33.768***	-10.364
	(0.860)	(0.178)	(0.925)	(0.000)	(0.533)
Industry dummies[a]	Chi2 (20) =35.26 Prob > chi2 = 0.018	Chi2 (20) =56.54 Prob > chi2 = 0.000	Chi2 (20) =28.42 Prob > chi2 = 0.099	Chi2 (20) =124.22 Prob > chi2 = 0.000	Chi2 (20) =44.72 Prob > chi2 = 0.001
Year dummies[b]	Chi2 (8) = 43.51 Prob > chi2 = 0.000	Chi2 (8) = 185.34 Prob > chi2 = 0.000	Chi2 (8) = 28.73 Prob > chi2 = 0.000	Chi2 (8) = 188.48 Prob > chi2 = 0.000	Chi2 (8) = 35.96 Prob > chi2 = 0.000
Nº observations	11,557	8,324	8,750	9,654	9,029
Nº of spells	4,001	3,291	3,056	3,086	3,068

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the 1%, 5% and 10% level of significance, respectively
[a] F test of joint significance of the industry dummies
[b] F test of joint significance of the year dummies

The results are presented in Table 10. Columns 1 and 2 show that export duration and R&D duration positively affects the likelihood of changing status and performing both, rather than only one activity in t. The more consecutive years a firm has been exporting (performing R&D), the higher the cumulative effect of learning and, hence, the likelihood of changing status and performing both activities.

Nevertheless, if we look at column 3 in Table 10 the consecutive years a firm has been neither exporting nor performing R&D has no effect on the probability of performing both activities in t. That is, there are no spillover and learning effects. So, the cumulative effect of learning, from either export or from R&D, increases the likelihood of performing both activities and makes sequential adoption more likely than simultaneous adoption (H1).

To check whether the rest of the hypotheses also hold and to quantify the higher likelihood of sequential adoption compared with simultaneous adoption, the predicted probabilities for each specification are calculated and, then, a test of differences is run. The results are presented in the second column of Tables 7, 8 and 9. All the results are aligned with those obtained through the bivariate model. That is, the cumulative effects of learning from the previous adoption of a strategy make the adoption of the other strategy more likely than in its absence (H2) while the depth of the absorptive capacity and the knowledge base generated by post-entry R&D increases with the number of years since adoption and make the adoption of export by firms engaging in R&D more likely than the opposite (H3). Finally, it is also found that the export strategy is more likely to be adopted by firms without any pre-entry knowledge (*individual adoption*).

In summary, the results confirm the underlying research hypothesis that not only the presence of pre-entry knowledge and learning but also its depth, measured by the cumulative effect of the number of years the firm has engaged with one strategy, make the uptake of a new strategy more likely. I also find that both the depth of learning and spillover effects is higher for R&D than for export. However, while the spillovers from the previous adoption of R&D favours the adoption of export strategies, the volume of knowledge and learning required to start engaging with R&D makes the adoption of export strategies more likely by firms that do not possess any pre-entry knowledge.[26]

Impact of the crisis

In order to check whether the crisis has had any effect on the likelihood of adoption of export and R&D (H5), the test of differences in the predicted probabilities is repeated over the partition of the sample before and after the crisis. Thed results reported in Table 11 indicate that the probability of performing both activities in t by R&D firms (R&D $only_{t-1}$) with respect to firms that did not previously engage in any activity ($None_{t-1}$) was 11.75% before the crisis, increasing to 27.21% after the crisis. Hence, the crisis doubled the likelihood to adopt an export strategy by existing R&D firms, rather than being adopted simultaneously with R&D. The same cannot be said about the adoption of R&D. Although, they were more likely to be adopted sequentially rather than simultaneously, their likelihood of adoption slightly decreased from 12.14% before the crisis to 10.04% after the crisis. The crisis has made the adoption of the export strategy by R&D firms 17.16% more likely than the adoption of the R&D strategy by export firms. In fact, before the crisis there were no significant differences between 'Export only' and 'R&D only' firms in the sequential adoption while after the crisis this difference was important and significant. Therefore, in line with hypothesis 5 it is

[26] See Appendix II for a robustness check of the survival models.

found that the crisis increased the likelihood to export for R&D firms more than the likelihood to carry out R&D for exporting firms.[27]

Table 11. Test of differences in the probability of performing both activities in t by export and R&D strategies undertaken by firms in t-1 (percentage points)

Sequential Vs Simultaneous adoption	**2004-2007**	**2008-2013**
Export only$_{t-1}$ vs None $_{t-1}$	12.14***	10.04***
R&D only $_{t-1}$ vs None $_{t-1}$	11.75***	27.21***
Sequential adoption order		
R&D only $_{t-1}$ vs Export only $_{t-1}$	-0.38	17.16***
Nº observations	10,524	29,804

Note: *** Significant at 1% level

The analysis of the results presented in this section shows that although export positively affects the likelihood of sequential adoption, the crisis has changed the strength of this sequentiality. From 2008 onwards, the likelihood of investing in R&D by exporting firms has decreased, while the probability of exporting has increased for firms already performing R&D. That is, the crisis has encouraged internationalisation more than innovation.

Growth regressions

Further to the probability approach, a profitability based approach to test the returns to the various adoption strategies is used, alongside the presence of any changes that the crisis has generated in this relationship. Following Love et al. (2014), fifteen strategy-switch possibilities are set up which will allow me to analyse the extra gains (if any) of sequential and simultaneous adoption. For this purpose, I define the variable '*Export to both'* taking on value 1 for firms that were only exporting in t-1 and performing both activities in *t.* I next define the variable '*R&D to R&D*' taking on value 1 for firms that were only performing R&D in t-1 and remain only performing R&D in *t*, etc.[28] In this way, not only can whether sequential has a stronger effect on sales growth than simultaneous adoption be analysed but, also, whether a difference exists between adding export when the firm was already performing R&D or adding R&D

[27] See Table 25 in Appendix I for a robustness check of these results.
[28] Being '*None to None'* the baseline.

when the firm was already exporting (asymmetries in sequential adoption). The results of the heteroscedasticity corrected fixed effect panel data are reported in Table 12.

Table 12. Estimations for firms' growth depending on previous status

VARIABLES	(1) **Whole Period**	(2) **2004-2007**	(3) **2008-2013**
Sequential adoption			
Export to Both	0.060***	0.005	0.081***
	(0.000)	(0.868)	(0.000)
R&D to Both	0.085***	0.057*	0.091***
	(0.000)	(0.092)	(0.000)
Simultaneous adoption			
None to Both	0.048	0.110	0.026
	(0.236)	(0.170)	(0.531)
Individual adoption			
None to Export	0.057***	0.145**	0.051***
	(0.000)	(0.018)	(0.004)
None to R&D	0.058**	0.036	0.064**
	(0.014)	(0.322)	(0.027)
Export to Export	0.035***	-0.007	0.049***
	(0.000)	(0.617)	(0.000)
R&D to R&D	0.079***	0.080***	0.055***
	(0.000)	(0.000)	(0.000)
Both to Both	0.063***	0.027**	0.076***
	(0.000)	(0.032)	(0.000)
Export to R&D	0.023	-0.016	0.047
	(0.499)	(0.800)	(0.272)
R&D to Export	0.028	-0.026	0.049*
	(0.470)	(0.584)	(0.065)
Both to Export	0.015	-0.010	0.023*
	(0.155)	(0.598)	(0.088)
Both to R&D	0.036***	0.031	0.010
	(0.006)	(0.113)	(0.609)
Both to None	-0.079***	-0.034	-0.201***
	(0.001)	(0.257)	(0.000)
Export to None	-0.057***	-0.122***	-0.021
	(0.003)	(0.000)	(0.350)
R&D to None	-0.024	-0.033	-0.045*
	(0.221)	(0.269)	(0.071)
Controls			
Size	0.017***	0.008**	0.023***
	(0.000)	(0.040)	(0.000)
Foreign	0.001		-0.006
	(0.925)		(0.620)
Internal	-0.030***	-0.024***	-0.033***
	(0.000)	(0.006)	(0.000)

External	0.001	0.005	0.000
	(0.868)	(0.587)	(0.937)
Industry conditions	0.095***	0.243***	0.070***
	(0.000)	(0.001)	(0.003)
Constant	-1.781***	-4.449***	-1.482***
	(0.000)	(0.001)	(0.000)
Observations	46,258	16,538	29,720
Number of firms	6,386	6,206	5,768

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the 1%, 5% and 10% level of significance, respectively

As can be seen in column 1 in Table 12, there are significant gains attached to the sequential adoption decision. *'Export to Both'* and *'R&D to Both'* are positive and significant while *'None to Both'* is not significant, corroborating the two conclusions reached with the probabilistic and survival approaches: the higher importance of sequential rather than simultaneous adoption (H1) and the higher returns associated with the adoption of export strategies after R&D (H3). Hypothesis 2 is also corroborated. *'Export to Both'* and *'R&D to Both'* have a higher impact on growth sales than *'None to R&D'* and *'None to Export'*, respectively.

These results are partly in line with the findings of Peters et al. (2015), suggesting that in the case of Germany, exporting firms have a higher payoff from R&D investment. However, contrary to Peters et al. (2015), I find that such effect is significant only when strategies are adopted sequentially (from 'Export only' or from 'R&D only' to 'Both') rather that simultaneously ('None' to 'Both'). It is also found that the adoption order is of consequence and that there are asymmetries in sequential adoption. Adopting R&D first and export strategies second can generate higher growth than the opposite.

This effect is amplified when I split the sample to assess the effect of the crisis on the adoption decision (see columns 3 and 4 in Table 12). Before the crisis, R&D firms were benefiting from higher growth while after the crisis performing both activities was clearly the most valuable strategy. This confirmed the importance of exploiting the existing synergistic effects between export and R&D with the adoption sequence R&D first and export second (R&D to both) being the most rewarding adoption strategy (H5). These findings are consistent with the probabilistic and survival approaches to the analysis of the two adoption sequences.

In line with the probabilistic approach and irrespective of the strategy, the size of the firm affects the size of the returns. Industry conditions as well as internal liquidity constraints affect the returns from the adoption of the various strategies although in opposite directions. Industry conditions are a significant driver of the adoption decision while internal liquidity constraints can significantly reduce the expected returns from the various adoption strategies.

Concluding remarks

The first chapter of this thesis aims to shed more light on the synergies between export and R&D, and, for the first time, explores the direction of their adoption sequence. It posits that both the presence and the depth of learning and spillovers from adoption are the main responsible for their adoption sequence. It also explores the impact that the 2008 crisis has had in this relationship.

The results obtained are manifold. First of all, a positive association between these two activities is detected, irrespective of the specification and the model used confirming that exporting positively affects the probability of performing R&D (and vice versa). Moreover, in line with the research hypotheses, it is found that their *sequential* adoption is significantly more likely than the *simultaneous* adoption and it is associated to higher growth than when the two strategies are adopted *simultaneously*. Secondly, it is also found that the *adoption sequence* is of consequence. Adopting R&D first and export second is more likely and is associated with higher growth than the opposite. These results are confirmed not only by the bivariate probit, but also using a duration model, individual probit and linear specification. The duration model allows me to demonstrate that there are significant *learning effects* associated to the various strategies and cumulative learning effects derived from the number of years the firm engages in the activity. Both level and cumulative effects impact the adoption decision. I also found that learning, and hence the spillover effects, are different for export and R&D, reflecting the knowledge stock generated by their activities. R&D firms, by possessing more intangibles and human capital assets and, hence, a greater absorptive capacity, are better positioned to overcome the export entry barriers than the opposite. Third, the *learning effects* are confirmed not only when the evaluation is done comparing sequential versus simultaneous adoption, but also when the comparison is done between sequential and individual adoption; and individual adoption in isolation. On the one hand, the probability of starting exports for firms without any pre-entry knowledge is higher than the probability of starting R&D. Consequently, the *knowledge barriers* to start performing R&D are higher than to start exporting. On the other hand, the probability of adding export (R&D) for firms that were already performing R&D (exporting) is higher than the probability of starting exporting (performing R&D) in isolation. Finally, the results also reveal that the 2008 crisis has changed the strength of the relationship between export and R&D. During this period, while firms performing R&D became even more likely to start exporting, an increasing number of exporting firms did not perform R&D, reinforcing the asymmetry in the adoption sequence. These results are confirmed not only by the probability of performing any of the activities, but also by the size of the firms' growth associated with the various strategies.

The findings of this chapter contribute to the understanding of the synergies between two of the most important strategies acknowledged to improve firms' performance and, therefore, economic growth. Given the potential complementarities between them, export strategies should go hand in hand with R&D strategies to maximise growth and to maintain the strategic competitive advantage with direct consequences on aggregated country productivity and long term growth. Policies oriented at export strategies alone, while possibly being beneficial in the short term, could also expose firms to low-cost competition based on volumes and thinner margin of profits and limited resources to devote to R&D with dangerous lock-in effects. For those firms, the lack of R&D could also significantly diminish their absorptive capacity, including the capability to exploit the learning by exporting effect. Hence, it is argued that policy should not promote single handed measures facilitating either the international growth of firms or their R&D capability independently of each, as higher gains can be generated when they are jointly adopted. Moreover, as the evidence suggests that the adoption order is of consequence and that the highest probability of joint adoption appears when export strategies are built on a robust knowledge base, promoting the adoption of R&D first and the adoption of export strategies among firms performing R&D seems to be highly desirable.

Finally, policies aimed to help firms to enter the virtuous circle between export and innovative activities should take into account that export is a *sales-oriented* strategy while R&D is an *investment-oriented* strategy. Therefore, firms may prefer to find new customers for their goods and increase their profits in the short term rather than committing to the R&D long term investments and uncertain outcomes. As the results in this chapter suggest, during a period of crisis this behaviour could be even stronger, since firms may prefer to sell their products abroad to compensate for their drop in demand (sales) and, hence, *survive one more day* rather than using the pull of scarce funds for the long term and riskier strategy of R&D. In the long run this could have detrimental effects. The promotion of international activities without the appropriate knowledge-base and absorptive capacity would allow firms to increase their profits in the short term, but does not guarantee a sustainable comparative advantage in the long run. Identification and analysis of the sequence of adoption is a key aspect that will help to achieve the goal.

Although this study provides relevant insights, I acknowledge some limitations. First, the results are obtained based on data from a single country and from firms operating in the manufacturing sector. It would be interesting to extend the analysis to other sectors as well as to other countries. Second, as mentioned in the data section, the sample used in the study is representative of the population of firms with 200 or more employees, but the representativeness of firms with less than 200 employees is biased towards firms having internal and/or external R&D. Therefore, it would be desirable to check whether results hold when analysing other datasets. Finally, some information contained in PITEC is subjective since it depends on the perception of the respondent firm. Mairesse and Mohnen (2004) suggest that ‘subjective’ measures (in CIS data) tend to be consistent with more ‘objective’ indicators. In fact, PITEC is a dataset widely used in similar studies to this.

Even though in this chapter I have explored the changes in the sequential adoption due to the crisis, the knowledge of the channels causing these switches is very limited. Chapter Two will address this issue exploring how the two exogenous shocks suffered by economies since 2008 have affected export and R&D strategies.

CHAPTER 2: DISENTANGLING THE ROLE OF THE CRISIS IN EXPORT AND R&D ADOPTION

Abstract

As shown in Chapter 1, the 2008 financial and economic crisis had different consequences upon export and R&D adoption. The aim of this chapter is to shed more light on the factors driving the adoption of these strategies during this period, disentangling the effects of the dropping demand and credit crunch. It is posited that due to the differences in the way firms finance R&D and exports and to the higher influence of demand conditions on exports, the crisis has negatively affected R&D more than exports. For this purpose, Spanish manufacturing data drawn from the *Survey of Business Strategies* for the period 2000-2014 are used. By using a probabilistic model, the results suggest that, during the crisis, access to external funds was an important factor explaining export adoption, while availability of internal funds was more important for R&D. Second, firms with higher access to external funds increased the likelihood of exporting and reduced the probability of performing R&D activities. Finally, demand conditions explain export adoption, but not R&D adoption.

Introduction

There is a wide consensus in the industrial organisation literature about the benefits of internationalisation. Firms operating beyond their boundaries are not only more productive than domestic firms (Peters et al., 2015; Bernard and Jensen, 1999; Greenaway and Kneller; 2007; Wagner, 2007; Wagner, 2012; among others) but also bigger, more capital-intensive and pay higher wages (Baldwin and Gu, 2003; Girma et al., 2004; Greenaway and Kneller, 2004). Likewise, R&D firms are more likely to innovate (Becheikh et al., 2006; De Jong and Vermeulen, 2007; Cohen and Levinthal 1989; among others), to be more productive (Bernard and Jensen, 2004; Greenaway and Kneller, 2004) and, due to the complexity of R&D which requires high investment in intangibles and human capital assets, generate important internal capabilities improving the absorptive capacity of firms (Cohen and Levinthal, 1989, 1990). Therefore, export and R&D are two strategies which will positively affect not only to firm's performance but also the competitiveness of a country as a whole.

Furthermore, research in the field has also concluded that there are some positive synergies between the two strategies. If jointly adopted, adding one strategy when the other was already in place generates a higher impact, either on productivity or on performance, than adopting the same strategy in isolation (Golovko and Valentini, 2011; Aw et al., 2007; Peters et al., 2015). From a theoretical point of view, the positive effects from R&D to export build, at least, on three arguments. First, R&D investments increase productivity growth and this improvement in productivity allows firms to *self-select* into international markets (Greenaway and Kneller, 2007; Wagner, 2007; Delgado, Farinas and Ruano, 2002).[29] Second, if R&D investments lead to either a better quality or a novel product in the market, foreign demand may increase thus pushing the firm to internationalisation (Hitt et al., 1997). Finally, R&D investments involve a process where organisational knowledge and learning capabilities are expanded (Cohen and Levinthal, 1990) and this learning may also be used to overcome export entry barriers (Dunning, 1993; Kotha et al., 2001; Lu and Beamish, 2001). The positive effect of export upon R&D adoption builds on the *learning-by-exporting* theory (Clerides et al., 1998; Young, 1991 or Aghion and Howitt, 1998). That is, exporters can access diverse knowledge inputs which are not available in the domestic market, and such learning can foster increased innovation (Salomon and Shaver, 2005). In the empirical literature, Aw et al. (2011), Becker and Egger (2013), Bernard and Jensen (1997) and Roper and Love (2002), among others, show how investments in innovative activities increase the propensity to export. Studies by Bustos (2011), Aw et al., (2008), Atkeson and Burstein (2010) and Costantini and Melitz (2008) defend the positive influence of exports on R&D. However, this positive effect may not be symmetric and exogenous shocks may affect this relationship. In the first chapter of this thesis it was concluded that, for a sample of Spanish manufacturing firms, the crisis reduced the probability that exporting firms embark on R&D strategies but not the probability that R&D firms embark on export. Even though the results of the first chapter confirm the changes in export/R&D adoption because of the crisis, nothing is said about the channels causing these switches. On the one hand, from 2008 onwards all major economies were hit by a very important credit crunch which, given the importance of sunk costs involved in these two strategies, may have influenced their adoption. On the other hand, firms suffered a dramatic decrease in the internal demand which may have forced them to reorganise their investments.

[29] See Hall, Mairesse and Mohnen (2010), Wieser (2005), Møen and Thorsen (2017) and Ugur, Trushin, Solomon and Guidi (2016) for reviews of the empirical literature about the effects of R&D on productivity.

Therefore, the aim of this study is to shed more light on the factors driving export and R&D adoption behaviour during the crisis, disentangling the effects of the dropping demand and credit crunch.

For various reasons, I posit that the effects of the credit crunch and poor internal demand conditions have had a different impact upon export and R&D adoption. First, given the greater difficulty of obtaining external funds for financing R&D activities (and therefore the higher importance of access to internal funds to finance innovative strategies) the dramatic decrease in the availability of internal funds suffered by firms during the crisis should have had a higher negative impact on R&D adoption when compared to export adoption. Second, the worsening conditions of access to external funds have made it impossible to reach all the planned investments for firms, forcing them to reject some. Given the higher risk of R&D investments, jointly with their long term nature, companies with access to external funds are more likely to have used them to adopt export rather than to invest in R&D. Finally, even if poor demand conditions may positively affect export and R&D adoption, the lack of funds to finance both activities, has made companies prefer export (as a way to survive) rather than R&D.

In the empirical analysis, discrete choice models for dynamic panel data are used to identify the factors explaining export and R&D behaviour during the crisis. These firms' decisions are characterised depending on the firms' internal and external measures of financial constraints, demand conditions and other controls. The potential simultaneity in the two firms' decisions is taken into account through the estimation of a bivariate probit. To allow the individual effect to be correlated with the regressors and to solve the 'initial conditions problem', the Wooldridge (2005) approach is applied.

The data used in this study come from the *Survey of Business Strategies* (ESEE hereafter) for the period 2000-2014. ESEE is an annual panel survey representative of Spanish manufacturing firms by industry and size categories. The final working sample consists of around 13,000 observations corresponding to 1,229 firms.

The main results can be summarised as follows. First, financial factors explain export and R&D behaviour during the crisis. Interestingly, the effects of these financial factors are not the same for export and R&D decisions. While access to external funds appears as an important factor explaining export adoption, availability of internal funds is the most important for R&D. This result highlights the relevance of access to finance to promote exporting activities and the importance of internal funds for financing innovative activities. Second, during the crisis, the probability of exporting for firms with higher access to external funds increased, while the likelihood of performing R&D activities decreased. Third, export adoption during the crisis period is also explained through the demand conditions, showing a countercyclical pattern, while demand conditions are not significant in explaining R&D adoption.

The rest of the chapter is organised as follows. Section 2 summarises the related literature and introduces the main hypotheses. In Section 3, data, variables used in the study and some descriptive statistics are introduced. Section 4 is devoted to explaining the methodologies and presents the estimates of the different models for the Spanish manufacturing firms, along with some robustness checks. Finally, Section 5 presents the main conclusions.

Related literature and main hypotheses

Financial constraints and demand conditions are two key aspects that may affect export and R&D adoption decisions (Chaney, 2016; Muûls, 2008; Manova, 2013; Brealey et al., 1977; Arrow, 1962; Lev, 2000; Belke et al., 2014; Esteves and Rua, 2015; Hall, 1991; Aghion et al., 2012). The world financial and economic crisis which started in 2008 supposed both a dramatic decrease in the availability of funds to finance firms' investments, but also a great drop in internal demand. Thus, these two exogenous shocks could have significantly influenced the adoption of export and R&D.

Both export and R&D activities involve important start-up costs that are largely sunk (Roberts and Tybout, 1997) and that need to be paid in advance. Exporting companies have to investigate competition and foreign demand, establish marketing and distribution channels and adjust the characteristics of the products to meet or comply with foreign legislation, as well as with the quality and security of other countries' standards (Roberts and Tybout, 1999). Moreover, the development of R&D may involve not only the creation of an R&D department, purchasing specific physical assets, hiring skilled labour, but also the collection of information concerning new technologies, organisational changes and adjustments to new technologies (Máñez et al., 2009; Máñez, Rochina-Barrachina and Sanchis-Llopis, 2015, among others). These high sunk costs, together with the high fixed costs to remain in activity, make liquidity very important for the participation in international markets and innovative activities (Melitz, 2003; Bellone, Musso, Nesta and Schiavo, 2010; Manova, 2013 and Aw et al., 2011). Given that from 2008 economies started to suffer a very important credit crunch, limiting access to credit for firms, but also a drop in the internal funds of firms, the adoption of these two strategies may have been negatively affected.

Recently, some theoretical models of heterogeneous firms have incorporated financial drivers as a factor explaining export adoption. The pioneer model was Chaney (2016)[30], followed by Muûls (2008) and Manova (2013).[31] Chaney (2016) added to the model of international trade with heterogeneous firms of Melitz (2003) financial constraints, to conclude that they prevent some firms from exporting due to the fixed costs that this entails. If a firm is experiencing financial constraints, the extra costs to access foreign markets are not affordable and, therefore, only those firms with sufficient internal funds will be able to export.[32] Muûls (2008) incorporates external funding to the original model of Chaney (2016) to conclude that, for Belgium manufacturing firms, the lower the financial constraints that the companies face, the higher the probability of exporting.[33] Furthermore, the author finds evidence supporting the idea that financial constraints not only have an effect on the extensive margin (percentage of exporting firms) but also upon the intensive margin (volume of exports). Finally, Manova (2013) shows that more constrained firms are less likely to participate in export markets and, in case they do, they export less. That is, financial constraints would affect both the decision to export and the amount exported by companies already exporting. The first empirical study analysing the link between financial constraints and exports, using firm-level data, was Greenaway, Guariglia and Kneller (2007). They find no evidence that firms enjoying better ex-ante financial health are more likely to start exporting but that participation in export markets improves firms' ex-post financial health (in the case of continuous exporters, but no for starters).[34] Later on Wagner (2014b), using as

[30] The first working paper of this study was in 2005.

[31] See Egger and Kesina (2013) and Minetti and Zhu (2011) for a discussion of the theoretical models.

[32] According to the model, financial constraints are only binding for firms with intermediate productivity, since firms with high productivity will always generate enough internal funds to afford the sunk costs and for firms with low productivity exporting is not profitable.

[33] Bellone et al. (2010) obtain the same results for a sample manufacturing firms in France.

[34] One possible explanation to these results is that, in the sample they use, the average number of employees is more than 200 for non-exporters and more than 300 for exporting firms. That is, the

a proxy for financial constraints the credit rating of German manufacturing companies, finds that the higher the credit quality of the company (associated with less restriction on liquidity) the higher the likelihood that it exports, and the higher the share of exports in total sales.[35] Forlani (2010), using data from the balance sheets of Italian SMEs, builds two indexes measuring the short term and long term financial situation of a firm. Using these indexes, he predicts whether companies have difficulty obtaining external funding and, therefore, if they are financially constrained. The results show that internal resources are an important factor for firms' internationalisation, especially for those that are financially constrained. Further, Damijan and Kostevc (2011) argue that access to finance is crucial to start and boost exports (extensive margin), as well as being particularly important for small firms to improve their intensive margin (number of products).

All in all, using different variables (and approaches) to measure internal and external financial constraints, liquidity constrained firms have more difficulties to start exporting. Wagner (2014) offers an exhaustive survey of the empirical works in the field.[36] The stylised fact is that *"financial constraints are important for the export decisions of firms: exporting firms are less financially constrained than non-exporting firms. Studies that look at the direction of this link usually report that less constrained firms self-select into exporting, but that exporting does not improve financial health of firms"* (Wagner, 2014, p. 1479).

Regarding R&D, because of information asymmetries (Brealey et al., 1977), high sunk costs (Arrow, 1962) and lack of collaterals (Lev, 2000; and Berger and Udell, 1990), theoretical models have also predicted a negative effect of financial constraints on R&D adoption. The existence of imperfect capital markets hinders the uptake of funding by companies to carry out investments, especially if it comes to investing in R&D. As Arrow suggested in 1962, an additional difficulty to finance R&D is the appropriability of the returns of that investment. The inventors of new knowledge do not fully appropriate of the rents generated by R&D, since knowledge is a right of not exclusive consumption. Therefore, the returns to investments in knowledge are

sample contains a considerable share of large firms which are not the most likely to be affected by financial constraints.

[35] As the author points out, the results have to be taken with caution because smaller firms are underrepresented (as the credit-rating score is not available for these firms).

[36] 32 empirical studies that cover 14 different countries plus five multi-country studies.

difficult to estimate, leading to greater difficulty in finding funds for that activity. In addition, there are many reasons, explained in what follows, that hinder access to external financing to meet the costs involved in R&D. In the first place, it should be noted that asymmetric information problems are more noticeable in R&D projects than in other, more current, investments. Such projects are usually very novel and, therefore, they are hardly understood by those who are not specialists in the field. As a result, those who must provide the funds for a project have many difficulties in calculating the probability of success. This situation may create moral hazard and adverse selection problems, as suggested by Jensen and Meckling (1976) and Stiglitz and Weiss (1981). Secondly, the returns linked to high technology projects are highly uncertain as R&D projects have a low probability of success (Brealey et al., 1977; and Carpenter and Petersen, 2002). Third, innovation investment generates a large number of intangible assets that cannot be used as collateral to the lender (Lev , 2000 ; Berger and Udell, 1990). Fifty per cent, or more, of expenditures on R&D is assigned to the wages and salaries of highly skilled workers, and they generate some intangible assets which, in the future, will bring benefits to the company (Hall, 2002). However, at the time of carrying out the investment, the collateral that the firm can offer is practically zero. Since the value of these projects goes under human capital, if researchers decide to change companies or are made redundant, the project loses much of its value. Fourth, companies have no incentives to explain their R&D projects in detail, as they might be concerned about imitation by competitors (Bhattacharya and Ritter, 1983), which makes it more difficult to estimate expected future profits. Finally, the fact that R&D projects are long term investments makes them more risky because when innovative companies are facing financial problems their market value, based on future options, quickly falls (Cornell and Shapiro, 1988).

Due to the reasons explained above one could expect a negative relationship between financial constraints and R&D. Moreover, due to the added difficulty of obtaining external financing to fund R&D, one might think that companies may prefer funding R&D through internal rather than external funds and, therefore, this type of investment would be more sensitive to internal funding measures such as cash flow. However, empirical studies show mixed results for both, internal and external financing measures. On the one hand, early works in the field did not find any relationship between internal funds and R&D (Scherer, 1965; Mueller, 1967; and Elliott 1971). [37] On the other hand, Himmelberg and Petersen (1994), Mulkay, Hall and Mairesse (2001) and Hall (1992) found a positive and significant correlation between cash flow and investments in R&D. However, there are a number of works that, although admitting a correlation between internal resources and investment in R&D, introduce some exceptions. Hao and Jaffe (1993) split the sample between small and large firms and conclude that financial constraints affect the former but not the latter. Similarly, Harhoff (1998) found a weak correlation for both small and large companies, although this effect does not appear significant when the Euler equation is used. Bond, Harhoff and Van Reenen (2005) argue that financial constraints may affect the decision to perform R&D but not its level. They conclude that cash flow may be important for a company when deciding whether to invest in R&D in the UK but not when choosing the level of this investment. Finally, Brown, Fazzari and Petersen (2009) conclude, for a sample of high-tech companies, that cash flow is relevant for young companies while having little impact on mature companies. Similar to export works, in addition to the studies using balance sheet information to build variables measuring financial constraints, there are also those that use a direct indicator built through survey data. Mancusi and Vezzulli (2014) built a financial indicator for Italian SMEs using a question that asked firms if they would want additional funding which they obtained, at the prevailing interest rate, with their main bank. Companies that answered affirmatively were considered financially constrained. The conclusion from this study was that financially constrained companies are less likely to engage in R&D projects. Savignac (2008), Hajivassiliou and Savignac (2011), Tiwari, Mohnen, Palm and van der Loeff (2007) and Efthyvoulou and Vahter (2016) also use data collected through a survey to construct a direct indicator to identify financially constrained companies. In the case of Savignac (2008) and Hajivassiliou and Savignac (2011) it was found that financial constraints reduce the likelihood of firms to undertake innovative activities. Meanwhile, in the case of Tiwari et al. (2007), the conclusion is that financial constraints affect the decision of how much to spend on R&D. Finally, Efthyvoulou and Vahter (2016), studying the effects of financial constraints upon innovation success for

[37] Himmelberg and Petersen (1994) argue that the results of these works are because in the sample they only considered large firms, which usually have more cash flow than they need to carry out such investments.

11 Western and Eastern European countries, found that financial constraints are strongly negatively related to innovation performance. They also conclude that the lack of internal funds is more important than limited access to external funds.[38] Aghion et al. (2012) define financially constrained companies as those that appear in a list of the French banking system, in which companies have not been able to fulfil the obligations of a loan (defaulting companies), since these companies, a priori, will face more difficulties to obtain a loan in the future. Their findings suggest that the percentage of R&D investment on total investment is less countercyclical when companies are more financially constrained. [39]

Overall, in light of these results, unlike what was concluded for exports, the empirical evidence is ambiguous and far from conclusive, although access to internal funds tends to be an important driver of R&D adoption.

According to the theoretical and empirical review, it seems clear that firms need sufficient liquidity to pay the extra costs to enter foreign markets and/or R&D activities. Moreover, due to the added difficulty in obtaining external financing to fund R&D, this type of investment should be more sensitive to access to internal funding. Thus, the following hypothesis is put forward:

HYPOTHESIS 1. Access to internal and/or external funds significantly affects export and R&D adoption, as access to internal funds is more important than access to external funds for R&D adoption.

Given the importance of liquidity to start exporting/performing R&D, the world financial and economic crisis, started in 2008, which supposed a dramatic decrease in the availability of funds to finance firms' investments, should have had some consequences upon export/R&D decisions. The scarce funds available in the economy may have forced firms to choose between different investment projects, making it impossible to reach all the planned investments. As mentioned by Garicano and

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[38] They also do the analysis by differentiating between the production and services sectors and between exporters and non-exporters. Their results indicate that financial constraints have more pronounced negative effects in the production sector and for non-exporters.

[39] Although the mainstream literature, based on the opportunity cost theory, defends the counter-cyclicality of R&D investment, there are also alternative theoretical models that explain the pro-cyclicality of R&D expenditure. For example, the empirical studies by Barlevy (2007) and Comin and Gertler (2006) found that R&D expenditures show a pro-cyclical pattern. Aghion et al. (2010), Aghion et al. (2012), López-García et al. (2013) and Beneito et al. (2015) show that when firms are credit constrained the counter cyclicality of R&D is reversed.

Steinwender (2016), credit shocks reduce the value of long term investments, in comparison to short term ones, and firms are willing to give up some future expected payoffs in order to increase the probability of surviving another day. Because of the dramatic drop in the internal demand from 2008 onwards, and the short term nature of export compared with the long term nature of R&D, it should be more likely for firms to decide to use the limited pull of funds to finance export, and sell their products abroad, rather than investing in risky medium and long term R&D projects. Campello, et al. (2010) surveyed 1,050 Chief Financial Officers in the US, Europe and Asia to evaluate the effects of credit constraints during the crisis in the corporate spending plans. They conclude that constrained firms planned deeper cuts in technology spending. This could mean that some firms might dismiss their R&D strategies as their costs are higher than the sunk costs of abandoning their adopted strategy. Aghion et al. (2010) for a sample of 21 OECD countries argue that tighter credit constraints contribute to a more pro-cyclical share of long term investment. Given these arguments, even if during the crisis the majority of firms were credit constrained, it is rational for those with higher access to external funds to have used them to sell abroad and try to survive another day. Conversely, the high risk of R&D investments jointly with their long term nature makes them less likely to be adopted during a period of dramatic turbulence. Therefore, the following is hypothesised:

HYPOTHESIS 2. During the crisis, less credit constrained firms increased their likelihood of exporting and decreased the likelihood of performing R&D.

The second exogenous shock which the Spanish economy suffered from 2008 onwards and which may have had some consequences on the export/R&D adoption was given by the very important decline in domestic demand. Traditionally, exports behaviour has been explained through two main drivers: the evolution of foreign demand and the evolution of the price competitiveness of the country. However, a growing number of studies have recently pointed out that such determinants are only able to explain part of the export performance (Fagan, Henry and Mestre, 2005; Di Mauro and Forster, 2008; Dieppe et al. 2012; Belke et al., 2014; Esteves and Rua, 2015). Belke et al. (2014) and Esteves and Rua (2015) are two studies supporting domestic demand as one of the possible drivers of exports. The theoretical idea behind these papers is that, due to the limited production capacity of firms in the short term, during periods of growing domestic demand, firms will work at full capacity and, therefore, will not be willing to pay the high sunk costs involved in exports. Nevertheless, when the economy is hit by a negative demand shock and firms are producing at very low capacities, free resources may be used to increase their efforts towards international markets. After the negative shock, more firms will be willing to pay the sunk costs and substitute domestic sales by exports, since the costs of excess capacity would be higher than the entry costs and the low expectations for the domestic demand may push firms to export as the only way to survive. The same idea applies to incumbent exporters. Under unfavourable internal economic conditions, exporter firms will remain in international markets to avoid repaying the entry costs (Máñez, Rochina and Sanchis Llopis, 2008; Bernard and Jensen, 2004; Campa, 2004; among others). Empirical studies have already supported the negative relationship between internal demand and exports. Esteves and Rua (2015) found a negative link between the lagged domestic demand developments and export performance for the Portuguese economy. They also found an asymmetric effect depending on the cycle, being stronger when domestic demand declines. In the same vein, Belke et al. (2014), using firm-level data for Spain, Portugal, Italy, France, Ireland and Greece, conclude that domestic demand is relevant for the dynamics of exports, especially for Spain, Portugal and Italy, and more significant during more extreme stages of the business cycle.[40] Despite the results of the studies mentioned above, a positive correlation between domestic and export sales is also plausible. Two are the main channels which could cause this positive effect. First, international trade allows firms to discover new technologies, processes or techniques not available in their home markets, expanding firms' capabilities (Álvarez and Robertson, 2004).[41] These efficiency improvements will positively affect both export but, also, domestic sales. Second, the increase in international sales will improve the financial situation of the firm generating higher cash flow that may be used to finance domestic operations (Berman, Berthou and Héricourt, 2015).

[40] Ahn and McQuoid (2012), Soderbery (2014) and Blum, Claro and Horstmann (2011) are studies which find this negative link between domestic and export sales using firm-level data for countries outside Europe.
[41] See Chapter 1 for a more extended explanation of the *'learning by exporting'* theory.

Considering the above arguments, one could conclude that internal demand conditions are one of the factors that could determine the strategic decision of firms to export, although it is not clear enough whether this relationship is positive or negative. However, there are at least two reasons why we should expect a negative relationship between export decision and demand conditions. First, the positive relationship will arise when the *learning by exporting* effects appear. Wagner (2007) offers an exhaustive survey of empirical works analysing the relationship between exports and productivity and concludes that evidence regarding *learning by exporting* is mixed and, therefore, inconclusive. As Griffith et al. (2004) and Cohen and Levinthal (1990) defend, only firms with sufficiently advanced internal R&D will be able to absorb the new knowledge and, thus, take advantage of the positive *learning by exporting* effects. Second, the positive relationship may also arise when improvements in cash flow are devoted to finance export activities. However, as mentioned earlier, one of the main targets of this study is to understand how access to internal funds affects the decision of starting to export/perform R&D. Therefore, I am already controlling for that and the effects of cash flow upon these decisions will be captured through the variable measuring access to internal funds.

With regard to the effects of the business cycle upon R&D, although the mainstream literature defends the counter-cyclicality of R&D, there are also studies showing the pro-cyclicality of R&D investments. The arguments for R&D spending to be counter-cyclical build on two main ideas. First, the opportunity cost theory (Hall, 1991; Aghion and Saint-Paul, 1998) states that firms can allocate their resources to current production or to productivity-enhancing activities (R&D). Therefore, during expansive cycles (characterised by a strong demand) devoting resources to R&D activities would mean detracting resources from current production, which would imply high opportunity costs for firms. That is the reason why, during growth periods, it will be optimal for firms to use their resources in current production while, during recessions, given the decrease in the opportunity costs of R&D, it will be optimal to allocate these resources to R&D activities. Second, according to the Schumpeterian view of business cycles, recessions give the opportunity for the market to correct inefficiencies and to encourage firms to reorganise and innovate (Schumpeter, 1939). However, these two mechanisms defending the counter-cyclicality of R&D investments imply that firms can borrow funds for innovation unlimitedly, and that may not be the case during a period where firms are facing credit constraints. When external financing is limited, firms can only finance innovation projects through internal funds which, during recessions, usually decrease. Therefore, during downturns credit constrained firms may follow a pro-cyclical R&D investment pattern. Empirical studies at the firm level as Aghion et al. (2012) for a sample of French firms, or López-García et al. (2013) for a sample of Spanish firms, corroborate the pro-cyclicality of R&D investment for credit constrained firms.[42] Beneito et al. (2015) also find this pro-cyclicality for credit constrained firms, but this effect is alleviated in family owned firms and in firms that are group-affiliated.

Considering the works mentioned above, it seems that empirical evidence remains inconclusive and the pro-cyclicality or counter-cyclicality of R&D may depend not only on the cycle but also on the availability of funds. As occurred in the export adoption, given the importance of liquidity for R&D investments, the effects of internal demand upon R&D adoption may be weak or even insignificant during credit constraint periods. Hence, on the basis of the above arguments, the next hypotheses are formulated:

HYPOTHESIS 3a. During the crisis, demand conditions significantly affected the export adoption and this relationship was negative.

HYPOTHESIS 3b. During the crisis, demand conditions explained R&D adoption and this relationship was positive.

Data and descriptive

For this study yearly data from the *Survey of Business Strategies* (ESEE) are used. ESEE is an annual panel survey representative of Spanish manufacturing firms by industry and size categories. This dataset provides exhaustive information at the firm level on: firm activity; sales; R&D expenditure; foreign trade; and accounting data. ESEE excluded firms with less than 10 employees. Firms with 10 to 200 employees were randomly sampled, holding around 5% of the population in the first year that the survey was carried out. All firms with more than 200 employees were requested to participate, obtaining a participation rate of around 70% during the first year. To minimise attrition, new firms with the same sampling criteria as in the base year have

[42] Ouyang (2011) also finds this pro-cyclical pattern of R&D at the industry level for a panel of twenty US manufacturing industries during the period 1958-1998.

been annually incorporated, so that the sample of firms remains representative over time.[43]

The sample analysed in this study covers the period 2000-2014. Sampling out those firms' observations that fail to supply relevant information about all the variables involved in the analysis, the final sample used in this chapter consists of around 13,000 observations corresponding to 1,229 firms. As the first year of the sample is needed to set up the variables solving the initial conditions problem and the explanatory variables are lagged one period, the estimation is carried out for the period 2002-2014. The dependent variables are *Export* and *R&D*. The former has been defined as a dummy variable that takes value 1 for firms that have exported during the current year. The same procedure was followed to set up the R&D variable. Among the explanatory variables, internal and external constraints and demand conditions are those of most interest in this study.

With regard to the financial situation, in Spain, bank loans are the most common form of external financing for firms and constitute the bulk of firms' financial debt (Schiantarelli and Sembenelli, 2000); the reason why, in this study, it has been considered that one of the most relevant variables when analysing financial constraints is the financial volume borrowed by firms. Following Beneito et al. (2015), using company balance sheet information, a variable is constructed that aims to measure access to external funding for each firm (*external funds*). First, the volume of firms' new long term debt is calculated as the debts that the firm has borrowed in a given year both from banks and from other long term lenders. Then, to avoid contamination from changing macroeconomic policies, in the link between the volume of debt and tighter financial constraints, in the estimation specifications the financial volume variable will be introduced as the deviation of the current firm's borrowed volume with respect to the average volume borrowed by manufacturing firms in the same year and industry.[44] Positive values of this variable would correspond to firms that may have access to higher volumes of external debt and, therefore, are less externally constrained.

[43] See https://www.fundacionsepi.es/investigacion/esee/spresentacion.asp for further details.

[44] This variable is deflated using industrial price indexes.

When a company does not have access to external financing, internal funds may be of great importance in order to carry out its investments. Therefore, cash flow is the second measure used in this study to capture financial constraints (*internal funds*). Many studies use cash flow-related measures as proxies for internal financial constraints. Manole and Spatareanu (2010) and Buch, Kesternich, Lipponer and Schnitzer (2010) use cash flow as an internal restriction measure. Stiebale (2011), Ito and Terada-Hagiwara (2011) and Berman and Héricourt (2010) are also works that use the cash flow ratio on assets, or capital, as a measure of internal restrictions of companies. Bellone et al. (2010) construct an index to measure financial constraints and among the variables, the ability of companies to generate cash flow is used.[45]

For the current study, the cash flow of each company and year is obtained as the firm's sales minus the sum of purchases, external services, and labour costs. Then, this variable is expressed in real terms, using an industrial price index to deflate cash flow in nominal terms. The next step is to calculate the average of cash flow per industry and year.[46] Finally, using similar arguments to those used for the variable measuring access to external funding, the deviation with respect to the average by industry and year is obtained. Thus, negative values should correspond to firms facing tight internal financial constraints; while positive values should correspond to firms with a large availability of internal funds.

Since the positive sign of both external and internal funds corresponds to firms with a large availability of external and internal funds respectively, a positive sign for the estimate of these two variables is expected.

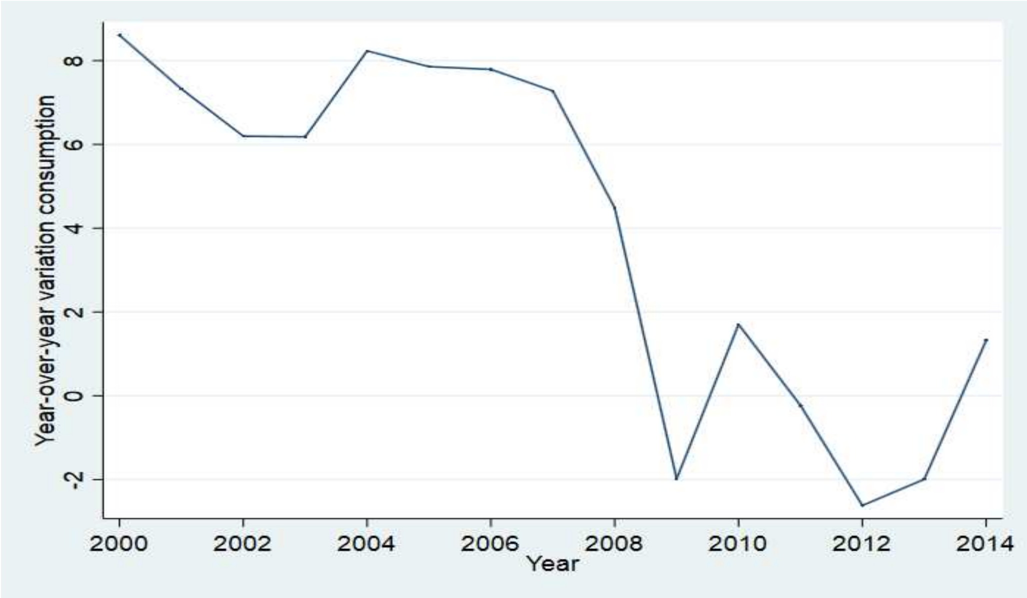
To measure demand conditions, instead of using a firm level variable the year-over-year variation of the final consumption expenditure at the macro level is used. Given that cash flow is one of the variables of greatest interest in this study, finding a variable measuring demand conditions at the firm level that does not generate collinearity problems was very difficult. That is the reason why a macro variable was chosen. As can be seen in Figure 1 the growth rate of consumption expenditure starts

[45] Other studies using cash flow (or its asset ratio) as a measure of firms' internal financing are, among others, Himmelberg and Petersen (1994), Ughetto (2008), Brown et al. (2009), and Hutchinson and Xavier (2006).

[46] Using the average by industry, it is possible to capture the different borrowing conditions depending on the industry which the firm belongs to.

to importantly decelerate from 2008, becoming negative in 2009. Therefore, in this study the crisis period will be considered as years from 2008 onwards.

Figure 1. Evolution consumption expenditure



Source: INE, 2000-2014

Table 13 presents descriptive statistics for both dependent variables and the main explanatory variables involved in the study for the whole period, before and during the crisis. The two exogenous shocks mentioned above are clearly unambiguous comparing columns 2 and 3. Both internal and external funds importantly decreased during the crisis period. Furthermore, the consumption growth rate dramatically decreased from 7.20% before the crisis to less than 1% during the crisis. Regarding export and R&D strategies, there were also significant changes. The percentage of R&D firms remained practically steady before and during the crisis, with a difference of two percentage points. However, in the case of exporters, the increase in this percentage was of more than four percentage points during the crisis.

Table 13. Mean and standard deviation

VARIABLES	Whole period	2000-2007	2008-2014
Internal funds	5.91 (25.89)	7.48 (29.46)	4.63 (22.50)
External funds	3.37 (82.72)	4.52 (118.54)	2.44 (31.24)
Consumption growth rate	3.36 (3.94)	7.20 (0.80)	0.24 (2.46)
% R&D firms	35.46 (1.37)	36.42 (1.30)	34.66 (0.81)
% Exporting firms	65.94 (3.38)	63.33 (1.06)	67.91 (3.19)

Observations	12,999	5,832	7,167

Notes: Internal and External funds in millions of € and deflated by the producer price index Standard deviations in parentheses. *Source: Survey of Business Strategies, 2000-2014*.

Besides the demand and financial variables, a number of variables commonly used in the related literature are also employed as controls. It still remains controversial whether market power encourages or inhibits firms from embarking on R&D activities and internationalisation. On the one hand, initially, Schumpeter (1942) defends that market power will positively affect the innovativeness of firms, since this market power will increase firms' financial means that could be used to finance innovation. Moreover, due to a greater level of market power, firms will reduce risk levels and, therefore, will have access to higher amounts of external funds. Given the importance of liquidity for export adoption, the same argument may be used for the export decision. On the other hand, Arrow (1962) suggests that the greater the market competition, the higher the incentives to innovate. Here, the argument is that the incremental rents, generated from innovating by firms operating in competitive markets, are higher in comparison to monopoly conditions.[47] To capture the degree of competition, two variables are introduced in the estimations: *Market share*, measuring the firm's market share in its main market; a set of dummy variables capturing the number of competitors with significant market share in the firms' main market: 10 or less competitors, from 11 to 25 competitors, more than 25 competitors, and atomistic market, this latter for firms declaring to have no competitors with a significant market share *(Number of competitors 0–10, Number of competitors 10–25 and Number of competitors >25,* being atomistic the baseline). One more control variable used in this study is *Size* (measured as the logarithm in the number of employees). Large firms usually have larger internal funds than SMEs, and have better access to financial markets (Damijan and Kostevc, 2011). Moreover, SMEs are usually more risk averse, which may force them to refuse taking external debt to finance exporting or innovation ventures. Finally, large firms may enjoy economies of scale, which would allow them to increase the profitability of export and innovative activities. For all these reasons, a positive effect of size on the probability of export and/or performing R&D is expected. A variable measuring the good performers (*Labour productivity*) is also

[47] There is also empirical evidence showing an inverted U-shaped relationship between competition and innovation. See, for example, Scherer (1967) or Aghion, Bloom, Blundell, Griffith and Howitt (2005).

included as a control variable. If the self-selection theory holds (Greenaway and Kneller, 2007), those firms which have better performance should be more likely to export (perform R&D). *Foreign* participation is also included as a control variable. Here the argument is that foreign firms may enjoy better access to international markets due to complementarities with other businesses within the group. Moreover, it has also been argued that foreign-owned firms are more efficient and, therefore, more capable of overcoming entry barriers both in export and R&D.

As defended by García-Quevedo et al. (2014) the age of the firm should also be a variable affecting the decision to perform R&D.[48] Given that technological change is path-dependent and cumulative, new R&D investments are unambiguously linked to previous R&D investments. Since R&D investment is characterised by cumulative learning (Arrow, 1962; Cohen and Levinthal, 1989, 1990), it is expected that more experienced incumbents might be characterised by stronger path dependence. Moreover, to mitigate capital market imperfections reputation and sources of collateral are two key aspects (Beck and Demirguc-Kunt, 2006; Czarnitzki, 2006). So, the more mature the firm, the higher the likelihood of mitigating these imperfections. By the same token, accumulated past profits are scarce by definition for younger firms (Hall, 2008). Finally, younger firms lack a long-term relationship with banks (Petersen and Rajan, 1994; Martinelli, 1997; Berger and Udell, 2002) and have a higher risk of default (Fritsch, Brixy and Falck, 2006) and, consequently, are more credit constrained.

Finally, export and R&D activities are persistent strategies (Dixit, 1989; Krugman, 1989; Roberts and Tybout, 1997; Mowery and Rosenberg, 1979; Flaig and Stadler 1998; Sutton 1991; Máñez et al. 2009) and, therefore, the lagged export and R&D status in the respective choice equations have been used to control for this.[49] As seen in Chapter 1 there are also some synergies between export and R&D and, therefore, lagged export status will also be included in the R&D equation and vice versa. Industry dummies are also used in all regressions.

Table 14 provides detailed information on all the variables involved in the estimations.

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48 See, among others, Bernard and Jensen (1995, 1999), Clerides, Lach and Tybout (1998) and Delgado et al. (2002) for the importance of persistence in exports.

49 See Wagner (2007) for a revision of the empirical literature testing persistency in exports and Máñez et al. (2015) for a summary of the theoretical frameworks explaining innovation persistence.

Table 14. Variable definition

Export	Dummy variable taking value 1 if the firm exports, and 0 otherwise
R&D	Dummy variable taking value 1 if the firm invests in R&D, and 0 otherwise
External funds$_{t-1}$	Firms' volume of new long-term debt with respect to the average volume borrowed by manufacturing firms in the same year, industry and size.
Internal funds$_{t-1}$	Firms' cash flow deviation with respect to the average by industry and year
Demand conditions$_{t-1}$	Year-over-year final consumption variation
Market share$_{t-1}$	The firm's market share in its main market (in %)
Number of competitors 0–10$_{t-1}$	Dummy variable taking value 1 if the firm asserts to have less than (or equal to) 10 competitors with significant market share in its main market, and 0 otherwise
Number of competitors 10–25$_{t-1}$	Dummy variable taking value 1 if the firm asserts to have more than 10 and less than (or equal to) 25 competitors with significant market share in its main market, and 0 otherwise
Number of competitors >25$_{t-1}$	Dummy variable taking value 1 if the firm asserts to have more than 25 competitors with significant market share in its main market, and 0 otherwise
Size$_{t-1}$	Log of the number of the firm's employees
Labour productivity$_{t-1}$	Output per employee
Foreign$_{t-1}$	Dummy variable taking value 1 if the firm's capital is participated by a foreign enterprise
Age$_{t-1}$	Log of the number of years since the firm was born.
Public sales$_{t-1}$	Dummy variable taking value one if more than 25% of firm sales go to the public sector and zero otherwise
High skill labour$_{t-1}$	Proportion of engineers and graduates in the firm's labour force
Med skill labour$_{t-1}$	Proportion of technical engineers, experts and qualified assistants in the firm's labour force
Appropriability$_{t-1}$	Ratio of the total number of patents over the total number of firms that assert to have achieved innovations in the firm's industrial sector (20 sectors of the two-digit NACE-93 classification) (in %)
Group$_{t-1}$	Dummy variables taking value 1 for firms belonging to a group of firms
Industry dummies	Industry dummies accounting for 20 industrial sectors of the NACE-93 classification

Source: Survey of Business Strategies, 2000-2014.

Estimation Results

Empirical model

To test the influence of financial constraints (H1 and H2) and demand conditions (H3) upon the decision to embark on R&D and/or export strategies by firm i during the crisis period, discrete choice models for panel data are employed. The equation for these models is as follows:

$$Y_{it}^{*j} = \beta X_{it-1}' + u_{it}^{j} \qquad (7)$$

where the dependent variable (Y_{it}^{*j}) is a latent (unobservable) variable representing the increase in the relative discounted utility derived from adopting each strategy j = Export, R&D and where X_{it-1}' is a vector of explanatory factors. As this variable is unobservable, the dependent variable is proxied by a binary variable (y_{it}^{j}) that takes value one if the relative utility associated to the strategy is positive, namely:

$$y_{it}^{j} = 1 \; if \; Y_{it}^{*j} > 0$$

$$y_{it}^{j} = 0 \; if \; Y_{it}^{*j} < 0$$

By using a probabilistic approach, it is tested whether or not the demand and financial variables have any impact on the likelihood of adoption of the strategy under consideration. In particular, to test whether the financial and economic crisis had any effect on the export and R&D decisions, through demand and financial conditions, the baseline specification is sequentially estimated by including interaction terms between the financial constraints and demand conditions variables and a dummy variable that takes on value 1 for years beyond 2007.

The model is estimated by maximum likelihood assuming a normal non-linear cumulative distribution function as well as random effects. Although the fixed effect model has the advantage of allowing the explanatory variables to be correlated with the individual effects, it has the shortcoming of eliminating a large number of observations. To allow the individual effect to be correlated with the regressors and to solve the 'initial conditions problem', the Wooldridge (2005) approach is applied.[50] Following this method, the unobserved individual effect (α_i) is conditioned on the initial values of the dependent variable (y_{i1}) and the individual mean of the time-

[50] See footnote 13 for an explanation of the 'initial conditions' problem.

varying covariates ($\bar{x}_i$), allowing for correlation between the individual effect and the observed characteristics:

$$\alpha_i = \alpha_0 + \alpha_1 y_{i1} + \alpha_2 \bar{x}_i + a_i \quad (8)$$

and therefore:

$$y_{i,t}^{j} \begin{cases} 1 \ if \ \theta_0^j y_{it-1}^J + \theta_1^j y_{it-1}^r + \beta^j X_{it-1} + \gamma^j Z_{it-1} + \omega DC + \delta^j Q_{it-1} + \\ \alpha_0 + \alpha_1 y_{i1} + \alpha_2 \bar{x}_i + a_i + S_i + u_{it}^j \geq 0 \\ 0 \ Otherwise \end{cases} \quad (9)$$

where θ_0 identifies the significance of persistence, $\theta_1$accounts for firms' expected profits from exporting to be affected by firms' R&D decisions and vice versa, X_{it-1} is a vector of variables controlling for firms' internal and external financial constraints and demand conditions, $Z_{it-1}$is a vector of control variables, ω identifies the overall crisis effects, δ the differential effects of the financial and demand conditions variables during the years of the crisis, plus the usual vector of industry dummies (S_i) and u_{it} is the error term. Moreover, due to interdependences in export and R&D decisions the error terms of the two equations are likely to be correlated. Hence, following Battisti et al. (2015) a bivariate probit that is estimated via the maximum likelihood is used. The resulting latent bivariate model is specified as:

$$\begin{cases} y_{i,t}^{Export} = \theta_0^{Export} y_{i,t-1}^{Export} + \theta_1^{Export} y_{i,t-1}^{R\&D} + \beta^{Export} X_{it-1} + \gamma^{Export} Z_{it-1} + \dots \\ \dots + \omega DC + \delta^{Export} Q_{it-1} + \alpha_i + S_i + u_{it}^{Export} \quad (10a) \\ \\ y_{i,t}^{R\&D} = \theta_0^{R\&D} y_{i,t-1}^{R\&D} + \theta_1^{R\&D} y_{i,t-1}^{Export} + \beta^{R\&D} X_{it-1} + \gamma^{R\&D} Z_{it-1} + \dots \\ \dots + \omega DC + \delta^{R\&D} Q_{it-1} + \alpha_i + S_i + u_{it}^{R\&D} \quad (10b) \end{cases}$$

Results

To analyse how financial constraints (H1 and H2) and demand conditions (H3) have affected the probability of exporting/performing R&D during the crisis period, a dummy variable taking on value 1 for years beyond 2007 is introduced in the model. Then, this dummy is interacted with the financial and demand conditions variables. In that way, the 'extra' effect of financial constraints and demand conditions during the crisis is picked up through the interaction terms, while the crisis dummy variable picks up any residual factor beyond the demand and the financial constraints. For example, the variable 'Internal*crisis' picks up the 'extra' effect of internal financial constraints upon export and R&D decisions from 2008 onwards. The variable 'Demand*crisis' picks up the 'extra' effect of demand conditions on the export/R&D probability from 2008 onwards, etc.

Table 15. Effects of financial constraints and demand condition on export and R&D decisions

	Crisis from 2008 onwards		Crisis from 2009 onwards	
	(1)	(2)	(3)	(4)
VARIABLES	Export	R&D	Export	R&D
Export $_{t-1}$	2.676***	0.252***	2.673***	0.253***
	(0.0659)	(0.0751)	(0.0657)	(0.0751)
R&D $_{t-1}$	0.185***	2.255***	0.181***	2.258***
	(0.0696)	(0.0491)	(0.0695)	(0.0491)
Internal funds $_{t-1}$	-0.0342	0.0514**	-0.0286	0.0549**
	(0.0283)	(0.0234)	(0.0272)	(0.0225)
External funds $_{t-1}$	0.000794	0.00315*	-0.000218	0.00206*
	(0.00205)	(0.00174)	(0.000987)	(0.00121)
Demand conditions $_{t-1}$	0.0600	0.00637	0.0601	0.00499
	(0.0377)	(0.0343)	(0.0381)	(0.0346)
Crisis	0.556*	0.0491	0.561*	0.0136
	(0.289)	(0.261)	(0.290)	(0.262)
Internal*crisis	0.0243	0.0104	0.0161	0.00338
	(0.0217)	(0.0199)	(0.0232)	(0.0198)
External*crisis	-1.47e-05	-0.00312*	0.0128**	-0.00255**
	(0.00222)	(0.00175)	(0.00558)	(0.00121)
Demand*crisis	-0.0695*	-0.0124	-0.0724*	-0.0259
	(0.0391)	(0.0358)	(0.0413)	(0.0371)
Number of competitors 0–10 $_{t-1}$	-0.0315	-0.0743	-0.0244	-0.0716
	(0.0919)	(0.0850)	(0.0921)	(0.0854)
Number of competitors 10–25 $_{t-1}$	-0.0113	0.0136	-0.0121	0.0137
	(0.114)	(0.102)	(0.114)	(0.102)
Number of competitors >25 $_{t-1}$	-0.202*	-0.137	-0.202*	-0.136
	(0.121)	(0.125)	(0.121)	(0.125)
Public sales $_{t-1}$	-0.0151	0.105	-0.0164	0.110
	(0.142)	(0.271)	(0.144)	(0.272)
High skill labour $_{t-1}$	0.00128	0.00584	0.00161	0.00577
	(0.00488)	(0.00469)	(0.00484)	(0.00468)
Med skill labour $_{t-1}$	-0.00571*	0.00376	-0.00537	0.00372
	(0.00341)	(0.00288)	(0.00341)	(0.00289)

Appropriability $_{t-1}$	0.00177	6.77e-05	0.00195	0.000110
	(0.00902)	(0.000636)	(0.00935)	(0.000637)
Market share $_{t-1}$	-0.000120	0.00191	-0.000144	0.00201
	(0.00206)	(0.00168)	(0.00203)	(0.00169)
Age $_{t-1}$	0.0827	-0.203*	0.0885	-0.179
	(0.139)	(0.121)	(0.132)	(0.116)
Size $_{t-1}$	0.121	0.0998	0.134	0.0977
	(0.0996)	(0.0850)	(0.0998)	(0.0850)
Foreign $_{t-1}$	-0.240	-0.0426	-0.263*	-0.0384
	(0.154)	(0.111)	(0.156)	(0.112)
Labour productivity $_{t-1}$	0.000199	-0.000232	0.000235	-0.000212
	(0.000228)	(0.000196)	(0.000227)	(0.000195)
Group $_{t-1}$	-0.1362	0.1120	-0.1415	0.1158
	(0.1214)	(0.0909)	(0.1208)	(0.0906)
Initial conditions				
Export$_1$	0.767***	0.0119	0.769***	0.00960
	(0.0595)	(0.0734)	(0.0594)	(0.0733)
R&D$_1$	0.123*	0.494***	0.125*	0.494***
	(0.0703)	(0.0454)	(0.0701)	(0.0454)
Constant	-2.324***	-2.597***	-2.338***	-2.584***
	(0.361)	(0.308)	(0.363)	(0.309)
Mean values explanatory variables (Wooldridge 2005)[a]	Chi2 (30) = 42.41 Prob > chi2 = 0.066		Chi2 (30) = 42.17 Prob > chi2 = 0.0693	
Industry dummies[b]	Chi2 (16) = 62.55 Prob > chi2 = 0.000		Chi2 (16) = 62.70 Prob > chi2 = 0.000	
Residual correlation	ρ =0.15 (s.e. = 0.05)		ρ=0.15 (s.e. = 0.05)	
LR test $\rho = 0$	χ2(1) = 9.231		$\chi^2(1)$ = 9.241	
Log likelihood	-4767.919		-4764.059	
Nº observations	13,093		13,093	

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the 1%, 5% and 10% level of significance, respectively
[a] F test of joint significance of the mean values of the time varying explanatory variables
[b] F test of joint significance of the Industry dummies

Table 16. Marginal effects upon R&D adoption

VARIABLES	Coefficients
Internal funds $_{t-1}$	0.00597**
	(0.00272)
External funds $_{t-1}$	0.000366*
	(0.000202)
Observations	13,093

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the 1%, 5% and 10% level of significance, respectively

The main conclusions from these regressions are as follows. First, the crisis positively affected the likelihood of exporting (see *Crisis* in columns 1 and 3 in Table 15). The same result was found in Chapter 1 of this thesis using a different dataset. Second, access to internal or external funds positively affects the probability of performing R&D (H1) but not the probability of exporting. There are, at least, two plausible explanations for the lack of significance of financial variables in export adoption. On the one hand, access to credit, in normal circumstances, does not vary much through time, as creditworthiness usually does not change greatly from year to year. On the other hand, taking into account that the model is also controlling for the lagged export status, the lack of significance may also be explained because credit constraints have no impact on firms' exporting status in t, if the firm was already exporting in t-1, as the start-up costs to export would have already been borne. To test what was more important for R&D adoption, access to external or internal funds (H1), the marginal effects of these two variables were calculated. Table 16 shows the higher importance of access to internal funds rather than external funds on the probability of performing R&D, confirming results obtained by Efthyvoulou and Vahter (2016). Third, the interaction between access to external funds and the crisis dummy variable is not significant for the export decision and negative and significant for R&D adoption (H2). That is, being a firm with higher access to external funds negatively affected the probability of performing R&D from 2008 onwards and had no effect on the probability of exporting. One possible interpretation of this result is that those firms less externally constrained, during a hardship period, decided to allocate the funds to other investments rather than in a long term investment such as R&D. Regarding export adoption, one should expect a positive and significant effect from the interaction between the crisis dummy variable and access to external funds. However, as mentioned in Garicano and Steinwender (2016) '*After the failure of Lehman Brothers in September 2008, conditions tightened severely. 2009 was the first full year in which the effects of the credit crunch were fully spread*' (Garicano and Steinwender, 2016, p.917). Thus, this positive effect may only arise from 2009 onwards. To check it, the same regression is run but in this case the crisis dummy variable takes on value 1 for years beyond 2008. The results are presented in columns 3 and 4 in Table 15. All the previous results maintain their sign and significance, but now the interaction term between the crisis and access to external funds, as expected, is positive and significant (H2). That is, from 2009 onwards (coinciding with the hardest period of the crisis) firms with higher access to external funds had a higher probability of exporting. In other words, the probability of exporting was higher for firms less external financial constrained. These opposed results for export and R&D may indicate the preference of companies to allocate the few available funds in a short term strategy (such as export), instead of assigning them to a long term strategy (such as R&D).

Regarding the demand shock suffered by the economy, the interaction term between the demand conditions and the crisis dummy variable in the export equation is negative and significant (H3a). This result would confirm the importance of internal demand conditions upon export adoption during the crisis. Therefore, the drop in internal demand is one of the factors explaining export adoption. As mentioned earlier, the negative demand shock suffered by firms from 2008 (jointly with the low expectations for domestic demand) may have forced firms to produce at very low capacities, releasing some resources that may have been used to increase their efforts towards international markets. With respect to the effects of demand conditions upon R&D adoption (H3b), neither the variable measuring these conditions nor the interaction term with the crisis dummy variable was significant in any of the regressions. Given the high significance of *Internal funds* in R&D adoption and the very similar evolution of cash flow and demand conditions, this result is, in fact, not surprising. Moreover, the crisis dummy variable, in a certain way, is already picking up part of the demand conditions and, therefore, decreasing the importance of the variable measuring demand conditions.

Besides these results, as was found in Chapter 1, export and R&D arise as persistent strategies (see $Export_{t-1}$ in column 1 and 3, and $R\&D_{t-1}$ in column 2 and 4 in Table 15) and sequential adoption is highly significant both in export and R&D decision adoption (see $Export_{t-1}$ in column 2 and 4, and $R\&D_{t-1}$ in column 1 and 3 in Table 15). In all regressions, the estimated correlations (ρ) between the residuals of export and R&D equations are positive and significant. This confirms the simultaneity of firms' export and R&D investment decisions and, hence, the need to jointly estimate the two decisions when analysing the factors affecting the probability of performing either activity.

The results presented above indicate that during the crisis, for firms with higher access to external funds the likelihood of exporting increased, while the likelihood of performing R&D decreased. A possible explanation for this result is that, during a period of scarce funds, the cost of funds to finance long term investment was even higher and that discouraged firms from engaging in R&D activities. In order to verify this and as a robustness test for previous results, the external constraint variable is now measured as in Máñez et al. (2014); that is, the cost of firms' new long term debt, calculated as a weighted average of the unit cost of debts the firm has borrowed in a given year both from banks and from other long term lenders. As in the former measure of external constraints, to avoid contamination from changing macroeconomic policies the financial cost variable is introduced as the deviation of the current firm's cost of financing with respect to the average cost paid by manufacturing firms in the same year. Negative values for the estimate of the cost of firms' new long term debt should be interpreted as evidence in favour of the existence of external financial constraints. So, a negative and significant coefficient is expected in the R&D equation. The results are presented in Table 17. Comparing the variable *External*crisis* in Tables 15 and 17, the negative and significant sign for R&D adoption in the former (indicating that firms with higher access to external funds had a lower probability of performing R&D) remains negative and significant for R&D adoption (indicating the existence of external financial constraints for R&D). That is, the higher cost paid to borrow funds for R&D investments negatively affected R&D adoption during the crisis period. As in the previous specification, the negative effect of the *External constraint* variable during the crisis is obtained both in the case of the crisis period starting from 2008 onwards and from 2009 onwards. All the previous results maintain their sign and significance. Namely, access to internal funds explain R&D adoption; during the crisis demand conditions explained export adoption; the crisis has positively affected the probability of exporting; R&D and export are persistent strategies; and sequential adoption is highly significant both in export and in the R&D decision adoption.

Table 17. Robustness with cost of debt as external constraint variable

	Crisis from 2008 onwards		Crisis from 2009 onwards	
	(1)	(2)	(1)	(2)
VARIABLES	Export	R&D	Export	R&D
Export $_{t-1}$	2.675***	0.245***	2.674***	0.244***
	(0.0660)	(0.0751)	(0.0658)	(0.0751)
R&D $_{t-1}$	0.178**	2.250***	0.178**	2.252***
	(0.0698)	(0.0493)	(0.0697)	(0.0492)
Internal funds $_{t-1}$	-0.0336	0.0528**	-0.0214	0.0561**
	(0.0281)	(0.0233)	(0.0269)	(0.0224)
External funds $_{t-1}$	0.0146	0.0397	-0.0134	0.0237
	(0.0489)	(0.0387)	(0.0405)	(0.0326)
Demand conditions $_{t-1}$	0.0597	0.00815	0.0586	0.00697
	(0.0378)	(0.0342)	(0.0381)	(0.0344)
Crisis	0.555*	0.0698	0.517*	0.0369
	(0.290)	(0.260)	(0.289)	(0.260)
Internal*crisis	0.0221	0.0107	0.00134	0.00442
	(0.0214)	(0.0198)	(0.0221)	(0.0199)
External*crisis	-0.0303	-0.104**	0.0288	-0.0845**
	(0.0561)	(0.0455)	(0.0490)	(0.0429)
Demand*crisis	-0.0694*	-0.0146	-0.0708*	-0.0287
	(0.0392)	(0.0357)	(0.0412)	(0.0370)
Number of competitors 0–10 $_{t-1}$	-0.0303	-0.0727	-0.0272	-0.0683
	(0.0913)	(0.0852)	(0.0914)	(0.0853)
Number of competitors 10–25 $_{t-1}$	-0.0101	0.0110	-0.00870	0.0143
	(0.113)	(0.103)	(0.113)	(0.103)
Number of competitors >25 $_{t-1}$	-0.196	-0.130	-0.197	-0.125
	(0.122)	(0.125)	(0.121)	(0.125)
Public sales $_{t-1}$	-0.0134	0.110	-0.0258	0.114
	(0.142)	(0.273)	(0.143)	(0.274)
High skill labour $_{t-1}$	0.00112	0.00582	0.00118	0.00570
	(0.00489)	(0.00474)	(0.00486)	(0.00473)
Med skill labour $_{t-1}$	-0.00552	0.00381	-0.00553	0.00376
	(0.00344)	(0.00292)	(0.00341)	(0.00293)
Appropriability $_{t-1}$	0.00194	-6.31e-05	0.00212	-6.05e-06
	(0.00895)	(0.000616)	(0.00925)	(0.000618)
Market share $_{t-1}$	-0.000115	0.00200	-0.000152	0.00207
	(0.00205)	(0.00170)	(0.00204)	(0.00170)
Age $_{t-1}$	0.0766	-0.213*	0.0883	-0.195*
	(0.138)	(0.121)	(0.131)	(0.116)
Size $_{t-1}$	0.115	0.0948	0.123	0.0922

	(0.0986)	(0.0852)	(0.0981)	(0.0851)
Foreign $_{t-1}$	-0.238	-0.0476	-0.251*	-0.0459
	(0.153)	(0.112)	(0.152)	(0.112)
Labour productivity $_{t-1}$	0.000176	-0.000219	0.000225	-0.000208
	(0.000221)	(0.000202)	(0.000223)	(0.000198)
Group $_{t-1}$	-0.1387	0 .1184	-0.1342	0.1189
	(0 .1203)	(0.091)	(0 .1197)	(0.0907)
Initial conditions				
Export$_1$	0.767***	0.0112	0.766***	0.0104
	(0.0596)	(0.0736)	(0.0595)	(0.0736)
R&D$_1$	0.118*	0.502***	0.119*	0.501***
	(0.0712)	(0.0456)	(0.0710)	(0.0455)
Constant	-2.293***	-2.597***	-2.258***	-2.582***
	(0.356)	(0.307)	(0.358)	(0.308)
Mean values explanatory variables (Wooldridge 2005)[a]	Chi2 (30) = 49.98 Prob > chi2 = 0.012		Chi2 (30) = 51.02 Prob > chi2 = 0.009	
Industry dummies[b]	Chi2 (16) = 61.26 Prob > chi2 = 0.000		Chi2 (16) = 61.38 Prob > chi2 = 0.000	
Residual correlation	ρ =0.15 (s.e. = 0.05)		ρ =0.15 (s.e. = 0.05)	
LR test $\rho = 0$	$\chi2(1) = 9.240$		$\chi2(1) = 9.307$	
Log likelihood	-4760.454		-4760.306	
Nº observations	13,093		13,093	

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the 1%, 5% and 10% level of significance, respectively
[a] F test of joint significance of the mean values of the time varying explanatory variables
[b] F test of joint significance of the Industry dummies

Concluding remarks

As a continuation of the first chapter, this chapter sheds more light on the factors explaining export and R&D adoption during the crisis period. The data used in the study are drawn from the *Survey of Business Strategies* for the period 2000-2014, with years beyond 2007 being of special interest. By using a probabilistic model, the results obtained are manifold. First, access to internal and external funds is an important factor explaining R&D adoption, the former being more binding (H1). This result corroborates the higher importance of internal funds for financing innovation activities. Second, access to liquidity (either externally or internally) is not an important factor explaining export adoption. However, when the analysis is done for the crisis period, access to external funds positively and significantly affects the likelihood of exporting (H2). This finding highlights the need for access to external funds to promote firms' internationalisation during a period of time where firms suffer an important hit in their availability of internal funds. Third, during the crisis, the probability of performing R&D activities decreased for firms with higher access to external funds. A possible explanation for these two last results is that given that credit shocks reduce the value of long term relative to short term investments, firms are willing to relinquish some risky medium and long term investments (R&D) and devote the limited pull of funds they have to access finance to short term investments (export) and increase the probability of surviving another day. Moreover, in the robustness check, the results also indicate that during the crisis the higher cost of debt to finance R&D activities may have also discouraged firms from engaging in this activity. Fourth, during the crisis, demand conditions were an important factor driving export adoption (H3a), but not significant in the case of R&D adoption (H3b). Therefore, during the crisis, availability of internal funds arises as the basic requirement to be able to invest in R&D.

All in all, the increase in export adoption (and the decrease in R&D adoption) during the crisis years can be explained through three mechanisms. First, the limited external funds available in the economy for funding firms' investments have been used to finance export rather than R&D activities. Second, given the high importance of the availability of internal funds to fund R&D investments, the very important decrease of these funds during the crisis has negatively affected the adoption of this strategy. Third, the dramatic decrease in the internal demand has pushed firms to sell their products abroad, in order to survive, while not affecting R&D adoption.

The findings of the study contribute to understanding that the roles of finance and of the crises in demand were important during the crisis period in explaining the export and R&D adoption decisions of firms. During periods of decreasing domestic demand and financial constraints, the lack of access to external funds and any drops in internal funds could dangerously limit export and R&D strategies, respectively, causing very negative consequences on long term growth. There is no doubt that the decision to start exporting during a period where firms were producing at very low capacities is absolutely rational and policy should help firms to overcome export entry barriers. One of these barriers is the sunk costs implied in this strategy which make liquidity a necessary condition. As shown in this chapter, those firms with higher access to external funds had a higher likelihood of exporting and, therefore, one priority of economic policy should be to find a way to provide these funds when the financial system is not able to do so. Nevertheless, when the goal is not only to enter but also to be able to permanently stay in foreign markets, firms cannot forget about innovative strategies. Given that during periods of scarce funds firms will rationally use the limited pull of funds to finance short term investments, it is very important that policies aimed at exploiting the complementarity gains between export and R&D stay ahead of the curve. That is, before firms start exporting (as the only way to survive) they should have reached the productivity threshold which will make them competitive in international markets and accumulate enough knowledge stock in advance to be able to fully exploit the learning by exporting effects. R&D investments would help to achieve both the productivity level but also the absorptive capacity needed which will enable firms to fully exploit the *learning by exporting* effects obtained through international markets, ensuring a sustainable comparative advantage in the long run. In order to sustain the potential complementarities between export and R&D, policy-makers should bear in mind, as a first pre-export requirement, that facilitating the knowledge stock in advance and promoting R&D activities, will help to achieve the target. Therefore, companies that do not have experience in R&D should be helped to adopt this strategy before starting to export. Meanwhile, the priority for companies that already undertake R&D is to facilitate their internationalisation.

The results of this chapter confirm the importance of financial factors for export and R&D adoption and how the crisis affected this relationship. However, nothing is said about the impact of the crisis upon the intensity of these strategies and whether these effects were symmetric or asymmetric (as occurred during the crisis period concerning export and R&D adoption). The last chapter of this thesis will study how the crisis affected the relationship between export intensity and R&D intensity.

CHAPTER 3: THE ROLE OF THE CRISIS IN EXPORT AND R&D INTENSITY AND THEIR SYNERGIES

Abstract

This chapter analyses the intensive margins of R&D and export strategies, as well as the impact of the latest financial and the economic crises upon them and their relationship. It is posited that the high importance of the availability of internal funds not only for R&D adoption but also for R&D intensity, jointly with the low domestic demand, have affected differently both export/R&D persistence and its relationship. For this purpose, Spanish manufacturing data drawn from the *Survey of Business Strategies* for the period 2000-2014 are used. By using a Heckman sample selection model, the results suggest that export intensity increased during the crisis, but not R&D intensity. Second, during the crisis there was a positive effect from R&D intensity to export intensity but not the opposite, confirming the asymmetries in the synergies between export and R&D during the years of the crisis. Finally, when the sample is split between firms exporting differentiated and non-differentiated goods the positive effect from export intensity to R&D intensity appears for the former but not for the latter.

Introduction

Exporting firms are more productive than domestic firms (Peters et al., 2015; Bernard and Jensen, 1999; Greenaway and Kneller, 2007; Wagner, 2007; Wagner, 2012; among others) and the likelihood of innovating is higher for firms performing R&D (Becheikh et al., 2006; De Jong and Vermeulen, 2007; Cohen and Levinthal 1989; among others). Therefore, exporter and R&D status are characteristics of the most innovative and productive firms that will drive the economy. Both theoretically and empirically the positive association between them is widely accepted. Within the theoretical literature, Constantini and Melitz (2008), Atkeson and Burstein (2010), and Long, Raff and Stähler (2011) are some of the studies showing how trade liberalisation creates incentives for firms' R&D investment, but also how firms increase their expected profits from exporting by investing in R&D.[51] However, as shown in the first chapter of this thesis, the crisis reduced the probability that exporting firms embark on R&D strategies but not the probability that R&D firms embark on export. Even though the results of the first chapter confirm the changes in export/R&D adoption because of the

[51] Bustos (2011), Aw et al. (2008), Atkeson and Burstein (2010) or Costantini and Melitz (2008) are some of the empirical studies showing the positive effects from exports to R&D. For empirical studies showing the positive effects of innovative activities upon export propensity see, among others, Aw et al. (2011), Becker and Egger (2013), Bernard and Jensen (1997) and Roper and Love (2002).

crisis, nothing is said about the effects upon the intensity of these strategies and its relationship. Besides the adoption of these strategies, if one wants to observe the whole picture about the consequences of the crisis upon export and R&D, the analysis should be done not only for the extensive margin (percentage of exporting/R&D firms), but also for their intensity (amount exported/invested in R&D). Improvements in learning capabilities (Cohen and Levinthal, 1990), the need to expand their markets to reach the return level that justifies the high costs incurred in R&D investment (Zahra, Ireland and Hitt, 2000) and the higher competitiveness of knowledge-intensive firms (Suárez-Porto and Guisando-González, 2014) are theoretical reasons defending the positive effect from R&D intensity to export intensity. Learning by exporting effects is behind the theoretical explanation of the positive effect from export intensity to R&D intensity (Clerides et al., 1998). However, as in the adoption decision, exogenous shocks may have some consequences upon the (possible) reinforcement between export and R&D intensity. Therefore, the aim of this study is to analyse the consequences of the world financial and economic crisis upon export and R&D intensity and its relationship.

In particular, I posit that bad internal demand conditions and the dramatic drop in the availability of internal funds for firms may have had different effects upon export and R&D intensities and its relationship. On the one hand, the low expectations for internal demand have not only increased the probability for firms of selling their products abroad, but also the importance of foreign sales comparing with domestic sales. On the other hand, in a period where firms were struggling to survive, increases in long term investments may have not been the case. Furthermore, given the high importance of access to internal funds in order to keep R&D investments going, the dramatic decrease of these funds during the years of the crisis may have also had an impact on R&D intensity. Finally, because of greater market power (Nevo, 2001) and the higher knowledge stock (Timoshenko, 2015) for firms selling differentiated goods, compared with firms selling non-differentiated goods, a different relationship between export and R&D intensity during the crisis years is expected.

In the empirical analysis, to avoid any potential sample selection bias, the Heckman (1979) procedure was applied. Moreover, the potential simultaneity in the two firms' decisions is taken into account through the estimation of a bivariate probit in the selection equation instead of a probit for each of the strategies. To allow the individual effect to be correlated with the regressors and to solve the 'initial conditions problem', the Wooldridge (2005) approach was applied.

The data used in the study come from the *Survey of Business Strategies* for the period 2000-2014. ESEE is an annual panel survey representative of Spanish manufacturing firms by industry and size categories. The final working sample consists of around 12,000 observations.

The main results can be summarised as follows. First, export and R&D appear as persistent strategies when the analysis is carried out within an intensity framework. However, this persistence increased during the crisis years for export but not for R&D intensity. Second, from 2008 onwards there was a positive effect from R&D intensity to export intensity but not the opposite. This last result confirms the asymmetries in the synergies between export and R&D during the crisis found in the first chapter, also, for their intensity. Finally, when the sample is split between firms exporting differentiated and non-differentiated goods a positive effect from export intensity to R&D intensity also appears for the former but not for the latter.

The rest of the chapter is organised as follows. Section 2 summarises the related literature and introduces the main hypotheses. In Section 3, data, variables used in the study and some descriptive statistics are shown. Section 4 is devoted to explaining the methodologies and presents the estimates of the different models for Spanish manufacturing firms, along with some robustness checks. Finally, Section 5 presents the main conclusions.

Related literature and main hypotheses

When the synergies between export and R&D have been studied, research in the field has generally followed two strategies. First, the evaluation of the effects on the likelihood of adoption of one strategy, given that the other had already been adopted (Esteve-Pérez and Rodríguez, 2013; see Chapter 1); second, evaluation of the complementarity effects of export and R&D on performance, either for sales or productivity growth (Golovko and Valentini, 2011; Aw et al., 2007; Peters et al., 2015). Differently from these studies, in the present work the analysis of the (possible) reinforcement between export and R&D will be completed through the effects of the intensity of these activities; that is, how the intensity of R&D affects the intensity of export and vice versa. As pointed out by Behrens et al. (2013), during the 2008-2009 trade collapse, the contribution of the intensive margin in explaining the changes in Belgian exports was much more important than the contribution of the extensive margin. 97% of the Belgian change in exports was explained through the intensive margin and only slightly more than 2% through the extensive margin. Similarly, Battisti and Stoneman (2003) and Pulkki and Stoneman (2013) are studies showing the importance of the intensive margin. Analysing the diffusion of new technology, both studies conclude that although the inter-firm diffusion (proportion of firms in the industry using the new technology) is more important in early stages, in later stages intra-firm diffusion (proportion of each firm's output produced using the new technology) dominates. Battisti and Stoneman (2003) conclude that (in the case of CNC technology in the UK metalworking and engineering industry) after 30 years' first usage, although the inter-firm diffusion (extensive margin) was nearing 82%, the overall diffusion was only 22%. Thus, studying the synergies between export and R&D without evaluating their intensity could lead to misleading results.

When analysing export intensity, it should be taken into account that firms with higher export intensity are more likely to further increase it since they have already gained experience, adapted their organisational structure or created communication channels (Stopford and Wells, 1972). Likewise, investment in R&D is an important process that expands organisational knowledge and learning capabilities over time (Cohen and Levinthal, 1990). This cumulative knowledge may be used in the future to further increase R&D intensity. In other words, R&D activities may be considered as a self-fuelled process (Mowery and Rosenberg, 1979). Therefore, persistence in export and R&D intensity should not be a surprise. However, the world financial and economic crisis, which started in 2008, may have had some consequences upon the persistence of these strategies. On the one hand, due to the limited production capacity of firms in the short term, during periods of growing domestic demand, firms will work at full capacity and, therefore, will not be willing to pay the high sunk costs involved in exports. Nevertheless, when the economy is hit by a negative demand shock and firms are producing at very low capacities, the free resources may be used to increase their efforts towards international markets. After the negative shock, more firms will be willing to substitute domestic sales with exports, since the costs of excess capacity would be higher than the costs of selling abroad (Belke et al., 2014 and Esteves and Rua, 2015). Given the dramatic drop in internal demand suffered by the Spanish economy from 2008 onwards (jointly with the low expectations for the domestic demand) firms may have decided to increase export intensity even more than in normal circumstances. In the case of incumbent exporters this effect should be even higher since their knowledge stock about international markets gains them an advantage over new exporters; that is, the current export intensity should have a higher positive effect on its future evolution during the crisis. On the other hand, given the long term nature of R&D investments (Cornell and Shapiro, 1988), the higher risk (Brealey, et al., 1977; Carpenter and Petersen, 2002) and the greater difficulty in obtaining funds to finance this type of investment (Arrow, 1962; Brealey, et al., 1977; Lev , 2000 ; Berger and Udell, 1990) the crisis may have hindered the increase in the R&D intensity. Therefore, the following two hypotheses are formulated:

HYPOTHESIS 1a. During the crisis, poor internal demand conditions pushed firms to increase their export intensity.

HYPOTHESIS 1b. During the crisis, the lack of internal funds hampered an increase in R&D intensity.

Both from a theoretical but also from an empirical point of view the positive effect of R&D in export and vice versa are widely accepted. On the one hand, the productivity increase generated by R&D investments (Crépon and Duget, 1997; Gu and Tang, 2004; Parisi et al., 2006; Rochina-Barrachina et al., 2010; Máñez et al., 2009) allows firms to reach the productivity level which will enable them to enter international markets (Greenaway and Kneller, 2007; Wagner, 2007 or Delgado et al., 2002). Moreover, R&D investments increase the probability of developing a new (or better quality) product increasing foreign demand and, therefore, pushing the firm to also operate overseas (Hitt, et al., 1997). Finally, learning and spillovers generated by R&D investments also increase the likelihood of exporting.[52] On the other hand, the knowledge acquired

[52] See Chapter 1 of this thesis.

through international markets positively contributes to returns on R&D investments (Clerides et al., 1998). Acknowledging the positive effects between the two strategies, a key aspect in this relationship is how the intensity of R&D affects the intensity of export and vice versa. From a theoretical point of view these are the main reasons that justify a positive effect from R&D intensity to export intensity. As suggested by Cohen and Levinthal (1990), investment in R&D is an important process that expands organisational knowledge and learning capabilities over time. Hence, the international expansion of firms may be explained by the use of this new knowledge (Dunning, 1993; Kotha et al., 2001; Lu and Beamish, 2001). The higher the R&D investment, the greater the organisational knowledge and learning capabilities improvements, factors that may drive not only internationalisation, but also international expansion by increasing exports as the proportion of total sales (Eriksson, Johanson, Majkgard and Sharma, 1997). Second, since investment in knowledge is an expensive strategy, knowledge-intensive firms may need to expand their markets in order to reach the return level that justifies the high costs incurred (Zahra et al., 2000). Finally, because of the better capabilities and efficiency of knowledge-intensive firms, they will be more competitive and will, therefore, reach better results in international markets (Suárez-Porto and Guisando-González, 2014). Considering the learning by exporting effects, it can also be argued that export intensity influences R&D intensity. Theories of *endogenous innovation and growth* (Romer, 1990; Grossman and Helpman, 1991; Young, 1991 or Aghion and Howitt, 1998) are consistent with the concept of learning by exporting. Firms operating abroad are exposed to a richer source of knowledge compared with those that only operate nationally. This new knowledge acquired beyond the national borders enhances firms' capabilities and can, therefore, foster increased R&D investment within firms; the higher the export intensity, the greater the contact with new knowledge and, thus, the higher the R&D intensity. Hobday (1995), using a technology-gap model, shows that innovation rates are accelerated by firm's exporting activities. Despite these arguments, a key aspect which will allow firms to take advantage of the positive learning by exporting effects is that firms must possess sufficiently advanced internal R&D allowing them to absorb the new knowledge (Griffith et al., 2004; Cohen and Levinthal, 1990). If this is not the case, these positive effects may either not arise or even be negative for R&D intensity, creating a substitution effect.

Empirical evidence in the field remains far from conclusive, though. Filatotchev and Piesse (2009) analyse the effects of R&D intensity upon export intensity for new listed firms in four European countries, finding that R&D intensity is an important antecedent factor for the internationalisation of sales and vice versa. However, they ran a simple Granger test to verify the direction of causality, finding that if R&D expenditures are increased by 1%, there is an expected increase in international sales of 1.3%. Meanwhile, if international sales are increased by 1%, R&D expenditures increases by only 0.005%. They conclude, then, that causality runs from R&D expenditures to internationalisation, and not the other way around. Using Spanish data, Barrios, Görg and Strobl (2003) found that firms export more the higher their R&D intensity and, also, that this effect is greater when firms are exporting to EU/OECD countries.[53] Apart from studies using R&D intensity, there are also works proxying *innovation intensity* with other variables. In a study on Italian manufacturing firms, Sterlacchini (2001) uses the percentage of R&D employees and finds a positive effect upon export shares. In a cross section study on German manufacturing firms, Lachenmaier and Wößmann (2006) apply a Tobit specification with instrumental variables, finding that the innovation expenditure positively affects the export share. However, studies that do not find any significant effects between the intensity of the two strategies can also be found. Using a panel dataset of the Taiwanese electronics industry, Aw et al. (2007), found no significant effects either from R&D intensity to export intensity or the other way around. The same not significant effect is found by Girma et al. (2008) in their study on British and Irish firms. Becchetti and Rossi (2000) find that for Italian firms R&D intensity increases neither the probability of being an exporter nor the share of exports on sales. Wagner (2007) offers an exhaustive survey of empirical works analysing the relationship between exports and productivity and concludes that evidence regarding learning by exporting is mixed and, therefore, not conclusive. Thus,

[53] The theory behind the higher effect for EU/OECD countries is that in order to be able to compete in those countries firms should improve first their own technology, while exporting to less advanced countries would not be a challenge because firms will not need to improve their own technology in advance.

further research needs to be done to understand the relationship between export and R&D intensity and whether the effects from export to R&D are the same as those from R&D to export. As shown in the first chapter of this thesis, the crisis reduced the probability that exporting firms embark on R&D strategies but not the probability that R&D firms embark on export. Therefore, there was an increase in the asymmetries in the sequential adoption between export and R&D during the crisis years. The results of Chapter 2 suggest that these asymmetries are explained through the higher preference of firms to use the scarce pull of funds available to finance export rather than R&D and because of the necessity to sell their products given the poor conditions of the internal demand. The same may occur with the intensity of these activities; that is, the synergies and the symmetries, or asymmetries, between export and R&D intensity may depend on exogenous shocks.

In Chapter 2 of this thesis the theoretical contribution of Garicano and Steinwender (2016) regarding the negative effects upon long term investments, compared with short term investments during credit shocks, has been confirmed. Given the very important fall in the internal demand from 2008 onwards in the Spanish economy, jointly with the short term nature of export compared with the long term nature of R&D, the positive effects from R&D intensity to export intensity may have arisen but not the opposite. Those firms with higher R&D intensity should be more competitive in international markets and, thus, an increase in R&D intensity should have a higher effect upon export intensity. Nevertheless, due to the lack of internal funds it may not have been possible to increase R&D intensity for firms increasing their export intensity. Consequently, the following hypotheses are formulated:

HYPOTHESIS 2a. During the crisis, R&D intensity positively affected export intensity.

HYPOTHESIS 2b. During the crisis, export intensity did not affect R&D intensity.

Finally, given that R&D investments improve not only the productivity of companies (Griliches, 2000; Ericson and Pakes, 1995; Pakes and Ericson, 1998; Romer, 1990; Aghion and Howitt, 1992) and, therefore, their competitiveness in international markets but, also, the likelihood of improving or commercialising new products (Becheikh et al., 2006; De Jong and Vermeulen, 2007; Cohen and Levinthal 1989; among others), a positive effect from R&D intensity to export intensity is expected; the higher the R&D investment the higher the export intensity, either because the firm is more competitive or because it has more (or better) products to sell abroad. In fact, R&D investments are considered as one of the principal means of gaining market share in international markets (Franko, 1989). Nevertheless, as mentioned earlier, the positive effects from export intensity to R&D intensity may depend not only on firms' capacity to absorb the new knowledge acquired through international markets, but also on the availability of internal funds. Information asymmetries (Brealey, et al., 1977), lack of collaterals (Lev, 2000; and Berger and Udell, 1990), low probability of success (Brealey, et al., 1977; Carpenter and Petersen, 2002) and the long term nature of R&D projects, which make them more risky (Cornell and Shapiro, 1988), are some of the arguments used in research to justify the higher difficulty in obtaining external funds to finance R&D projects. Thus, access to internal funds should be more important for financing R&D projects than access to external funds. In fact, this is the result obtained in Chapter 2 of this thesis and also in Efthyvoulou and Vahter (2016). Since the crisis may have decreased firms' mark-up, which will lead to less internal funds, this decrease may have negatively affected the increase of R&D intensity even for exporting firms.[54] However, this decrease in the mark-up could have been different depending on the type of goods the firm is selling abroad. Firms selling differentiated goods have a higher market power compared with firms selling non-differentiated goods (Nevo, 2001), which make them less likely to have suffered this decrease in the mark-up.[55] If this is the case, we should expect a different impact between firms selling differentiated and non-differentiated goods. Moreover, differently from firms selling homogeneous goods, firms selling differentiated products can benefit from potential internal knowledge spillovers and so be better positioned to understand the applicability of new ideas (Henderson and Cockburn, 1996). In a study disentangling the role of sunk costs and learning upon export persistence, Timoshenko (2015) concludes that persistence among firms operating in homogeneous industries primarily arises due to sunk costs while, in the case of firms exporting within

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[54] According to Behrens et al. (2013), during the 2008-2009 trade collapse average unit prices for Belgium manufacturing exporters fell by 7.04% and quantities by 20%.

[55] Krugman (1980) and Helpman and Krugman (1985) are some of the studies showing that trade in homogeneous and differentiated goods is different.

differentiated industries, three quarters of the state dependence can be attributed to learning. Finally, as found by Rauch (1999) and Esteve-Pérez, Mánez-Castillejo, Rochina-Barrachina and Sanchis-Llopis (2007) the expected survival for firms exporting differentiated products is longer, and, therefore, the cumulative knowledge generated by exports too. As shown in Chapter 1, the higher the number of years a firm has been exporting the higher the positive effects from export to R&D. Therefore:

HYPOTHESIS 3: During the crisis, there was a positive effect from export intensity to R&D intensity for firms selling differentiated goods but not for those selling non-differentiated goods.

Data and descriptive

For this study yearly data from the *Survey of Business Strategies* (ESEE) are used. ESEE is an annual panel survey representative of Spanish manufacturing firms by industry and size categories. This dataset provides exhaustive information at the firm level on: the firm's activity; sales; R&D expenditure; foreign trade; and accounting data. ESEE excludes firms with less than 10 employees. Firms with 10 to 200 employees were randomly sampled, holding around 5% of the population in the first year that the survey was carried out. All firms with more than 200 employees were requested to participate, obtaining a participation rate of around 70% during the first year. To minimise attrition, new firms with the same sampling criteria as in the base year have been annually incorporated, so that the sample of firms remains representative over time.[56]

The sample analysed in this study covers the period 2000-2014. After sampling out those firm observations that fail to supply relevant information about all the variables involved in the analysis, the final sample used in this chapter consists of around 12,000 observations corresponding to 1,229 firms. As the first year of the sample is needed to set up the variables solving the initial conditions problem and the explanatory variables are lagged one period, the estimations are carried out for the period 2002-2014.[57]

[56] See https://www.fundacionsepi.es/investigacion/esee/spresentacion.asp for further details.

[57] In the estimations where the analysis is only done for the crisis period the number of observations are around 7,200.

The dependent variables in this chapter are *export intensity* and *R&D intensity*. The former has been defined as the value of exports over total sales while the latter is defined as the total R&D expenses over total sales.

Among the explanatory variables, the lagged export and R&D intensity are those of most interest in this study. When the analysis is done for export intensity (R&D intensity) the lagged export intensity (R&D intensity) will pick up the importance of persistence while the lagged R&D intensity (export intensity) will pick up the synergies between the intensity of the strategies. Besides the lagged export and R&D intensity, a number of variables commonly used in the related literature are also employed as controls. As mentioned earlier, liquidity is a key aspect involved in export and R&D activities. This liquidity can come either from external or internal sources, therefore one variable measuring access to external funds and one measuring access to internal funds are needed. The way these variables are set up is exactly the same as in Chapter 2. The same applies for the remaining explanatory variables used in this chapter.

As can be seen in Figure 2, the percentage of firms declaring to face a recessive demand dramatically increased from 2008 onwards (which coincides with the beginning of the financial and economic crisis). Therefore, this study will consider as crisis period the years beyond 2007.[58]

Figure 2. Evolution percentage of firms declaring facing a recessive demand

Source: Survey of Business Strategies, 2000-2014.

[58] See also Figure 1 in Chapter 2 for the evolution of consumption expenditure.

Finally, to test hypothesis 3, a variable for firms selling differentiated and non-differentiated goods was needed. Unfortunately, with the data available, it was impossible to set up this variable at the firm level. Therefore, following Rauch (1999), Timoshenko (2015) and Esteve-Pérez et al. (2007) the variable was set up at the sector level. Rauch (1999) classifies goods as differentiated, reference priced and homogeneous. According to this author, most consumer goods are classified as differentiated. Therefore, following Esteve-Pérez et al. (2007), this study considers firms selling differentiated products as those belonging to a final consumption sector. [59]

Given that the econometric analysis in this study will be done through a Heckman sample selection model, the identification problem needs to be solved (Manski, 1989). To do so, at least one variable should be included in the selection equation but not in the interest equation. Due to the sunk costs involved in export and R&D strategies (Roberts and Tybout, 1997; Máñez et al., 2009; Máñez et al., 2015, among others), the importance of liquidity when firms have to decide whether to start exporting/performing R&D is widely accepted (Máñez et al., 2014; Muûls, 2008; Bellone et al., 2010; Manova, 2013; Aw et al., 2011; Chaney, 2016).[60] This liquidity can come either from internal or external sources. In any case, being part of a group increases the chances of having access to both. On the one hand, firms belonging to a group have access to the internal capital market built within the group that may, at least partially, replace the external capital market (Gertner, Scharfstein and Stein, 1994). In other words, group-affiliated firms have higher access to internal funds. On the other hand, being part of a group sends a signal to the lenders since those firms have more collateral to offer (Frazzoni, Mancusi, Rotondi, Sobrero and Vezzulli, 2014), increasing, thus, the access to external funds and, therefore, the likelihood of exporting/performing R&D. However, once the firm is exporting/performing R&D the signal is, indeed, that the firm was able to *self-select* into export/R&D markets. So, being part of a group could be important for the decision to export/perform R&D, but

[59] Meat, food and tobacco, beverages, textiles, leather, and shoes, motors and cars, furniture and other manufacturing goods, have been considered as final consumption sectors.

[60] See Wagner (2014) for a survey of empirical studies regarding exports and liquidity constraints and Hall (2002) and Hall and Lerner (2010) for R&D and liquidity constraints.

not for the intensity of these activities. Therefore, *group* is the variable chosen to be included in the selection equation but not in the interest equation.

Table 18 provides detailed information on all the variables involved in the estimations.

Table 18. Variable definition

Export intensity	Value of exports over total sales
R&D intensity	Total expenses in R&D over total sales
External funds$_{t-1}$	Firms' volume of new long-term debt with respect to the average volume borrowed by manufacturing firms in the same year, industry and size.
Internal funds$_{t-1}$	Firms' cash flow deviation with respect to the average by industry and year
Expansive demand$_{t-1}$	Dummy variable taking value 1 if the firm declares to face an expansive demand
Recessive demand$_{t-1}$	Dummy variable taking value 1 if the firm declares to face a recessive demand
Market share$_{t-1}$	The firm's market share in its main market (in %)
Number of competitors 0–10$_{t-1}$	Dummy variable taking value 1 if the firm asserts to have less than (or equal to) 10 competitors with significant market share in its main market, and 0 otherwise
Number of competitors 10–25$_{t-1}$	Dummy variable taking value 1 if the firm asserts to have more than 10 and less than (or equal to) 25 competitors with significant market share in its main market, and 0 otherwise
Number of competitors >25$_{t-1}$	Dummy variable taking value 1 if the firm asserts to have more than 25 competitors with significant market share in its main market, and 0 otherwise
Size$_{t-1}$	Log of the number of the firm's employees
Labour productivity$_{t-1}$	Output per employee
Foreign$_{t-1}$	Dummy variable taking value 1 if the firm's capital is participated by a foreign enterprise
Public sales$_{t-1}$	Dummy variable taking value one if more than 25% of firm sales go to the public sector and zero otherwise
High skill labour$_{t-1}$	Proportion of engineers and graduates in the firm's labour force
Med skill labour$_{t-1}$	Proportion of technical engineers, experts and qualified assistants in the firm's labour force
Appropriability$_{t-1}$	Ratio of the total number of patents over the total number of firms that assert to have achieved innovations in the firms industrial sector (20 sectors of the two-digit NACE-93 classification) (in %)
Age$_{t-1}$	Log of the number of years since the firm was born.
Group$_{t-1}$	Dummy variables taking value 1 for firms belonging to a group of firms

Year dummies	Dummy variables taking value 1 for the corresponding year, and 0 otherwise
Industry dummies	Industry dummies accounting for 20 industrial sectors of the NACE-93 classification
Product differentiated	Dummy variable taking value 1 for firms belonging to the sectors: meat, food and tobacco, beverages, textiles, leather and shoes, motors and cars, furniture and other manufacturing goods

Source: Survey of Business Strategies, 2000-2014.

Table 19 presents descriptive statistics for both dependent variables and the main explanatory variables involved in the study for the whole period, before and during the crisis.

Table 19. Mean and standard deviations

VARIABLES	Whole period	2000-2007	2008-2014
Export intensity	32.03 (28.70)	29.87 (27.24)	33.34 (29.48)
Export intensity differentiated sectors	28.65 (28.08)	28.56 (27.96)	28.70 (28.15)
Export intensity non-differentiated sectors	34.10 (28.80)	30.64 (26.79)	36.28 (29.92)
R&D intensity	1.79 (3.16)	1.79 (3.88)	1.79 (2.58)
R&D intensity differentiated sectors	1.37 (2.20)	1.33 (2.40)	1.40 (2.06)
R&D intensity non-differentiated sectors	2.04 (3.59)	2.05 (4.47)	2.04 (2.82)
Internal funds	5.82 (25.96)	7.55 (30.07)	4.69 (22.81)
External funds	3.54 (86.66)	5.08 (131.76)	2.53 (32.52)
% Recessive demand	41.69 (14.34)	18.64 (2.63)	47.99 (8.67)
% R&D firms	35.26 (1.28)	36.17 (1.32)	34.66 (0.81)
% R&D firms differentiated sectors	35.25 (1.28)	36.19 (1.33)	34.66 (0.81)
% R&D firms no differentiated sectors	35.28 (1.28)	36.16 (1.32)	34.67 (0.81)
% Exporting firms	66.09 (3.50)	63.09 (1.04)	67.92 (3.19)
% Exporters differentiated sectors	66.20 (3.52)	63.09 (1.04)	67.99 (3.19)
% Exporters no differentiated sectors	66.03 (3.48)	63.08 (1.04)	67.88 (3.19
Gross Operating Margin	8.99 (13.72)	10.19 (10.45)	8.20 (15.44)
Gross Operating Margin differentiated exporters	8.83 (12.93)	9.58 (9.93)	8.41 (14.36)
Gross Operating Margin no differentiated exporters	9.84 (13.46)	11.27 (10.12)	8.94 (15.12)

Observations	11,853	4,691	7,162

Notes: Cash flow and External funds are in millions of € and deflated by the producer price index. Standard deviations in parentheses. *Source: Survey of Business Strategies, 2000-2014*.

The two exogenous shocks suffered from 2008 (the dramatic drop in internal demand and the credit crunch) are clearly unambiguous when comparing columns 2 and 3 in Table 19. Both internal and external funds importantly decrease during the crisis period. Availability of internal funds decreased by almost 50%, while the access to external funds decreased by more than 50%. Furthermore, the percentage of firms declaring that they were facing a recessive demand dramatically increased from by around 19% before the crisis to almost 50% during the crisis period. Regarding export and R&D strategies, there were also significant changes both in the extensive but also in the intensive margin (mainly for export). The percentage of R&D firms remained practically steady before and during the crisis, with a difference of two percentage points. The same applies for the intensity of R&D. However, in the case of exporters, both the increase in the extensive and intensive margin was around four percentage points during the years of the crisis. Finally, the differences between sectors selling differentiated and non-differentiated goods during the crisis were not very noticeable, with two exceptions. First, while the export intensity remained steady for firms belonging to differentiated sectors, this margin importantly increased for firms belonging to non-differentiated sectors. Second, during the crisis the decrease in the gross operating margin for the former was around one percentage point, whereas it was almost of 2.5 percentage points for the latter. That is, even though firms selling non-differentiated goods increased their export intensity the decrease in the gross operating profits were much more important than for those selling differentiated goods, which could be a signal of the higher market power for firms selling differentiated goods.

Estimation Results

Empirical model

To test the influence of the financial and economic crisis upon export/R&D intensity (H1) and the synergies between them (H2), one concern that arises is the sample selection bias. The observation of export and R&D intensity is not random but conditional on the decision of firms to export/perform R&D. To solve this problem, the Heckman (1979) sample selection bias model was applied; that is, first the probability of exporting/performing R&D is estimated, and then, for those firms exporting/performing R&D, the intensity of these strategies is calculated. The interdependence between export and R&D adoption must also be considered in the estimation of the export/R&D adoption decision. Therefore, the selection equation instead of being estimated through a probit will be estimated using a bivariate probit specification. This probabilistic model is estimated by maximum likelihood assuming a normal non-linear cumulative distribution function as well as random effects. Although the fixed effect model has the advantage of allowing the explanatory variables to be correlated with the individual effects, it has the shortcoming of eliminating a large number of observations. To allow the individual effect to be correlated with the regressors and to solve the 'initial conditions problem', the Wooldridge (2005) approach is applied.[61] Following this method, the unobserved individual effects (α_i) is conditioned on the initial values of the dependent variable (y_{i1}) and the individual mean of the time-varying covariates ($\bar{x}_i$), allowing for correlation between the individual effect and the observed characteristics:

$$\alpha_i = \alpha_0 + \alpha_1 y_{i1} + \alpha_2 \bar{x}_i + a_i \qquad (11)$$

and therefore:

$$y_{i,t}^{j} \begin{cases} 1 \; if \; \theta_0^j y_{it-1}^J + \theta_1^j y_{it-1}^r + \beta^j X_{it-1} + \\ \alpha_0 + \alpha_1 y_{i1} + \alpha_2 \bar{x}_i + a_i + S_i + u_{it}^j \geq 0 \\ 0 \; Otherwise \end{cases} \qquad (12)$$

where θ_0 identifies the significance of persistence, $\theta_1$accounts for firms' expected profits from exporting to be affected by firms' R&D decisions and vice versa, X_{it-1} is a vector of control variables, plus the usual vector of industry dummies (S_i) and u_{it} is the error term. Moreover, due to interdependences in export and R&D decisions the error terms of the two equations are likely to be correlated. Hence, following Battisti et al. (2015) the resulting latent bivariate model is specified as:

[61] See footnote 13 for an explanation of the 'initial conditions' problem.

$$\begin{cases} y_{i,t}^{Export} = \theta_0^{Export} y_{i,t-1}^{Export} + \theta_1^{Export} y_{i,t-1}^{R\&D} + \beta^{Export} X_{it-1} + \\ \qquad \alpha_i + S_i + u_{it}^{Export} \quad (13a) \\ y_{i,t}^{R\&D} = \theta_0^{R\&D} y_{i,t-1}^{R\&D} + \theta_1^{R\&D} y_{i,t-1}^{Export} + \beta^{R\&D} X_{it-1} + \\ \qquad \alpha_i + S_i + u_{it}^{R\&D} \quad (13b) \end{cases}$$

Once the bivariate probit is estimated, the Heckman's lambda is calculated and then introduced into the interest equations as an additional explanatory variable. To test whether the financial and economic crisis had any effect on export/R&D intensity and their synergies, the baseline specification is estimated by including interaction terms between the lagged export/R&D intensity variables and a dummy variable that takes value 1 for years beyond 2007. In that way, the 'extra' effect of persistence and synergies during the crisis is picked up through the interaction terms. Therefore, the interest equation is:

$$z_{i,t}^{j} = \vartheta_0^{j} z_{it-1}^{J} + \vartheta_1^{j} z_{it-1}^{r} + \beta^{j} X_{it-1} + \omega DC + \delta^{j} Q_{it-1} + \mu \widehat{\lambda_i} + \alpha_0 + \alpha_1 y_{i1} + \alpha_2 \bar{x}_i + a_i + S_i + u_{it}^{j} \quad (14)$$

where ϑ_0 identifies the significance of persistence in export/R&D intensity, $\vartheta_1$accounts for firms' export intensity to be affected by firms' R&D intensity and vice versa, X_{it-1} is a vector of control variables, ω identifies the overall crisis effect, δ the differential effects of the lagged export/R&D intensity during the years of the crisis, $\widehat{\lambda_i}$ is the estimation of the inverse Mills ratio (lambda), plus the usual vector of industry dummies (S_i) and u_{it} is the error term.[62] As was done in the bivariate probit, to solve the initial conditions problem the Wooldridge (2005) approach was applied.[63] The resulting interest equations are specified as:

[62] The explanatory variables included in the interest equation are the same included in the selection equation but to solve the identification problem the variable *Group* is not included.
[63] In this case, instead of including the initial export/R&D status, the initial export/R&D intensity are included.

$$\begin{cases} z_{i,t}^{Export} = \theta_0^{Export} z_{i,t-1}^{Export} + \theta_1^{Export} z_{i,t-1}^{R\&D} + \beta^{Export} X_{it-1} + \omega DC + \delta^{Export} Q_{it-1} + \\ \qquad \alpha_i + S_i + u_{it}^{Export} \quad (15a) \\ z_{i,t}^{R\&D} = \theta_0^{R\&D} z_{i,t-1}^{R\&D} + \theta_1^{R\&D} z_{i,t-1}^{Export} + \beta^{R\&D} X_{it-1} + \omega DC + \delta^{R\&D} Q_{it-1} + \\ \qquad \alpha_i + S_i + u_{it}^{R\&D} \quad (15b) \end{cases}$$

As a robustness check, the above Heckman model is estimated by removing the crisis dummy variable and the interaction terms and running the model only for the years of the crisis. The same model is used to test the different impact of the crisis for firms selling differentiated and non-differentiated goods (H3).

Results

Using the whole sample and introducing the crisis dummy variable and the interaction terms between this dummy and the lagged export/R&D intensity, hypotheses 1 and 2 are tested. It has been widely proven that export and R&D are persistent strategies. This can be checked by looking at the sign and significance of the lagged dependent variable through a probability approach, where the analysis is done for the likelihood of exporting (performing R&D). When the analysis is done within an intensity framework, persistence is confirmed if past export intensity (R&D intensity) positively affects current export (R&D) intensity. As can be seen in columns 3 and 4 in Table 20, both the lagged export intensity in the export equation ($\theta_0^{Export} = 0.800$) and the lagged R&D intensity in the R&D equation ($\theta_0^{R\&D} = 0.704$) are positive and significant, indicating persistence in the intensity of both strategies; the higher the export (R&D) intensity in t-1, the higher the export (R&D) intensity in t. However, this study is more interested in analysing the consequences (if any) during the years of the crisis. The analysis of the effects of the crisis deepening requires checking the sign and significance of the interaction terms between the crisis dummy variable and the lagged export/R&D intensity variables (*Export intensity $_{t-1}$*Crisis and R&D intensity $_{t-1}$*Crisis*), which capture the differential effects of the previous export/R&D intensity for the crisis period. Looking at column 3 in Table 20, the variable *Export intensity $_{t-1}$*Crisis* is positive and significant, which means that from 2008 onwards there was an 'extra' positive effect from past export intensity to current export intensity. Therefore, during the crisis there was an increase in export intensity (H1a). However, this result does not hold for R&D intensity. *R&D intensity* $_{t-1}$**Crisis* in column 4 in Table 20 is not significant in the R&D equation, meaning that during the crisis R&D intensity did not increase (H1b).

Table 20. Relationship between export and R&D intensity (whole sample)

	Selection equations		**Interest equations**	
VARIABLES	(1) Export Adoption	(2) R&D Adoption	(3) Export Intensity	(4) R&D Intensity
Lagged export dummy	2.708***	0.234***		
	(0.055)	(0.072)		
Lagged R&D dummy	0.184***	2.281***		
	(0.070)	(0.043)		
Export intensity $_{t-1}$			0.800***	-0.001
			(0.015)	(0.002)
R&D intensity $_{t-1}$			-0.033	0.704***
			(0.084)	(0.059)
Crisis	0.057	0.042	0.481*	-0.070
	(0.065)	(0.054)	(0.254)	(0.060)
Export intensity $_{t-1}$*Crisis			0.019**	-0.001
			(0.009)	(0.001)
R&D intensity $_{t-1}$*Crisis			0.257**	0.018
			(0.124)	(0.061)
Internal funds $_{t-1}$	-0.029	0.052**	0.039	0.055***
	(0.027)	(0.022)	(0.107)	(0.014)
External funds $_{t-1}$	0.001	0.000	-0.000	-0.000
	(0.002)	(0.001)	(0.001)	(0.000)
Demand conditions $_{t-1}$	-0.004	-0.008	-0.074**	0.004
	(0.008)	(0.007)	(0.034)	(0.005)
Number of competitors 0–10 $_{t-1}$	-0.002	-0.065	-0.475	-0.080
	(0.103)	(0.089)	(0.407)	(0.091)
Number of competitors 10–25 $_{t-1}$	-0.034	-0.006	0.419	-0.087
	(0.122)	(0.106)	(0.457)	(0.092)
Number of competitors >25 $_{t-1}$	-0.161	-0.136	-0.613	-0.050
	(0.129)	(0.134)	(0.445)	(0.070)
Public sales $_{t-1}$	0.123	-0.175	0.054	-1.119**
	(0.337)	(0.300)	(1.382)	(0.546)
High skill labour $_{t-1}$	0.003	-0.006	0.031	-0.000
	(0.007)	(0.006)	(0.030)	(0.005)
Med skill labour $_{t-1}$	-0.006	-0.000	0.015	0.001
	(0.004)	(0.003)	(0.015)	(0.004)

Appropriability $_{t-1}$	0.003	-0.000	0.005	-0.002
	(0.011)	(0.001)	(0.008)	(0.002)
Market share $_{t-1}$	-0.000	0.001	0.002	-0.000
	(0.002)	(0.002)	(0.011)	(0.001)
Age $_{t-1}$	0.328**	-0.277**	0.468	0.149
	(0.160)	(0.140)	(0.648)	(0.138)
Size $_{t-1}$	0.154	0.062	-0.125	0.046
	(0.106)	(0.095)	(0.424)	(0.072)
Foreign $_{t-1}$	-0.055	0.042	-0.439	0.072
	(0.234)	(0.132)	(0.918)	(0.082)
Labour productivity $_{t-1}$	0.000	-0.000*	0.000	-0.000
	(0.000)	(0.000)	(0.001)	(0.000)
Group$_{t-1}$	-0.135	0.107		
	(0.126)	(0.098)		
Initial conditions				
Export dummy$_1$	0.768***	0.012		
	(0.058)	(0.070)		
R&D dummy$_1$	0.117*	0.469***		
	(0.063)	(0.044)		
Export Intenity$_1$			0.135***	0.003*
			(0.014)	(0.002)
R&D Intensity$_1$			-0.060	0.057***
			(0.061)	(0.021)
Heckman's lambda export			-0.863***	
			(0.099)	
Heckman's lambda R&D				-0.110***
				(0.035)
Constant	-2.099***	-2.573***	2.708***	0.309**
	(0.231)	(0.192)	(0.875)	(0.152)
Observations	11,841	11,853		
Censored obs			3,981	7,624
Uncensored obs			7,860	4,229
Mean values explanatory variables (Wooldridge 2005)[a]	Chi2 (30) = 52.56 Prob > chi2 = 0.0220		Chi2 (30) = 59.39 Prob > chi2 = 0.002	
Sector dummies[b]	Chi2 (16) = 55.99 Prob > chi2 = 0.000		Chi2 (16) = 94.3 Prob > chi2 = 0.000	

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the 1%, 5% and 10% level of significance, respectively
[a] F test of joint significance of the mean values of the time varying explanatory variables
[b] F test of joint significance of the industry dummies

As mentioned earlier, though, the main objective of this study is to examine the synergies between export and R&D intensity (H2). Therefore, the variables of greatest interest are the lagged R&D intensity in the export equation and vice versa. From previous research, it is known that the crisis positively affected the probability of exporting and, also, that it increased the probability of adding export by R&D firms, but reduced the probability that exporting firms embark on R&D strategies.[64] That is, there was a positive effect from R&D to export but not vice versa. To check whether this was also the case between export and R&D intensities, the important variables are *R&D intensity* $_{t-1}$**Crisis* in the export equation and *Export intensity* $_{t-1}$**Crisis* in the R&D equation. As can be seen in columns 3 and 4 in Table 20 the former is positive and significant, while the latter is not significant; that is, from 2008 onwards the R&D intensity positively affected export intensity (see *R&D intensity* $_{t-1}$**Crisis* in column 3 in Table 20), confirming the reinforcement from R&D to export (H2a). However, export intensity had no significant effects on R&D intensity (H2b), corroborating the asymmetries between export and R&D synergies also in the intensities (see *Export intensity* $_{t-1}$**Crisis* in column 4 in Table 20).

Before moving to the robustness checks and to test hypothesis 3, it is worth mentioning some interesting results obtained from the last regression. First, as many studies have found for the R&D adoption decision, access to internal funds is also positive and significant for R&D intensity, confirming the importance of internal funds not only for the decision of performing R&D but also for its intensity (see *Internal funds* in column 4). Given the important decrease that these funds suffered during the crisis may offer an explanation of both the impossibility of increasing R&D intensity and the lack of a positive effect from export intensity to R&D intensity. Second, while demand conditions are not significant for R&D intensity, this variable is negative and significant in the export equation (see *Demand conditions* in column 3); that is, as found in Chapter 2, the worsening of demand conditions not only explained export adoption during the crisis, but also its intensity. Third, the Heckman's lambda is highly significant both in export intensity and in R&D intensity equations. This result confirms the adequacy of using the Heckman sample selection model when analysing export and R&D intensities. Finally, looking at the selection equations, as was found in Chapters 1 and 2, export and R&D are persistent strategies (see *Lagged export dummy* in column 1 in Tables 20 and 21, and *Lagged R&D dummy* in column 2 in Tables 20 and 21). Moreover, as also found in Chapters 1 and 2, being a firm performing R&D (export) in

[64] See Chapter 1 and 2 of this thesis.

t-1 positively affects the likelihood of exporting (performing R&D) in t (*sequential adoption between export and R&D*).

To confirm results about export/R&D persistence and their relationship, the crisis dummy variable and the interaction terms are removed and then the regression is run using only the years of the crisis. The results are presented in Table 21.

Table 21. Relationship between export and R&D intensity (Crisis years)

	Selection equations		**Interest equations**	
VARIABLES	(1) Export Adoption	(2) R&D Adoption	(3) Export Intensity	(4) R&D Intensity
Lagged export dummy	2.719***	0.248***		
	(0.070)	(0.092)		
Lagged R&D dummy	0.185*	2.255***		
	(0.095)	(0.055)		
Export intensity $_{t-1}$			0.818***	-0.001
			(0.016)	(0.001)
R&D intensity $_{t-1}$			0.223**	0.733***
			(0.102)	(0.040)
Internal funds $_{t-1}$	-0.037	0.047*	0.177	0.054***
	(0.034)	(0.028)	(0.149)	(0.016)
External funds $_{t-1}$	0.001	0.000	-0.001**	-0.000
	(0.002)	(0.001)	(0.000)	(0.000)
Demand conditions $_{t-1}$	-0.004	-0.013	-0.040	-0.002
	(0.011)	(0.009)	(0.043)	(0.005)
Number of competitors 0–10 $_{t-1}$	-0.038	-0.030	-0.602	-0.109
	(0.126)	(0.111)	(0.525)	(0.068)
Number of competitors 10–25 $_{t-1}$	-0.077	0.013	0.670	-0.074
	(0.150)	(0.131)	(0.566)	(0.078)
Number of competitors >25 $_{t-1}$	-0.132	-0.153	-0.225	-0.035
	(0.159)	(0.177)	(0.571)	(0.067)
Public sales $_{t-1}$	0.412	0.168	-0.867	0.007
	(0.398)	(0.337)	(2.020)	(0.340)
High skill labour $_{t-1}$	-0.000	-0.001	-0.013	0.000
	(0.010)	(0.007)	(0.045)	(0.005)
Med skill labour $_{t-1}$	-0.015***	0.004	0.024	-0.002
	(0.006)	(0.004)	(0.021)	(0.003)
Appropriability $_{t-1}$	0.010	-0.000	-0.001	-0.003*
	(0.015)	(0.001)	(0.004)	(0.002)
Market share $_{t-1}$	0.001	-0.000	0.002	0.001

	(0.003)	(0.002)	(0.016)	(0.002)
Age $_{t-1}$	0.520**	-0.131	1.665	0.053
	(0.237)	(0.219)	(1.105)	(0.127)
Size $_{t-1}$	0.164	0.259**	-0.799	0.099
	(0.129)	(0.119)	(0.557)	(0.064)
Foreign $_{t-1}$	0.029	-0.031	-0.139	0.052
	(0.323)	(0.169)	(1.411)	(0.102)
Labour productivity $_{t-1}$	0.001	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.002)	(0.000)
Group$_{t-1}$	-0.100	0.078		
	(0.166)	(0.120)		
Initial conditions				
Export dummy$_1$	0.752***	0.025		
	(0.074)	(0.088)		
R&D dummy$_1$	0.178**	0.475***		
	(0.085)	(0.055)		
Export Intenity$_1$			0.122***	0.002
			(0.017)	(0.001)
R&D Intensity$_1$			-0.050	0.036***
			(0.078)	(0.014)
Heckman's lambda export			-1.160***	
			(0.136)	
Heckman's lambda R&D				-0.104***
				(0.032)
Constant	-2.581***	-2.890***	3.056**	0.192
	(0.366)	(0.306)	(1.544)	(0.190)
Observations	7,155	7,162		
Censored obs			2,263	4,622
Uncensored obs			4,892	2,540
Mean values explanatory variables (Wooldridge 2005)	Chi2 (30) = 42.18 Prob > chi2 = 0.1583		Chi2 (30) = 68.31 Prob > chi2 = 0.000	
Sector dummies	Chi2 (16) = 27.62 Prob > chi2 = 0.0350		Chi2 (16) = 87.47 Prob > chi2 = 0.000	

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the 1%, 5% and 10% level of significance, respectively
[a] F test of joint significance of the mean values of the time varying explanatory variables
[b] F test of joint significance of the industry dummies

Confirming the results in Table 20, *R&D intensity $_{t-1}$* is positive and significant in the export equation (see *R&D intensity $_{t-1}$* in column 3 in Table 21), whereas *Export intensity $_{t-1}$* is not significant in the R&D equation (see *Export intensity $_{t-1}$* in column 4 in Table 21); that is, from 2008 onwards there were positive synergies from R&D intensity to export intensity (H2a), but not vice versa (H2b).

Robustness checks

Changing the selection equations

In order to verify previous results, the model used to obtain the results presented in Table 21 is run again but, now, instead of having the probability of exporting and the probability of performing R&D, three selection equations are included: One for the probability of only exporting, one for the probability of only performing R&D and one for the probability of performing both activities. In this way, firms that were only exporting (only performing R&D) are not mixed with those that were performing both activities. Results for the interest equations are presented in Table 22. In the first column we can see how export intensity in t-1 affects export intensity in t for firms only exporting in t. In the second column, how R&D intensity in t-1 affects R&D intensity in t for firms only performing R&D in t. In column 3 the results show how export intensity in t-1 and R&D intensity in t-1 affect export intensity in t for firms performing both activities in t. Similar to column 3, in column 4 we can see how export intensity in t-1 and R&D intensity in t-1 affect R&D intensity in t for firms performing both activities in t.

Table 22. Robustness with only export, only R&D and both in the selection equations

VARIABLES	(1) Export Intensity (Only Export)	(2) R&D Intensity (Only R&D)	(3) Export Intensity (Both)	(4) R&D Intensity (Both)
Export intensity $_{t-1}$	0.794***	0.0308	0.792***	-0.00140
	(0.0135)	(0.143)	(0.0147)	(0.00203)
R&D intensity $_{t-1}$	0.315	0.624***	0.285**	0.716***
	(0.455)	(0.0747)	(0.127)	(0.0174)
Internal funds $_{t-1}$	0.403	0.110	0.176	0.153***
	(0.266)	(0.211)	(0.306)	(0.0426)
External funds $_{t-1}$	0.0112	-0.000498	-0.00102	-7.21e-05
	(0.0125)	(0.00768)	(0.00157)	(0.000220)
Demand conditions $_{t-1}$	-0.0462	0.0415	-0.107	-0.00292
	(0.0846)	(0.0637)	(0.0871)	(0.0122)
Number of competitors 0–10 $_{t-1}$	-2.104**	-0.492	0.811	-0.310*
	(0.895)	(0.810)	(1.204)	(0.168)
Number of	0.627	0.944	1.102	-0.346*

competitors 10–25 $_{t-1}$				
	(1.060)	(0.938)	(1.395)	(0.194)
Number of competitors >25 $_{t-1}$	-0.727	-0.429	-0.269	-0.177
	(1.291)	(1.080)	(1.854)	(0.258)
Public sales $_{t-1}$	-0.343	-1.214	-2.548	0.626
	(3.170)	(1.481)	(2.937)	(0.410)
High skill labour $_{t-1}$	-0.0351	0.0391	-0.000161	0.00308
	(0.0815)	(0.0682)	(0.0700)	(0.00978)
Med skill labour $_{t-1}$	-0.00156	0.0329	0.0573	-0.00996*
	(0.0459)	(0.0421)	(0.0385)	(0.00538)
Appropriability $_{t-1}$	0.00123	0.0177	0.00362	-0.0147***
	(0.0144)	(0.0679)	(0.0338)	(0.00473)
Market share $_{t-1}$	0.0400*	-0.0108	-0.0364	0.00375
	(0.0228)	(0.0179)	(0.0224)	(0.00313)
Age $_{t-1}$	2.402	3.790**	3.142	-0.362
	(2.004)	(1.683)	(2.517)	(0.351)
Size $_{t-1}$	-1.629	2.704***	-0.727	-0.0183
	(1.067)	(0.961)	(1.404)	(0.195)
Foreign $_{t-1}$	2.861	-2.496	-2.345	0.133
	(1.989)	(2.008)	(1.545)	(0.216)
Labour productivity $_{t-1}$	0.000382	-0.000557	0.00206	-1.99e-05
	(0.00166)	(0.00192)	(0.00273)	(0.000380)
Initial conditions				
Export Intensity$_1$	0.151***	-0.0361	0.117***	0.00328
	(0.0139)	(0.0308)	(0.0148)	(0.00206)
R&D Intensity$_1$	-0.128	-0.0386	-0.0352	0.0370***
	(0.255)	(0.0434)	(0.0725)	(0.0100)
Constant	4.555	0.242	5.370	1.003**
	(2.827)	(2.386)	(3.464)	(0.489)
Observations	7,175	7,182	7,165	7,165
Censored obs	4,635	6,994	4,813	4,813
Uncensored obs	2,540	188	2,352	2,352
Mean values explanatory variables (Wooldridge 2005)[a]	Chi2 (30) = 30.62 Prob > chi2 = 0.5360	Chi2 (30) = 55.53 Prob > chi2 = 0.006	Chi2 (30) = 24.04 Prob > chi2 = 0.843	Chi2 (30) = 69.26 Prob > chi2 = 0.000
Sector dummies[b]	Chi2 (30) = 57.00 Prob > chi2 = 0.000	Chi2 (30) = 26.02 Prob > chi2 = 0.052	Chi2 (30) = 65.03 Prob > chi2 = 0.000	Chi2 (30) = 45.24 Prob > chi2 = 0.000

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the 1%, 5% and 10% level of significance, respectively
[a] F test of joint significance of the mean values of the time varying explanatory variables
[b] F test of joint significance of the industry dummies

As can be seen in columns 1 and 2, export and R&D are persistent strategies (see

Export intensity $_{t-1}$ and *R&D intensity* $_{t-1}$ in column 1 and column 2 respectively in Table 22). However, the most interesting results are presented in columns 3 and 4. Aligned with results obtained in Tables 20 and 21, from 2008 onwards there was a positive and significant effect from R&D intensity to export intensity but not the opposite. *R&D intensity* $_{t-1}$ is positive and significant in column 3 in Table 22, while *Export intensity* $_{t-1}$ is not significant in column 4 in Table 22; that is, during the crisis years positive synergies appeared from R&D intensity to export intensity but not the other way around. As found in Chapter 1, I find *asymmetries* in the synergies between export and R&D from 2008 onwards also in the intensity of these strategies.

Differentiated versus non-differentiated goods

Chapter 1 showed that the crisis increased the probability of exporting for firms already performing R&D but not the opposite. Similarly, in this chapter the results indicate that the intensity of R&D positively affected the intensity of export but not the opposite. Both adoption and intensity approaches highlight the asymmetries in the synergies between export and R&D during the crisis years. As mentioned in section 2, these asymmetries between the intensity of export and R&D may be explained by the type of goods the firm is exporting. If the firm is selling differentiated goods, its greater market power, compared with firms selling non-differentiated goods, will lead to a lower decrease in internal funds during the crisis and, then, given the higher importance of internal funds for financing R&D activities,[65] to a lower negative impact upon R&D intensity. Moreover, the knowledge-base of firms selling differentiated goods may be higher than for those selling non-differentiated goods and, thus, the positive effects from export to R&D should also be higher; that is, the positive synergies from export intensity to R&D intensity may appear for firms selling differentiated goods but not for firms selling non-differentiated goods (H3). According to Rauch (1999), most consumption goods are classified as differentiated. Therefore, to test hypothesis 3, the sample is split between firms that belong to a final consumption industrial sector and those that do not. The results are presented in Table 23. Interestingly, the positive effect from R&D intensity to export intensity is significant both for sectors selling differentiated goods and for those selling non-

[65] See Chapter 2 of this thesis and Efthyvoulou and Vahter (2016).

differentiated goods. However, a positive and significant effect from export intensity to R&D intensity is only found for sectors selling differentiated goods, confirming hypothesis 3.

Table 23. Relationship between export and R&D intensity for firms selling differentiated and non-differentiated goods

	Non-Differentiated		Differentiated	
VARIABLES	(1) Export Intensity	(2) R&D Intensity	(3) Export Intensity	(4) R&D Intensity
Export intensity $_{t-1}$	0.823***	-0.001	0.838***	0.002*
	(0.019)	(0.002)	(0.025)	(0.001)
R&D intensity $_{t-1}$	0.288**	0.827***	0.314**	0.661***
	(0.117)	(0.049)	(0.129)	(0.059)
Internal funds $_{t-1}$	0.220	0.033	-0.024	0.065***
	(0.181)	(0.025)	(0.213)	(0.019)
External funds $_{t-1}$	-0.001**	-0.000	-0.000	-0.000
	(0.001)	(0.000)	(0.003)	(0.000)
Demand conditions $_{t-1}$	-0.053	0.001	-0.034	0.006
	(0.057)	(0.008)	(0.059)	(0.005)
Number of competitors 0–10 $_{t-1}$	-0.825	-0.062	-0.043	-0.085
	(0.632)	(0.095)	(0.778)	(0.072)
Number of competitors 10–25 $_{t-1}$	0.607	-0.087	0.825	-0.020
	(0.703)	(0.105)	(0.831)	(0.086)
Number of competitors >25 $_{t-1}$	-0.637	0.006	0.230	-0.033
	(0.710)	(0.083)	(0.885)	(0.093)
Public sales $_{t-1}$	0.485	-0.099	-3.571	-0.603***
	(2.054)	(0.368)	(3.049)	(0.229)
High skill labour $_{t-1}$	-0.025	0.006	0.028	0.002
	(0.040)	(0.008)	(0.055)	(0.006)
Med skill labour $_{t-1}$	0.021	-0.002	0.011	-0.001
	(0.023)	(0.004)	(0.027)	(0.003)
Appropriability $_{t-1}$	0.001	-0.002	0.002	-0.005
	(0.004)	(0.001)	(0.023)	(0.004)
Market share $_{t-1}$	-0.014	-0.001	0.010	0.001
	(0.020)	(0.003)	(0.023)	(0.002)
Age $_{t-1}$	1.996	0.079	-1.647	0.103
	(1.974)	(0.273)	(1.658)	(0.138)
Size $_{t-1}$	-0.304	0.097	-0.578	0.005
	(0.657)	(0.096)	(0.886)	(0.072)
Foreign $_{t-1}$	0.336	0.033	-0.658	0.004
	(1.603)	(0.147)	(2.438)	(0.093)

Labour productivity $_{t-1}$	0.002	0.000	0.000	0.000
	(0.004)	(0.000)	(0.001)	(0.000)
Group $_{t-1}$	0.407	0.175	-0.798	-0.033
	(0.791)	(0.139)	(1.054)	(0.161)
Initial conditions				
Export Intensity$_1$	0.120***	0.002	0.119***	-0.000
	(0.020)	(0.002)	(0.025)	(0.001)
R&D Intensity$_1$	-0.149	0.081***	0.063	0.006
	(0.146)	(0.026)	(0.049)	(0.007)
Heckman's lambda export	-1.381***			
	(0.164)			
Heckman's lambda R&D		-0.070		
		(0.044)		
Heckman's lambda export			-0.662***	
			(0.182)	
Heckman's lambda R&D				-0.181***
				(0.048)
Constant	1.845	0.021	5.238**	0.489**
	(2.038)	(0.359)	(2.226)	(0.240)
Observations	4,790	4,790	2,966	2,966
Mean values explanatory variables (Wooldridge 2005)[a]	Chi2 (30) = 62.83 Prob > chi2 = 0.000		Chi2 (30) = 46.86 Prob > chi2 = 0.043	

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the 1%, 5% and 10% level of significance, respectively
[a] F test of joint significance of the mean values of the time varying explanatory variables

Concluding remarks

As a natural extension of the first chapter of this thesis, where the synergies between export and R&D adoption were analysed, this chapter investigates the possible reinforcement between these two strategies but in an intensity framework rather than in an extensive one. The data used in the study are drawn from the *Survey of Business Strategies* for the period 2000-2014, with years beyond 2007 being of special interest. By using a Heckman sample selection model, the results obtained are manifold. First, export and R&D emerge as persistent strategies when the analysis is done within an intensity framework. However, this persistence increases during the crisis period for export but not for R&D intensity. Second, from 2008 onwards there was a positive effect from R&D intensity to export intensity but not the opposite, confirming the asymmetries in the synergies between export and R&D during the crisis years found in the first chapter using a probabilistic approach. These two last results, jointly with results obtained in Chapter 1, seem to indicate that, clearly, during the crisis firms preferred to use their limited resources for short term strategies (as export) instead of long term investments (as R&D). Finally, the positive synergies from export intensity to R&D intensity also appear for firms selling differentiated goods but not for those selling non-differentiated goods. Firms selling differentiated goods have a greater market power compared with firms selling non-differentiated goods and, therefore, the decrease in internal funds because of the crisis has been lower, allowing them to maintain their R&D investments. A possible explanation for this result is also provided by the higher knowledge-base of firms selling differentiated goods, which allows them to better exploit the learning by exporting effects. However, these are only two of the possible explanations about the asymmetries between export and R&D intensities during the crisis and more in-depth research needs to be done to deeply understand other mechanisms.

The findings of the chapter contribute to the understanding of the relationship between two strategies that, when jointly adopted, generate important synergies which allow firms not only to increase their performance but also to improve their knowledge stock and, therefore, to positively contribute to economic growth. Usually, research in the field has focused on the extension of these strategies rather than on their intensity. However, to fully understand the mechanisms which exploit the potential synergies between export and R&D, the analysis needs to be done both for the extensive but also for the intensive margin. As shown in Chapter 2, during crisis periods firms may prefer to use the scarce pull of funds to finance export activities rather than R&D investments and this could dangerously damage R&D strategies, causing very negative consequences on long term growth. The results obtained in this chapter also confirm the negative effects of the crisis upon the synergies from export intensity to R&D intensity and for R&D persistence. Therefore, the crisis negatively affected both R&D adoption but also R&D intensity. Given the high complementarity gains between export and R&D, to maintain them, policies should take into account that in a period where more firms tend to export, to be able to compete in international markets, firms need to increase their innovative intensity, as well. However, due to the importance of internal funds for financing R&D, this will only happen when firms have enough public support. Hence, policies aimed to help firms to enter the virtuous circle between export and innovative activities during crisis periods should not only facilitate the international growth of firms but also make sure that firms have access to funds to finance R&D investments which will allow them to fully exploit the *learning by exporting* effects. The promotion of international activities will not only allow firms to survive in a hardship period but, also, the high absorptive capacity achieved through R&D investments will help to fully exploit the *learning by exporting* effects, ensuring a sustainable comparative advantage in the long run.

Even though the results of this study confirm the asymmetries of the synergies between export and R&D during the crisis also within an intensity framework, very little is said about the factors that drive these asymmetries. At the same time, the hypothesis about the different effects for firms selling differentiated and non-differentiated goods is tested, due to the lack of data, using a sector level differentiation instead of a firm level differentiation. Therefore, it would be desirable to check whether the results hold when analysing other datasets with information available at the firm level. Finally, future research could also study the factors and mechanisms through which the crisis has affected the complementarity gains from export intensity to R&D intensity, but not vice versa.

GENERAL DISCUSSION

The three chapters presented in this thesis have a clear aim; to further our knowledge about the relationship between export and R&D and to evaluate how the latest world financial and economic crisis affected it. The achievement of this target aims at improving our understanding concerning how firms should behave in order to fully exploit the positive complementarities between internationalisation and innovative activities. In this section I will present the main contributions of my research, splitting them into theoretical and practical implications. I will also propose future research directions and present my concluding thoughts.

Theoretical implications

The new findings of this thesis offer important benefits for the understanding of the path that firms should follow in order to adopt and exploit both export and R&D activities. It is also acknowledged that this path may be hampered by exogenous shocks affecting firms in different ways depending on the strategies adopted thus far. The main theoretical contributions achieved by this thesis can be summarised into three aspects.

First, export and R&D strategies involve an important learning process that gives the opportunity for firms not only to stay longer in these strategies, but also to use this new knowledge to overcome the entry barriers of the other strategy. Arguably, either the learning by exporting (Clerides et al., 1998) or the expansion of organisational knowledge and learning capabilities generated by R&D investments (Cohen and Levinthal 1989, 1990) are important drivers for the adoption of R&D and exports, respectively. Since the seminal studies of Cohen and Levinthal (1989) and Sutton (1991), persistence in R&D has been extensively tested in Industrial Organization research. The former defends persistence in the performance of R&D because of the cumulative nature of knowledge in the learning process involved in R&D while the latter justifies persistence in R&D due to the sunk costs implied by this type of investment. The sunk costs argument was also used by Roberts and Tybout (1997) as the cause of persistence in exports. However, for the first time, the argument of the learning process either from export or from R&D as the origin of the positive synergies between the two strategies has been used. Therefore, the higher likelihood of sequential adoption between export and R&D, compared with the adoption of both strategies simultaneously, may be explained through the positive effects of learning linked to a strategy, on the adoption of the other. Moreover, given the higher knowledge base of R&D, compared with exports, the learning accomplished through this strategy should be greater than that achieved through exports. Thus, overcoming export entry barriers for R&D firms should be easier than overcoming R&D entry barriers for exporting firms. This argument also implies that, given the higher complexity of R&D, overcoming the R&D knowledge entry barriers for firms with no pre-entry knowledge should be more difficult than for exports. With these aspects in mind, the most desirable path for firms aiming to adopt both export and R&D implies first adopting R&D and, once the firm has a robust knowledge base, then promoting exports.[66]

Second, even if the learning behind the performance of either strategy positively contributes the adoption of the other, exogenous shocks might differently influence the sequential adoption between them. The different effects of demand conditions upon export and R&D strategies, jointly with the long term nature of R&D strategies, compared with the short term of exports, make the asymmetries between export and R&D sequential adoption even more notorious within a crisis scenario. When the economy is hit by both a credit crunch and a drop in internal demand, R&D firms are even more willing to add exports. Conversely, exporting firms are less willing to adopt an innovation strategy. The explanation for this behaviour may be found in the lack of funds (which forces firms to choose between different investment projects) but, also, on the efforts of firms to internationalise as the only way to survive. Poor internal demand conditions act as an *extra motivation* which encourages the internationalisation of companies (Esteves and Rua, 2015). The intuition rests on the limited production capacity of companies in the short run. When internal demand is growing, firms are not willing to use their funds in a riskier and less profitable strategy, since using their production capacity only for the domestic market is already

[66] See Chapter 1.

profitable.[67] Nevertheless, when the domestic market is suffering a fall in internal demand, the costs of excess capacity for companies may be higher than the costs of entering foreign markets. Thus, the internal demand, in a certain way, is pushing firms to internationalise. In the case of R&D, even if the opportunity cost theory defends the counter-cyclicality of R&D (Hall, 1991; Aghion and Saint-Paul, 1998), when the economy is hit by a credit crunch as well, the funds to pay the start-up costs are not available and, thus, this counter-cyclicality is reversed (Aghion et al., 2010, Aghion et al. 2012). Moreover, given the high sunk costs involved in export and R&D, liquidity is a compulsory requirement. During a period of scarce funds in the economy, firms may prefer to devote these limited funds to a short term (and sales) strategy, rather than to a long term (and investment) strategy. Therefore, the sequential adoption from R&D, to export plus R&D might be even higher, but not the opposite. The latest world financial and economic crisis brought a perfect scenario to test these ideas, since it supposed both a credit crunch and a dramatic decrease in internal demand.[68]

Third, to evaluate the entire consequences of the crisis, started in 2008, upon the synergies between export and R&D, the relationship between the intensity of these strategies cannot be ignored. Using similar arguments to those made below, we should not expect the same impact of the crisis upon export intensity and R&D intensity. On the one hand, low expectations on internal demand should have increased not only the number of exporting firms (see Chapter 1 and Chapter 2), but also the importance of foreign sales upon total sales. That is, the crisis may have fostered the substitution of national by foreign sales as the only way to survive. Conversely, in a period of turbulence in the economy, the long term nature of R&D investments (Cornell and Shapiro, 1988), higher risk (Carpenter and Petersen, 2002) and higher difficulty in obtaining funds (Arrow, 1962), may have hampered the increase in R&D intensity. On the other hand, the crisis should have also had an impact on the relationship between the intensity of these strategies. Firms with higher R&D intensity should be better

[67] Selling products in international markets may be less profitable, for example, due to the higher transaction costs for exports. Companies have to adapt products to comply with foreign legislation, new documentation is required, transport expenses are higher, etc. (Djankov, Freund and Pham, 2010). The higher risk of exports compared with domestic sales can be explained by the exchange rate fluctuations, the difficulty of enforcing certain contracts abroad or the higher delay in collections (Wagner, 2014).

[68] See Chapter 2.

prepared to compete in international markets and, therefore, the higher the R&D intensity, the higher the export intensity.[69] However, the asymmetries between export and R&D adoption found in the first chapter of this thesis should also hold for their intensity. That is, during the crisis, a positive impact from R&D intensity to export intensity may not appear. Two arguments may be used to explain this result. First, only firms with enough advanced internal R&D will be able to absorb the new knowledge acquired through participation in international markets (Griffith et al., 2004; Cohen and Levinthal, 1990). Second, as occurred with the adoption of R&D for exporting firms during the crisis years (see Chapter 1), companies may have preferred to use their funds for a short term strategy (export), giving up long term investments (R&D). Nonetheless, the asymmetries between the effects from export intensity to R&D intensity, and vice versa, might be not the same for companies exporting differentiated and non-differentiated products. Here, the justification can be found in the higher market power of firms selling differentiated goods (Nevo, 2001), which will allow them access to a greater amount of internal funds, permitting them to maintain their R&D investment. Furthermore, the higher internal knowledge of firms selling differentiated goods will also make them better positioned to understand and apply new ideas (Henderson and Cockburn, 1996) and, therefore, increasing R&D intensity when export intensity is growing.[70]

Practical implications

The present research has practical implications from an economic policy perspective. Existing research emphasises the importance of exploiting synergies due to the joint adoption of export and R&D strategies (Golovko and Valentini, 2011; Aw et al., 2007; Peters et al., 2015). However, to the best of my knowledge, there is no attempt in the literature explaining the dynamics behind joint adoption. This thesis provides a better understanding of these dynamics to improve not only firms' performance but also the economic situation of a country as a whole. Given the high knowledge entry barriers

[69] At least three arguments may be used to explain the higher competitiveness of higher R&D intensive firms. First, the increases in productivity generated by R&D will be higher (Crépon and Duget, 1997). Second, the likelihood of developing a new or better quality product will be higher as well (Hitt et al., 1997). Third, the learning generated by R&D will be higher as well and therefore the likelihood of success in foreign markets too (Suárez-Porto and Guisando-González, 2014).
[70] See Chapter 3.

linked to export and R&D and the post-entry knowledge obtained through the performance of any of the strategies, it is rational for firms to adopt both strategies in a sequential way rather than simultaneously. Either the adoption of export first and R&D second, or vice versa, is more likely than adopting both at the same time.[71] Thus, policies aimed to help firms to fully exploit the synergistic gains between export and R&D should bear in mind that adopting one strategy, and then the other, is more efficient (and likely) than adopting both at the same time. Moreover, because the learning process differs between export and R&D, the likelihood of adding exports for R&D firms is not the same as the likelihood of adding R&D for exporting firms. The higher knowledge base implicit in R&D projects makes innovative firms better positioned to adopt an internationalisation strategy than vice versa. At the same time, these higher knowledge entry barriers for R&D adoption make it more likely for firms without any pre-entry knowledge to start exports than to start R&D. With all these components in mind, the best policy strategy consists of facilitating R&D investments first and, once companies have reached the productivity threshold which will allow them to compete in international markets and accumulate enough knowledge stock, then facilitating the entry to foreign markets. Doing it the other way around (facilitating exports first and R&D second) entails two important drawbacks. First, higher competitiveness in international markets can cause shrinkage in business mark-ups and therefore a decrease in access to internal funds. Given the high importance of access to internal funds in the adoption of innovative activities, this can have a very negative effect on the adoption of R&D.[72] Second, the lower learning linked to exports, compared with R&D, will make the joint adoption process longer.

Besides the effects just mentioned, advising to promote R&D first and exports second, we should take into account that exogenous shocks might affect even more the asymmetries in the sequential adoption between the two strategies. As shown in Chapter 1, during the crisis years, the probability of adding export for firms already performing R&D increased, while the probability of adding R&D for firms already exporting decreased. The results presented in Chapter 2 indicate that this increase in sequential adoption asymmetries may be explained through three mechanisms. First,

[71] See Chapter 1.

[72] See Chapter 2.

firms with higher access to external funds decided to use them to finance the internationalisation of firms rather than R&D activities. Second, given the greater importance of access to internal funds to finance R&D activities, the rapid decline of them during the years of the crisis had very negative consequences on the adoption of innovative strategies. Finally, the drop in the internal demand pushed companies to sell their products abroad, while this did not have significant effects upon R&D adoption. Putting all these aspects together, the economic policy measures suggested above should be even stronger during a crisis period. Given that firms will rationally prefer adopting exports rather than R&D, policies should promote the adoption of R&D strategies even harder as a way to increase the survival chances in the short term, but also to build a sustainable comparative advantage in the long run. During a period of time where more firms tend to export, competition in international markets will be higher and, therefore, only those companies that are productive enough will be able to compete. The adoption of R&D will help to reach this productivity level. According to the results obtained in Chapter 2, one important factor which hampered R&D adoption during the crisis was the lack of funds. As the robustness check presented in Chapter 2 suggests, this may have happened due to the high financial costs linked to the financing of R&D which, during a period of strong turbulence, have caused these investments to disappear from the investment plans of companies. Therefore, public policies should facilitate access to credits, at reasonable financial prices, as a way to avoid the abandonment of R&D strategies from business plans. Facilitating R&D adoption will help to increase export adoption by firms that were not exporting and also to be more competitive for firms which are already exporting.

Finally, the results presented in Chapter 3, suggest that also the synergies between export and R&D intensity were affected because of the crisis. During the crisis years, besides the decrease in the likelihood of adding R&D by exporting companies,[73] export intensity had no effect upon R&D intensity. Conversely, aligned with results obtained in Chapter 1 (where the likelihood of adding exports for R&D performers increased during the years of the crisis) R&D intensity positively and significantly affected export intensity. Jointly, the results of Chapters 1 and 3 highlight that, from 2008 onwards,

[73] See Chapter 1.

there was an increase in the synergies from R&D to export, but not from export to R&D. Given that the main goals of R&D investments are either reducing costs or achieving a differentiated product, the higher the R&D intensity, the higher the competitiveness of the firm and, thus, the higher the export success. In fact, R&D investments are considered as one of the principal means of gaining market share in international markets (Franko, 1989). However, the positive effects from export intensity to R&D intensity may not appear for various reasons. First, it is possible that what is important for firms in order to compete in foreign markets is reaching a certain level of *internal knowledge*. Once this threshold has been reached firms are able to absorb the learning obtained through international markets and then exploit the learning by exporting. Therefore, we should expect a positive effect from export intensity to R&D intensity before the threshold is reached, but not once firms have already reached this level. Second, depending on the technological dynamics attached to the sector where firms are selling products, the synergies from export to R&D may or may not appear. For example, for firms exporting homogeneous goods, innovation intensity may not be as important as for firms selling differentiated goods, since the technological change in the former is much lower than in the latter. Therefore, firms selling differentiated products are more likely to continuously invest in R&D in order to maintain (or increase) their competitive position. Finally, also related to the last argument, firms selling differentiated goods because of their higher market power (Nevo, 2001), may enjoy a better financial health and, therefore, a higher probability of continuously investing in R&D. Taking into account all these arguments, policy-makers should bear in mind that to maximise the effects of their measures the priority targets are companies exporting differentiated goods. Helping these firms to keep going with their R&D investments will help to maintain their comparative advantage but, also, to promote sectors where the innovative charge is high. Given that during the crisis more firms were willing to sell their products abroad, countries should take advantage of that and promote R&D in order to maximise the potential complementarities between internationalisation and innovation.

Future research

Through the present research I find that sequential adoption between export and R&D is more frequent than simultaneous adoption and the adoption sequence is not symmetric. However, nothing is said about the remaining possible dynamics. I invite fellow researchers to investigate all the various combinations between these strategies. To the best of my knowledge, there is no work analysing all the possible switches between them. Research in the field has mainly focused on the effects of adding a strategy, assuming that firms can only move forward rather than going backwards. Therefore, the causes and consequences of dismissing a strategy have been neglected. Some interesting questions arise from this matter. In the same way that there are synergistic gains from the joint adoption of export and R&D, are there '*complementary losses*' from the joint dismissal? Are the consequences of giving up international markets and giving up R&D investments the same? Are the consequences of joint dismissal the same as the consequences of *'sequential dismissal'*? Future research could explore all the paths that firms follow and answer all these questions.

A second line of research that I would propose after the completion of this thesis is related to the persistence of exports and R&D activities. On the one hand, Roberts and Tybout (1997) defend the role of sunk costs as the factor explaining persistence in exports. In the same vein, R&D persistence has also been explained as the result of the existence of high sunk costs associated to these investments (Sutton, 1991). On the other hand, the learning effects generated either by R&D (Cohen and Levinthal, 1989) or by exports (Timoshenko, 2015) have been also used as an argument to defend persistence in any of the strategies. However, to the best of my knowledge, gaps remain to be filled in this field. Firstly, there is no attempt to disentangle the role of sunk costs versus learning in explaining persistence in R&D. Secondly, even if Timoshenko (2015) disentangles the role of each factor in exports persistence, she does the analysis within an extensive framework, neglecting the importance of the intensive margin as well. Therefore, either of these two recommendations are fertile ground for future research.

My study focuses on manufacturing firms within a specific country and I invite fellow academics to undertake similar approaches in other sectors as well as other countries.

Given that not all services are tangible or durable, the exporting dynamics for service companies compared with manufacturing companies may be absolutely different. Furthermore, innovation processes can also substantially vary between manufacturing and service firms (Hoffman et al., 1998). Regarding the use of other countries, given the importance of liquidity upon export and R&D adoption, different financial systems may lead to different conclusions. Spain is a country where bank loans are the most common form of external financing for firms and constitute the bulk of firms' financial debt (Schiantarelli and Sembenelli, 2000). It would be interesting to check whether the conclusions reached in this thesis also hold for firms operating in countries with a financial system more based on the stock-market.

Finally, another challenge to be addressed by future research consists of making a deeper analysis taking into account the *size* element. Only 0.1% of firms operating in Spain are considered large firms. Furthermore, within the SME population around 45% are micro-businesses (firms employing between one and nine employees). The mechanisms and paths followed by micro-businesses and large firms may largely differ. Given the high importance of SMEs, in general, and micro-businesses, in particular, in the Spanish economy, a deeper understanding of how these firms behave and how the crisis has affected them is highly desirable. I invite fellow researchers to undertake such study and also to make an international comparison for firms of this size.

Concluding remarks

The main purpose of this thesis was to provide a better understanding concerning export and R&D synergies and to evaluate the role that the 2008 world financial and economic crisis had upon these synergies. In view of the results presented and discussed in the preceding chapters, the following final conclusions may be drawn: There are positive synergies between export and R&D although they are asymmetric and the worsening of the crisis magnified these asymmetries. In light of the findings of this thesis, it can be concluded that the positive synergies between the two strategies can be explained through the learning process and that the asymmetries in these synergies are due to the different knowledge bases between export and R&D. The increase in the asymmetries because of the crisis is the result of the different effects of the credit crunch and the fall in internal demand on export and R&D.

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APPENDIX I: ROBUSTNESS CHECK FOR THE NON-LINEAR MODELS

As a robustness check for the bivariate probit specifications used in Chapter 1, instead of analysing the probability of each strategy in isolation, a probit model is run to analyse the probability of performing the various combinations between them. Again, the model applied is the random effects estimator using the Wooldridge (2005) approach, allowing correlation between the individual effects and the explanatory variables. The only difference with equation (2) is that, in this case, the estimation will be individually run for each strategy (Export only, R&D only, Both and None) rather than simultaneously. Besides, instead of using the lagged export (R&D) status, the lagged strategy status will be used. In other words, when analysing the probability of performing both activities the lagged variables will be 'Export only', 'R&D only' and 'Both' to identify the effect of each of these strategies on the probability of performing both activities.[74] The same procedure was carried out in analysing the probability of performing the various combinations of strategies ('Export only', 'R&D only' and 'None'). Table 24 presents the results for the whole period and Table 25 for the crisis effects.

[74] Being '*None*' the baseline case.

Table 24. Probit model estimations for the various combination of export and R&D strategies

VARIABLES	(1) Both	(2) Export only	(3) R&D only	(4) None
$Both_{t-1}$	2.301***	-0.498***	0.335***	-2.243***
	(0.000)	(0.000)	(0.000)	(0.000)
Export $only_{t-1}$	0.556***	1.069***	-0.350***	-1.434***
	(0.000)	(0.000)	(0.000)	(0.000)
R&D $only_{t-1}$	1.242***	-0.768***	1.514***	-1.520***
	(0.000)	(0.000)	(0.000)	(0.000)
$Size_{t-1}$	0.227***	0.051	-0.076*	-0.139***
	(0.000)	(0.168)	(0.063)	(0.000)
$Foreign_{t-1}$	-0.058	-0.031	0.005	0.089
	(0.458)	(0.721)	(0.962)	(0.433)
$Internal_{t-1}$	-0.076**	0.119***	-0.003	-0.054
	(0.017)	(0.000)	(0.947)	(0.152)
$External_{t-1}$	-0.036	-0.024	-0.048	0.143***
	(0.255)	(0.484)	(0.195)	(0.000)
Industry $conditions_{t-1}$	-0.076	0.034	0.072	-0.155**
	(0.146)	(0.556)	(0.237)	(0.015)
Initial conditions				
Export $Status_1$	0.850***	0.814***	-0.680***	-0.792***
	(0.000)	(0.000)	(0.000)	(0.000)
R&D $Status_1$	0.663***	-0.422***	0.464***	-0.438***
	(0.000)	(0.000)	(0.000)	(0.000)
Mean Size	-0.006	-0.165***	0.069	-0.059
	(0.873)	(0.000)	(0.103)	(0.119)
Mean Foreign	0.485***	-0.107	-0.245	-0.663***
	(0.003)	(0.609)	(0.185)	(0.005)
Mean Internal	-0.059	-0.010	-0.039	0.183***
	(0.337)	(0.890)	(0.572)	(0.008)
Mean External	0.187***	-0.040	0.152**	-0.352***
	(0.002)	(0.590)	(0.028)	(0.000)
Mean Industry conditions	-0.086	-0.047	-0.130	0.389***
	(0.225)	(0.550)	(0.123)	(0.000)
Constant	-1.246	-0.627	-1.030	-1.904
	(0.285)	(0.619)	(0.454)	(0.153)
Mean values explanatory variables (Wooldridge 2005)[a]	Chi2 (5) = 21.12 Prob > chi2 = 0.000	Chi2 (5) = 19.47 Prob > chi2 = 0.001	Chi2 (5) = 12.10 Prob > chi2 = 0.033	Chi2 (5) = 56.33 Prob > chi2 = 0.000
Industry dummies[b]	Chi2 (20) =272.46 Prob > chi2 = 0.000	Chi2 (20) =146.54 Prob > chi2 = 0.000	Chi2 (20) =29.97 Prob > chi2 = 0.070	Chi2 (20) =147.05 Prob > chi2 = 0.000
Year dummies[c]	Chi2 (7) =	Chi2 (7) =	Chi2 (7) =	Chi2 (7) =

	208.83 Prob > chi2 = 0.000	509.34 Prob > chi2 = 0.000	760.43 Prob > chi2 = 0.000	255.76 Prob > chi2 = 0.000
Nº observations	40,326	40,326	40,326	40,326

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the1%, 5% and 10% level of significance, respectively
[a] F test of joint significance of the mean values of the time varying explanatory variables
[b] F test of joint significance of the industry dummies
[c] F test of joint significance of the year dummies

Three are the main conclusions from these regressions results. First, as reported in column 1 switching from 'Export only' or 'R&D only' to 'Both' (H1) is highly significant ($\theta^{Export\ only}$=0.556 and $\theta^{R\&D\ only}$=1.242). The probability of adopting one strategy when the firm was already performing the other suggests that sequential adoption in either directions, is more likely that simultaneous adoption (none to both being the baseline case). Secondly, it suggests that it is more likely that R&D firms start exporting (H2) rather than the opposite (asymmetries in sequential adoption). Lastly, export and R&D are persistent strategies. As columns 2 and 3 in Table 24 show, the probability of performing 'Export only' or 'R&D only', when the firm was already performing this strategy, it is positive and significant **(**$\theta^{Export\ only}$=1.069 and $\theta^{R\&D\ only}$=1.514 in column 2 and 3 respectively). The same applies to the probability to continue performing both activities (see θ^{both}=2.301 in column 1). It is also found that dismissing a strategy ie from 'Export only', 'Both' or 'R&D only' to 'None' (see column 4 in Table 24) carries a negative and significant coefficient**.** Supporting the view of Roberts and Tybout (1997) that sunk cost prevent the firm from dismissing a strategy.

As a robustness check for the crisis effects, the level and the interaction terms between the previous status variables ($Both_{t-1}$, Export $only_{t-1}$ and R&D $only_{t-1}$) and a dummy variable that takes on value 1 for the years beyond 2007 (C8) are used. The interaction term should pick up the effects of the crisis depending on the adoption status and hence any induced asymmetries in the adoption sequence.

Table 25. Probit model estimations for the crisis effects on the combination of export and R&D strategies

VARIABLES	(1) Both	(2) Export only	(3) R&D only	(4) None
C8	0.061	1.016***	-0.306***	-0.558***
	(0.530)	(0.000)	(0.000)	(0.000)
$Both_{t-1}$	2.140***	-0.023	0.585***	-2.280***
	(0.000)	(0.752)	(0.000)	(0.000)
$Both_{t-1}$*C8	0.149	-0.582***	-0.369***	0.143*
	(0.139)	(0.000)	(0.000)	(0.058)
Export $only_{t-1}$	0.682***	1.510***	-0.034	-1.265***
	(0.000)	(0.000)	(0.688)	(0.000)
Export $only_{t-1}$*C8	-0.163	-0.510***	-0.501***	-0.113*
	(0.135)	(0.000)	(0.000)	(0.099)
R&D $only_{t-1}$	0.687***	-0.453***	1.851***	-1.872***
	(0.000)	(0.000)	(0.000)	(0.000)
R&D $only_{t-1}$*C8	0.787***	-0.386***	-0.514***	0.623***
	(0.000)	(0.000)	(0.000)	(0.000)
Size	0.226***	0.013	-0.016	-0.173***
	(0.000)	(0.720)	(0.692)	(0.000)
Foreign	-0.079	0.013	-0.025	0.133
	(0.314)	(0.878)	(0.813)	(0.252)
Internal	-0.077**	0.127***	-0.009	-0.051
	(0.017)	(0.000)	(0.812)	(0.180)
External	-0.037	-0.017	-0.062*	0.152***
	(0.242)	(0.618)	(0.096)	(0.000)
Industry conditions $_{t-1}$	-0.034	-0.096*	0.224***	-0.156***
	(0.472)	(0.066)	(0.000)	(0.007)
Initial conditions				
Export $Status_1$	0.888***	0.806***	-0.688***	-0.875***
	(0.000)	(0.000)	(0.000)	(0.000)
R&D $Status_1$	0.723***	-0.413***	0.447***	-0.460***
	(0.000)	(0.000)	(0.000)	(0.000)
Mean Size	-0.000	-0.125***	0.009	-0.044
	(0.998)	(0.001)	(0.825)	(0.247)
Mean Foreign	0.526***	-0.152	-0.228	-0.762***
	(0.002)	(0.463)	(0.223)	(0.002)
Mean Internal	-0.065	-0.030	-0.031	0.181**
	(0.298)	(0.677)	(0.658)	(0.013)
Mean External	0.195***	-0.043	0.172**	-0.369***
	(0.002)	(0.567)	(0.014)	(0.000)
Mean Industry conditions	-0.113	0.016	-0.192**	0.386***
	(0.113)	(0.836)	(0.022)	(0.000)
Constant	-1.692	-0.569	-1.973	-1.177
	(0.149)	(0.649)	(0.149)	(0.383)

Mean values explanatory variables (Wooldridge 2005) [a]	Chi2 (5) = 23.26 Prob > chi2 = 0.000	Chi2 (5) = 12.41 Prob > chi2 = 0.029	Chi2 (5) = 14.49 Prob > chi2 = 0.012	Chi2 (5) = 55.51 Prob > chi2 = 0.000
Industry dummies[b]	Chi2 (20) =267.39 Prob > chi2 = 0.000	Chi2 (20) =143.73 Prob > chi2 = 0.000	Chi2 (20) =26.82 Prob > chi2 = 0.000	Chi2 (20) =148.85 Prob > chi2 = 0.000
Nº observations	40,326	40,326	40,326	40,326

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the1%, 5% and 10% level of significance, respectively
[a] F test of joint significance of the mean values of the time varying explanatory variables
[b] F test of joint significance of the industry dummies
[c] F test of joint significance of the year dummies

Results presented in Table 25 are aligned with those obtained through the bivariate probit specifications as well. First, the crisis has increased the probability that firms engage in export strategies. The probability of performing 'Export only' have increased from 2008 onwards (see C8 in column 2 in Table 25). The opposite applies to 'R&D only' and 'None' (see C8 in column 3 and 4 in Table 25). Second, the crisis has increased the probability that R&D firms embark on export strategies but not the probability that exporting firms embark on R&D strategies (sequential adoption from export to both). The interaction term between the crisis dummy variable and the previous firm status it is negative and insignificant for the 'Export only' firms and positive and significant for the 'R&D only' firms (see Export only_{t-1}*C8 and R&D only_{t-1}*C8 in column 1 in Table 25). Across model specifications evidence of size effects is also found for the 'Both' strategy. That is, the larger the firm the higher the probability of being a firm performing both export and R&D.

APPENDIX II: ROBUSTNESS CHECK FOR THE SURVIVAL MODELS

As robustness test for the survival models I partition the sample in subsamples, run individual probits and calculate predicted probabilities. Now there are 4 subsamples, one for firms that are neither exporting nor performing R&D, one for firms that are only exporting, one for firms that are only performing R&D and one for firms performing both activities.[75] Using the first subsample I run 3 individual probits where the dependent variable is either 'Only export', 'Only R&D' or 'Both', and then calculate the predicted probabilities. That is, I am interested on the probability of 'only exporting', 'only performing R&D' and performing 'both' activities in t for a sample of firms which were neither exporting nor performing R&D in t-1. Using the second subsample (firms that were only exporting in t-1) I run a probit where the dependent variable is 'Both', and calculate the predicted probabilities of performing both activities in t for a sample of firms that were only exporting in t-1. I proceed in the same way for the subsample of firms only performing R&D in t-1. Table 26 shows the predicted probabilities from these regressions.

Table 26. Probability of exporting/performing R&D/both in t by subsamples (percentage points)

Subsamples	***Probability export***	***Probability R&D***	***Probability both***
None sample (Nº of observations 7,068)	11.92	3.47	0.11
Export only sample (Nº of observations 8,538)	-	-	9.18
R&D only sample (Nº of observations 5,660)	-	-	25.09

Aligned with previous results the likelihood of performing both activities for firms that were neither exporting nor performing R&D in t-1 (*Probability* $Both_{None}$*=0.11%*) is much lower than the likelihood of performing both activities for firms that were either only exporting (*Probability* $Both_{OnlyExport}$*=9.18%*) or only performing R&D in t-1 (*Probability*

[75] I will not use the last subsample since I am not interested in the persistency of both activities or the dismissal of any strategy.

Both$_{OnlyR\&D}$=25.09%). Second, the adoption order matters, being much more likely adopting export for firms already performing R&D (*Probability Both$_{OnlyR\&D}$=25.09%*) than the other way around (*Probability Both$_{OnlyExport}$=9.18%*). Third, it is more likely adding one activity when the other one is already in place than start this strategy in isolation (*Probability Both$_{OnlyExport}$=9.18%* > *Probability R&D$_{None}$=3.47%* and *Probability Both$_{OnlyR\&D}$=25.09%* > *Probability Export$_{None}$=11.92%*). Finally, it is more likely start exporting for firms without any pre-entry knowledge (*Probability Export$_{None}$=11.92%*) than start performing R&D (*Probability R&D$_{None}$=3.47%*).

APPENDIX III: ROBUSTNESS CHECK BY SIZE

Because of the possible differences for SME and large firms mentioned in the *'Variables'* section of Chapter 1 and to further explore the impact of firm size I also experimented testing the model over the sample of SMEs and large firms separately. Results presented in Table 27 show that the learning effects of each strategy and the synergies between export and R&D are substantially the same independently of the firms' size, both with and without the Wooldridge correction. The only significant difference between the two groups is that liquidity constraints are significant for SME firms but not for large firms. More specifically, either internal or external liquidity constraints negatively affect to the likelihood of performing R&D, while external liquidity constraints negatively affect to the probability of exporting. These results are in line with the existing literature, since due to information asymmetries (Brealey et al., 1977), low probability of success of R&D projects (Carpenter and Petersen, 2002), the large number of intangible assets that cannot be used as collateral to the lender for R&D investments (Lev , 2000 ; Berger and Udell, 1990) and the long term nature of R&D projects, which make them more risky (Cornell and Shapiro, 1988), firms have more difficulties on obtaining external funds and, therefore, also access to internal funds should be an important factor to invest on R&D.

Table 27. Bivariate model estimations for SMEs and large firms

	SME Firms				**Large Firms**			
	Model 1		Model 2 Wooldridge correction		Model 1		Model 2 Wooldridge correction	
VARIABLES	Export	R&D	Export	R&D	Export	R&D	Export	R&D
Export$_{t-1}$	2.032***	0.260***	1.740***	0.154***	2.085***	0.403***	1.706***	0.259***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R&D $_{t-1}$	0.261***	2.194***	0.175***	2.145***	0.305***	2.489***	0.202***	2.348***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
Size $_{t-1}$	0.185***	0.173***	0.145***	0.038	-0.036	0.112***	0.083	0.035
	(0.000)	(0.000)	(0.000)	(0.271)	(0.191)	(0.001)	(0.255)	(0.691)
Foreign $_{t-1}$	0.187**	0.085	0.009	-0.010	-0.015	0.018	-0.102	-0.196
	(0.020)	(0.202)	(0.927)	(0.906)	(0.894)	(0.863)	(0.464)	(0.105)
Internal $_{t-1}$	-0.006	-0.088***	0.035	-0.070**	-0.001	-0.036	-0.007	-0.100
	(0.789)	(0.000)	(0.249)	(0.029)	(0.984)	(0.556)	(0.927)	(0.262)
External $_{t-1}$	-0.001	0.037	-0.068**	-0.077**	0.021	0.084	-0.003	-0.097
	(0.962)	(0.106)	(0.028)	(0.015)	(0.698)	(0.166)	(0.967)	(0.240)
Industry conditions $_{t-1}$	-0.053	-0.052	0.023	-0.006	-0.065	-0.065	0.002	-0.001
	(0.231)	(0.224)	(0.652)	(0.904)	(0.571)	(0.590)	(0.987)	(0.997)
Initial conditions								
Export Status$_1$			0.804***	0.120***			0.887***	0.167**
			(0.000)	(0.000)			(0.000)	(0.020)
R&D Status$_1$			0.129***	0.492***			0.057	0.562***
			(0.000)	(0.000)			(0.356)	(0.000)
Mean Size			-0.001	0.138***			-0.137*	0.119
			(0.968)	(0.000)			(0.063)	(0.188)
Mean Foreign			0.508***	0.238			0.199	0.536**
			(0.001)	(0.188)			(0.420)	(0.018)
Mean Internal			-0.095*	-0.085			0.025	0.164
			(0.078)	(0.116)			(0.845)	(0.265)
Mean External			0.165***	0.235***			-0.065	0.213
			(0.003)	(0.000)			(0.644)	(0.160)
Mean Industry conditions			-0.172***	-0.172**			-0.107	-0.404**
			(0.004)	(0.011)			(0.384)	(0.021)
Constant	-0.979	-1.169	0.514	0.469	0.045	-0.912	0.608	4.222
	(0.189)	(0.101)	(0.649)	(0.674)	(0.981)	(0.645)	(0.802)	(0.192)
Mean values explanatory variables (Wooldridge 2005) [a]			Chi2 (10) = 69.98 Prob > chi2 = 0.000				Chi2 (10) = 25.72 Prob > chi2 = 0.004	
Industry dummies[b]	Chi2 (40) =631.15 Prob > chi2 = 0.000		Chi2 (40) =391.36 Prob > chi2 = 0.000		Chi2 (42) =648.62 Prob > chi2 = 0.000		Chi2 (42) =527.80 Prob > chi2 = 0.000	
Year dummies[c]	Chi2 (16) = 1585.1 Prob > chi2 = 0.000		Chi2 (14) = 1263.98 Prob > chi2 = 0.000		Chi2 (16) = 123.32 Prob > chi2 = 0.000		Chi2 (14) = 93.73 Prob > chi2 = 0.000	
Residual correlation	ρ =0.14 (s.e. = 0.014)		ρ =0.12 (s.e. = 0.016)		ρ =0.14 (s.e. = 0.036)		ρ =0.11 (s.e. = 0.04)	
LR test $\rho = 0$	$\chi2(1)$ = 104.44		$\chi2(1)$ = 57.33		$\chi2(1)$ = 15.323		$\chi2(1)$ = 8.130	
Log likelihood	-27391.48		-22369.44		-4839.91		-3920.30	
Nº observations	37,702		32,845		8,667		7,482	

Notes: Robust standard errors in parentheses

***, **, * indicate mean significant at the1%, 5% and 10% level of significance, respectively
[a] F test of joint significance of the mean values of the time varying explanatory variables
[b] F test of joint significance of the industry dummies
[c] F test of joint significance of the year dummies

APPENDIX IV: RESULTS WITH A BALANCED PANEL

Because of the concerned that using a balanced panel would have biased the results towards the strategies adopted of the most successful firms, ie the survivors, in Chapter 1 the analysis is done using an unbalanced panel. Nevertheless, as a robustness check the bivariate model is estimated using the balanced panel and the results are unchanged with the exception of the significance of external funds in the Export equation with the Wooldridge correction. See Table 28.

Table 28. Bivariate model estimations for the export and R&D decisions (balanced sample)

	Model 1		Model 2 Wooldridge correction	
VARIABLES	(1) Export	(2) R&D	(3) Export	(4) R&D
$Export_{t-1}$	2.062***	0.277***	1.750***	0.158***
	(0.000)	(0.000)	(0.000)	(0.000)
$R\&D_{t-1}$	0.268***	2.268***	0.182***	2.201***
	(0.000)	(0.000)	(0.000)	(0.000)
$Size_{t-1}$	0.129***	0.162***	0.097***	0.025
	(0.000)	(0.000)	(0.002)	(0.474)
$Foreign_{t-1}$	0.100	0.067	-0.020	-0.008
	(0.152)	(0.265)	(0.810)	(0.918)
$Internal_{t-1}$	-0.002	-0.066***	0.016	-0.066**
	(0.936)	(0.005)	(0.612)	(0.045)
$External_{t-1}$	0.015	0.054**	-0.034	-0.071**
	(0.507)	(0.023)	(0.270)	(0.027)
Industry conditions $_{t-1}$	-0.045	-0.034	-0.019	-0.014
	(0.320)	(0.402)	(0.702)	(0.762)
Initial conditions				
Export $Status_1$			0.825***	0.134***
			(0.000)	(0.000)
R&D $Status_1$			0.118***	0.513***
			(0.000)	(0.000)
Mean Size			-0.005	0.156***
			(0.866)	(0.000)
Mean Foreign			0.321**	0.194
			(0.022)	(0.211)
Mean Internal			-0.071	-0.049
			(0.203)	(0.385)

Mean External			0.125**	0.246***
			(0.033)	(0.000)
Mean Industry conditions			-0.053	-0.092
			(0.297)	(0.120)
Constant	-0.867	-1.543**	-0.513	-0.815
	(0.255)	(0.023)	(0.617)	(0.410)
Mean values explanatory variables (Wooldridge 2005) [a]			Chi2 (10) = 55.39	
			Prob > chi2 = 0.000	
Industry dummies[b]	Chi2 (40) =577.70		Chi2 (40) =360.31	
	Prob > chi2 = 0.000		Prob > chi2 = 0.000	
Year dummies[c]	Chi2 (16) = 1363.80		Chi2 (14) = 1084.44	
	Prob > chi2 = 0.000		Prob > chi2 = 0.000	
Residual correlation	ρ =0.12		ρ =0.09	
	(s.e. = 0.014)		(s.e. = 0.016)	
LR test $\rho = 0$	$\chi2(1)$ = 75.06		$\chi2(1)$ = 35.01	
Log likelihood	-26548.96		-22093.11	
Nº observations	39,121		34,627	

Notes: Robust standard errors in parentheses

***, **, * indicate mean significant at the1%, 5% and 10% level of significance, respectively

[a] F test of joint significance of the mean values of the time varying explanatory variables

[b] F test of joint significance of the industry dummies

[c] F test of joint significance of the year dummies

APPENDIX V: ROBUSTNESS CHECK FOR THE LINEAR REGRESSIONS

As a robustness check for the growth regressions of Chapter 1, the sample is split before (column 1) and during the crisis (column 2). As can be seen in Table 29, results confirm the findings presented in Table 8. That is, returns from '*Both*' and '*Export only*' strategies are higher from 2008 onwards than before 2008 while the effects of '*R&D only*' are lower from 2008 onwards than before 2008. Again, it seems the crisis encouraged internationalisation of firms, by means of increasing sales growth for firms either only exporting or exporting plus performing R&D, while the expected payoffs for firms only performing R&D have been negatively affected.

Table 29. Estimations for firms' growth before and after the crisis

VARIABLES	(1) Growth	(2) Growth
Both	0.064***	0.083***
	(0.000)	(0.000)
Export only	0.028*	0.053***
	(0.097)	(0.000)
R&D only	0.089***	0.071***
	(0.000)	(0.000)
Size	0.003	0.020***
	(0.614)	(0.000)
Internal	-0.024**	-0.032***
	(0.030)	(0.000)
External	0.000	0.001
	(0.993)	(0.846)
Industry conditions	0.324***	0.078***
	(0.002)	(0.000)
Foreign		-0.004
		(0.753)
Constant		-1.488***
		(0.000)
Observations	10,787	35,472
Number of firms	6,072	6,017

Notes: Robust standard errors in parentheses
***, **, * indicate mean significant at the1%, 5% and 10% level of significance, respectively