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Analysing the link between export intensity, innovation and firm size in a science-based industry

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Abstract

The aim of this paper is to contribute to a better understanding of the relationship between export intensity, innovation and size in a particular technological setting: a science-based industry. Using a sample of 121 firms in the French biotechnology industry, we have found that firm size is not a determinant for innovation or for export intensity. However, the results show a positive and significant link between innovation and export intensity. Our findings open a new agenda for policy-makers when interpreting how they should promote innovation and exports in science-based firms.

Keywords: Export intensity; Innovation; Size; Science-based industry; SEM

1. Introduction

In the global environment, firms can no longer persist in believing that international competition will not affect them because they are small or focused solely on their local market. The increasing engagement of firms in export activities has therefore been one of the more visible answers to the constantly changing dynamics of this new environment. Nowadays, exporting plays a vital role in company strategies and its importance is expected to grow further as markets become increasingly globalised.

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As a consequence, the investigation of the elements that are critical to firms' export success has been the focus of scholarly research for the last two decades (Katsikeas, Deng, & Wortzel, 1997). A substantial amount of empirical research has been developed, concentrating on the effect that various external and internal forces have on determining firms' export performance (e.g. Cavusgil & Zhou, 1994; Moen, 2002). Although significant progress has been made in understanding the effect of a firm's external factors on export performance (Johanson & Mattson, 1988; Madsen & Servais, 1997; Zhao & Shaoming, 2002), knowledge of the internal determinants is contradictory and warrants further research. In particular, the relationships between export performance and certain organisational factors, such as innovation and size, need further clarification in the context of specific sectors with different levels of technology (López-Rodríguez & García-Rodríguez, 2005).

Firms can overcome some international risks if they have a particular competitive advantage that differentiates them from indigenous competitors. In this context, innovation is becoming more and more relevant as a source of competitive advantages. In fact, competitive advantage is increasingly derived from knowledge, technological skills and experience in the creation of new products (Teece, Pisano, & Shuen, 1997; Tidd, Bessant, & Pavitt, 1997).

The demand for policies to encourage exports and innovation raises the need for further empirical analyses that clarify the relationships between exports, innovation and size, as previous research shows some contradictory findings. Additional understanding needs to be developed, so that scholars provide policy-makers with some more reliable clues.

The aim of this paper is to contribute to a better understanding of the relationship between export intensity, innovation and size, focusing on a particular technological setting: a science-based industry. We will try to enrich the knowledge of the export behaviour of firms in a young, science-based industry like the biotechnology industry. From a theoretical point of view, recent research has suggested that traditional internationalisation theories may not account for the special circumstances faced by firms in a science-based industry (Preece, Miles, & Baetz, 1998). Rather that evolving through a series of international stages, as is thought to be the case for many firms (Johanson & Vahlne, 1977; Leonidou & Katsikeas, 1996), science-based firms are likely to encounter international pressures much earlier in their existence. In this sense, the biotech industry is especially interesting due to its specific global nature: the marketing of biotech products and services, the competition in the sector, and the sources fuelling the biotech industry are international (i.e. finance, knowledge, human resources, legal advice, etc.). Furthermore, the international community closely scrutinises scientific or industrial developments in biotechnology (Gurau & Ranchhod, 2007).

The paper is structured as follows. The section that follows sets out a conceptual framework and a theoretical review of the connection between export intensity, innovation and firm size. Following this theoretical review, we develop our research hypotheses in the context of the biotechnology industry. In Section 3, the design of the survey, the measures, and the analyses are outlined. Finally, results and conclusions are presented in Sections 4 and 5.

2. Conceptual framework

2.1. Export intensity and innovation

Innovation is commonly defined as the taking up of an idea in relation to a product which is new to the company. Innovation consists of successful exploitation of new ideas: it

therefore requires two conditions to be met: novelty and use (Amabile, Conti, Coon, Lazenby, & Herron, 1996; Myers & Marquis, 1969). Accordingly, an innovative firm is one that implements technologically new or significantly improved products during the period under review (OECD-EUROSTAT, 1997). The innovation process requires inputs such as R&D, specialised human resources, or technical equipments, and generates a number of outputs, such as new or significantly improved products.

The innovation phenomenon could differ from one industry to another because of technology issues, such as product technology or the production process. Pavitt (1984) suggested that industrial sectors differ greatly in the sources of technology they adopt, the users of the technology they develop, and the methods used by successful innovators to appropriate the benefits of their activities. As a result, Pavitt produced a classification with four technological categories, including firms with common traits and conditions: supplier-dominated firms, scale-intensive firms, specialised suppliers, and science-based firms. Further research confirmed that, as well as the innovative opportunities open to a firm, the determinants of innovation results are strongly conditioned by these technological trajectories (Pavitt, 1990; Pavitt, Robson, & Townsend, 1989; Souitaris, 2002).

Science-based firms usually belong to the chemical, pharmaceutical, biotechnological and electrical and electronic engineering sectors. These are knowledge-intensive activities and their main source of technology is internal R&D. Recently, Souitaris (2002) applied Pavitt's technological trajectories in a sample of Greek manufacturing firms. He found that science-based firms together with specialised supplier firms had significantly higher rates of innovation than supplier-dominated firms and scale-intensive firms. Science-based firms produced the highest number of innovative products (incremental and radical) and had by far the highest mean number of patents.

Specific features of biotech firms point at the importance of R&D, global competition, and a lack of critical mass that cancels out the benefits of economies of scale (Khilji, Mroczkowski, & Bernstein, 2006). The product development cycle is especially long. Biotech inventions come up from the laboratory with a clear global demand waiting for them in the market. Moreover, biotech products do not need to be tailored to regional markets. They are wanted for their technical properties; marketing issues are not relevant at the product level. Once specific pre-market trials are successful, international distribution agreements are the norm in the industry because biotech firms usually lack the necessary competences to make their discoveries available to end consumers all over the world (Baker, 2003; Gans & Stern, 2004; Khilji et al., 2006).

The link between innovation and exports has received a great deal of interest by scholars. However, despite the number of determinants and contexts in which export behaviour has been investigated, technology issues have received little consideration (Nassimbeni, 2001). Industry issues also need further development (Leonidou, 1998a). For this reason, we are interested in examining the link between innovation and export intensity in science-based firms, more specifically in the context of biotech firms.

Generally, theory claims a positive relationship between innovation and export intensity from several perspectives. Firstly, technology-based models of international trade such as Posner's technology-gap theory of trade (Posner, 1961) and Vernon's product life-cycle approach to trade (Vernon, 1966), when applied at the firm level, suggest that innovation confers market power and, as a consequence, facilitates a better export performance (Roper & Love, 2002).

Secondly, the international business literature proposes that export behaviour depends on structural factors of the firm, management factors, and incentives and obstacles in the process of internationalisation (Bonaccorsi, 1992). The technology profile is a structural factor that would affect positively export performance in the case of science-based firms (Nassimbeni, 2001; Piercy, Kaleke, & Katsikeas, 1998; Yli-Renko, Autio, & Tontti, 2002). Moreover, biotech management is rather entrepreneur (Khilji et al., 2006), and the process of internationalisation has no significant obstacles in biotechnology (Gurau & Ranchhod, 2007). The determinants of exporting have received a great deal of attention in international business research (Leonidou, 1998a, 1998b). The following factors seem to be particularly relevant in biotechnology: (1) the industry type since it is a science-based globalised industry both concerning R&D and market issues, (2) product characteristics since new biotech product come up from the pipeline being patented, unique and usually technically superior, and (3) the possession of comparative advantages against competitors on a world basis because of the unique qualities of new products (DeCarolis & Deeds, 1999; Gurau & Ranchhod, 2007; Khilji et al., 2006).

Thirdly, the resource-based view of the firm is an influential theoretical framework for understanding the creation and sustainability of competitive advantage and therefore for explaining why firms perform differently (Barney, 1991; Hitt, Bierman, Shimizu, & Kochhar, 2001). This perspective assumes that firms can regarded as a set of resources, that these resources are heterogeneously distributed across firms, and that resource differences might persist over time (Teece et al., 1997). Based on these assumptions, it has been theorized that valuable and rare resources constitute the foundation of competitive advantage, in both domestic (Yeoh & Roth, 1999) and international markets (Fahy, 2002; López-Rodríguez & García-Rodríguez, 2005; Pla-Barber, 2001). The technology profile of a firm and its innovation capabilities might be considered as relevant resources to achieve competitive advantage (Yeoh & Roth, 1999). López-Rodríguez and García-Rodríguez (2005) have recently analysed from this perspective the influence of a firm's technological capacity over its export intensity in the context of Spanish manufacturing firms. Their findings showed that both innovation inputs (R&D spending) and outputs (product innovations and patents) positively and significantly affected export intensity.

Finally, the technology and innovation management literature generally predicts that innovative firms will have a tendency to enter foreign markets in order to increase sales volume and spread the fixed costs of innovation over a larger number of units (Rogers, 2004; Tidd et al., 1997). Besides several exceptions (Becchetti & Rossi, 2000; Lefebvre, Lefebvre, & Bourgault, 1998), previous research is rather consistent in supporting that innovation encourages exports. The technology and innovation management literature provides evidence of a positive relationship between innovation and export intensity regardless of whether the focus has been on R&D (Hirsch & Bijaoui, 1985; Kumar & Siddharthan, 1994), on non-R&D innovation inputs (Sterlacchini, 1999), or on innovation outputs (Basile, 2001; Nassimbeni, 2001; Roper & Love, 2002; Wakelin, 1998).

In this study, we want to corroborate the suggested positive relationship between innovation and export intensity in a science-based industry like biotechnology. We believe that, in the case of biotech firms, this positive relationship might be even stronger due to its high technology profile and its specific nature. A single market may not be broad enough to support the R&D, finance, marketing and distribution needs of a typically niche-focused biotech firm. Once these firms have developed a final product, they attempt to sell it in order to obtain a quick return on investment. In some cases, the number of customers or

purchasing power within the national market might be too small to ensure a proper return on investment. Only by integrating potential customers from many different countries into a global market segment with homogeneous demand is a company able to compete and to efficiently develop its activities (Gurau & Ranchhod, 2007).

Thus, we hypothesise:

H1. *There is a significant positive relationship between innovation and export intensity in biotechnology firms.*

2.2. Export intensity and firm size

The link between firm size and export intensity has been one of the most widely analysed relationships in international business literature, although it still remains controversial. There are theoretical explanations suggesting that there is a positive relationship between firm size and export intensity. Large companies are considered to possess more financial and human resources and higher economy of scale levels (Wagner, 1995, 2001). These characteristics facilitate their entry into international markets (Leonidou, 1998a). Moreover, size is narrowly related to a number of export barriers (Leonidou, 1995) such as the level of risks in foreign markets (Majocchi, Bacchiocchi, & Mayrhofer, 2005; Piercy et al., 1998; Preece et al., 1998). In many studies, firm size has been considered as a contributing variable to export performance (Mittelstaedt, Harben, & Ward, 2003).

Two main theoretical approaches have been used to support a positive link between firm size and export intensity: the transaction costs approach (Verwaal & Donkers, 2002) and the resource-based view of the firm (Dhanaraj & Beamish, 2003). Verwaal and Donkers (2002) transaction costs analysis of the firm size and export relationship is founded on economies of scale and risk perception assumptions that would not really match the biotechnology specific context. Competition in this industry is mainly based on innovation outputs: new products having successfully passed through the different product development cycle stages are patented, unique, and superior products (Elmes & Kasouf, 1995; Khilji et al., 2006). Because of these specific features, it comes up that the most important strategic resources in biotechnology are technology and innovation. In fact, technological capabilities have been usually found to be positively linked with export intensity (Dhanaraj & Beamish, 2003; Moen, 1999). Other size-related organisational resources such as production and marketing capabilities have been proved to be important in other multi-industrial samples of firms (Dhanaraj & Beamish, 2003; Majocchi et al., 2005). However, in the biotechnology industry, these size-related organisational resources are relevant but not determinant (DeCarolis & Deeds, 1999; Khilji et al., 2006). Therefore, the resource-based view could support that, in a specific context, non size-related resources could be the determinant ones for achieving international competitiveness (Wolff & Pett, 2000).

Small size has been regarded as an export barrier (Majocchi et al., 2005; Verwaal & Donkers, 2002). Leonidou and Katsikeas (1996) analysed export development process models and found three main phases of export development: the pre-engagement phase (uninvolved in exporting but considering this option), the initial phase (sporadic exporters), and the advanced phase (consistent exporters). Recently, Mittelstaedt et al.

(2003) analysed 2822 manufacturing firms in 49 different industries to investigate if a minimum size could be required to be an advanced exporter. Their study determined that 20 employees was the minimum necessary size condition for exporting. This is rather a small minimum, so this result suggests that size might not be so important for exporting in an heterogeneous manufacturing context. The economies of scale implications, the fixed cost of industrial certifications such as ISO 9000, and the increase of non-tariff fixed costs were outlined as the main reasons explaining their finding. However, how do these three main reasons affect science-based firms? Leonidou (2004) recently examined export barriers for small businesses and concluded that the impact of barriers was situation-specific, largely depending on the idiosyncratic managerial, organisational, and environmental background of the firm. Accordingly, we argue that these are not relevant factors in the biotechnology industry.

Moreover, previous research offers further theoretical reasons to contradict the positive effect of size on export intensity (Bonaccorsi, 1992; Calof, 1993; Czinkota & Johnson, 1983; Moen, 1999; Moini, 1995). On the basis of an Italian nationwide sample of manufacturing firms, Bonaccorsi (1992) did not find support for such a proposition and provided several reasons for rejecting it. He argued that entry barriers to export activity are not as high as assumed and that information on foreign markets is quite accessible. He also pointed out two more powerful reasons: (1) small firms are very often integrated into a system of firms that use common external resources and (2) small firms show outstanding imitative behaviour when another small firm has been successful in achieving an initiative like exporting.

In this vein, Calof (1993) found that firm size was not a barrier to exporting: small firms could do well in international markets as long as they implemented internationalisation strategies consistent with their resources. The research carried out by Moen (1999) revealed that small exporting firms were as successful in international markets as larger exporting firms. Moen (1999) also noted in its Norwegian sample that most small exporting firms were very competitive because they were highly specialised firms using cutting-edge technology.

Following the resource-based approach, Wolff and Pett (2000) found that when exporting small firms seemed to play to their particular strengths and capabilities. Their findings indicated that it is not the amount of resources but the types of resources available to the firm that determined the firm's export performance. Their conclusion is in line with Calof's findings (Calof, 1993).

Subscribing to this point of view, we argue that the proposition of a positive effect between size and export intensity may not be confirmed in a science-based industry such as biotechnology for two main reasons. Firstly, in biotechnology, competitiveness is mainly based on scientific findings; that is, on the effectiveness of their R&D processes and not on the efficiency of their operations. Cost issues such as economies of scale or the costs required to enter foreign markets are not as important as they might be in other capital-oriented industries. For these firms, internationalisation does not involve a large investment of resources in the host country, as it does not require sizeable investment in plants, machinery, buildings and other physical assets; a firm's international presence may be represented by a single agent or office (Erramilli & D'Souza, 1995). Moreover, the provision of knowledge-intensive products mainly requires investments in human resources, with careful recruitment, training and control in a home-base setting (Erramilli & Rao, 1993).

Secondly, a science-based industry such as biotechnology is highly globalised. Research teams have a scientific reputation and frequent international conferences and scientific meetings (Elmes & Kasouf, 1995). The evolution of product development stages are known by the market. So, once a new product is developed there is a global demand awaiting for it.

Accordingly, we hypothesise:

H2. *Size is not a determinant for export intensity in biotechnology firms.*

2.3. Firm size and innovation

Innovation literature offers an interesting debate on the relationship between firm size and innovation. There are theoretical arguments and empirical findings supporting a positive relationship: firm size affects the endowment of important inputs for the innovation process, such as money, people and facilities (Capon, Farley, Lehman, & Hulbert, 1992; Rogers, 2004). More specifically, firm size has been shown to influence both R&D expenditure (Baysinger & Hoskinsson, 1989) and product introduction (Chaney & Devinney, 1992). In fact, Wakasugi and Koyata (1997) carried out an empirical study on these two issues on Japanese companies in the electrical machinery industry and found that (1) large firms were more aggressive in their innovation efforts than small firms, and (2) the number of new products increases as sales volume increases.

However, there are a number of factors that suggest small firms may have several advantages over large firms such as flexibility (Rogers, 2004), and fluid communication (Sosa, Eppinger, Pich, McKendrick, & Stout, 2002). Firm size may also lead to other disadvantages, such as inefficiency and slack in research units (Wakasugi & Koyata, 1997). The literature offers empirical findings in this direction. Arvanitis (1997) found no evidence for the existence of economies of scale in the innovation activity in a database of Swiss manufacturing firms. Rogers' (2004) research revealed a higher innovation ratio per employee in small Australian firms.

In general, besides the effect of the methods used in previous empirical studies (Audretsch & Acs, 1991; Camisón-Zornoza, Lapiedra-Alcamí, Segarra-Ciprés, & Boronat-Navarro, 2004), it appears that the relationship between firm size and innovation depends on the specific technological and market conditions (Damanpour, 1992; Rogers, 2004). While in mature industries the amount of resources, such as facilities or financial funds, may be a determinant for successfully carrying out innovation projects, in science-based industries this logic may not apply. Audretsch and Acs (1991) examined the relationship between firm size and innovation in a sample of 1695 US firms representing a full spectrum of firm sizes. They found that low-technology firms showed increasing returns related to firm size in generating innovative activity. However, high-technology firms showed no evidence of such a relationship. We believe further evidence is needed on the relationship between size and innovation in different technological settings.

The biotech industry is characterised by a high degree of innovation, and also by a great use of collaborative relationships in order to access, survey, and exploit emerging technological knowledge. The number and scope of inter-organisational collaborations have grown notably in the field of biotech firms. Inside this densely connected field, organisations must adjust to a novel perspective in which it is no longer necessary to have

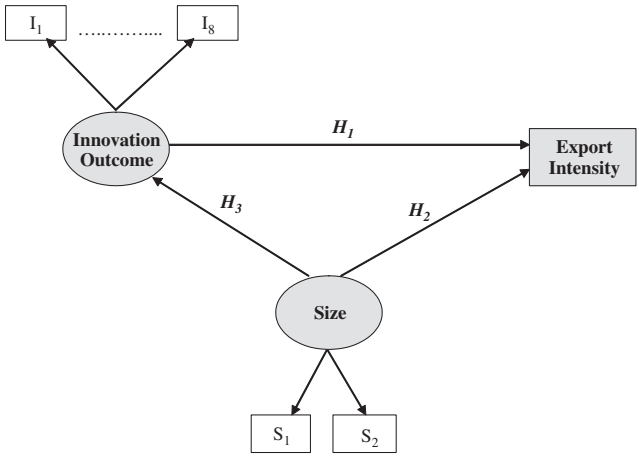

Fig. 1. Research model.

exclusive, proprietary ownership of an asset in order to extract value from it (Gurau & Ranchhod, 2007; Powell, 1998). We can therefore find small or even "virtual" firms with the capabilities to develop highly innovative products.

Therefore, we hypothesise:

H3. *Size is not a determinant for innovation in biotechnology firms.*

Fig. 1 depicts our research model. Innovation outcome is conceived as a latent construct (ellipse) with eight manifest variables (boxes) that constitute a subjective measurement scale. Size is also conceived as a latent construct with two objective indicators. Finally, export intensity and experience are objective indicators.

3. Research method

3.1. Sample and data collection

We tested the proposed hypotheses by focusing on French biotechnology producers because we find this industry representative of science-based industry. Biotechnology is characterised by a high degree of innovation (DeCarolis & Deeds, 1999). The analysis of a single industry is useful in assessing innovation, as new products will be more homogeneous in terms of their technology and their economic effects (Santarelli & Piergiovanni, 1996).

Biotechnology is a young, science-based industry. Biotech firms invest heavily in R&D and are organised along similar lines to university laboratories, in that they allow their scientists considerable autonomy to work on their own projects, to publish and to participate in the scientific community (Elmes & Kasouf, 1995).

French biotechnology carries substantial weight in the international arena (Kopp, 2003; Pouletty, 2002). France remains amongst the most advanced nations in the scientific research and industrial application of biotechnology. In 2003, this industry employed in France around 6000 people. Researchers represent approximately 50% of French biotech employees. In 2008, the French biotechnology market is forecast to have a value of $4.2

billion, an increase of 89.7% since 2003. In the 2003–2008 period the compound annual growth rate of the market is predicted to be 13.7% (Datamonitor, 2004).

Biotechnology firms in France are classified in the biotechnology directory of the French Research Ministry. This directory is a database with information about French biotechnology firms: postal addresses, telephone and fax numbers, e-mail addresses, business activities, and the directors' full names. This database included 298 organisations at the time the research was carried out. However, the sample for this study was defined narrowly to include a homogeneous set of firms. We were only interested in private production firms that satisfied the following requirements: (1) at least 3 years of experience, and (2) a concrete product portfolio offered in the market. The OECD recommends taking 3-year periods into account in innovation surveys, as innovation is a time-dependent process (OECD-EUROSTAT, 1997). Our final target population included 220 biotechnology manufacturing firms.

The questionnaire was sent to the R&D director of each organisation, and included his/her full name in the introductory letter. We chose to elicit responses from R&D directors because they are responsible for innovation inputs and outputs. In our view, the use of biotechnology R&D directors satisfies two accepted criteria for identification of appropriate key respondents: (1) possession of sufficient knowledge of the domain being studied, and (2) adequate level of involvement with regard to the issues under investigation (Campbell, 1955). Furthermore, there are precedents for the use of R&D directors in previous surveys on assessments of innovation (Gatignon, Tushman, Smith, & Anderson, 2002).

The survey was launched during the first week of July 2002. The questionnaire was largely sent by e-mail and by fax, together with an introductory letter describing the objective of our research project and emphasising the confidentiality of the responses. Both the questionnaire and the letter were sent in French. Following Malhotra (1993), we offered participating firms a feedback report on the survey results in order to encourage companies to answer. Questionnaires were sent out in four general rounds. The use of e-mail allowed us to solve any problem concerning the questionnaire quickly and to carry out a follow-up on the sample. We obtained a sample of 121 firms, representing 55% of the target population. While some scholars accept samples as of 100 cases (Hair, Anderson, Tatham, & Black, 1998; Shook, Ketchen, Hult, & Kacmar, 2004; Tabachnick & Fidell, 1996), other scholars recommend samples as of 150 (Anderson & Gerbing, 1988). Therefore, the sample size constitutes a limitation of this study.

3.2. Measurement of variables

Innovation outcome is assessed using the measurement scale provided by OECD's Oslo Manual for the assessment of the economic objectives of innovation (OECD-EUROSTAT, 1997). This scale was put forward by the OECD to give some coherent drivers for innovation studies, thereby achieving greater homogeneity and comparability between them. Nowadays, many innovation surveys use this scale, which has been widely validated. An example is the Survey on Technological Innovation carried out by the Spanish Institute of Statistics every 3 years (INE, 2004). Appendix A shows this innovation outcome scale.

Export intensity represents the share of exports in total sales for a particular firm. This variable is by far the most widely used indicator in empirical international business

research. Also, as it is an objective measurement, this indicator does not suffer from the problem of manager resistance concerning confidentiality (Majocchi et al., 2005).

Firm size is assessed by means of the logarithmic transformation of two indicators: the total number of employees and total sales. Although most empirical studies include just one single indicator (number of employees or sales) for size (Camisón-Zornoza et al., 2004), recent research tends to include both indicators to offer a more thorough picture of the size dimension (Dhanaraj & Beamish, 2003).

Firm experience was included as control variable in the overall model because it has been discussed to impact decisions regarding internationalisation (Johanson & Vahlne, 1977; Madsen & Servais, 1997). Thus, following Bouquet, Hébert, and Delios (2004) we measured firm experience through a logarithmic transformation of the firm's age.

Our measures combine primary (innovation outcome) and secondary data (export intensity, firm size, and firm experience) providing a balanced database that avoids problems such as common method variance (Schminke, 2004; Yang, Wang, & Su, 2006).

3.3. Analyses

The primary analyses of the data set are based on structural equation modelling (SEM). Structural equation models have been developed in a number of academic disciplines to substantiate theory. This approach involves developing measurement models to define latent variables and then establishing relationships or structural equations between the latent variables. EQS 6.1 software was used to estimate the models for our research hypotheses. EQS 6.1 operates upon the normalised variance–covariance matrix derived from the raw database (Bentler, 1995). confirmatory factor analysis (CFA) was used to check the goodness of the innovation outcome measurement scale (Mueller, 1996, p. 125).

Previous studies on the relationship between innovation, export intensity, and firm size have usually applied regression analysis for each pair of variables. Applying SEM has the advantage that the three links can be examined simultaneously in the same analysis. Furthermore, SEM has a number of additional advantages over regression analysis: mainly that it reports measurement errors and makes it possible to test the reliability and validity of the measurement instruments (Dhanaraj & Beamish, 2003; Hair et al., 1998).

4. Results

4.1. Psychometric properties of the measurement scales

The psychometric properties of the Innovation Outcome measurement scale was evaluated by following accepted practice in the literature (Anderson & Gerbing, 1988), including establishment of scale reliability, discriminant and convergent validity.

First, we ran a CFA to assess the measurement model. The loadings of the measurement items on the factors were all significant and reasonably high. The chi-square statistic for the measurement model was not significant and the goodness of fit indices met their recommended thresholds. This finding provided evidence supporting the *convergent validity* of the indicators.

We computed both the Cronbach's alpha coefficient and composite reliability to assess scale *reliability*. Table 1 shows the reliability evaluation. The composite reliability values

Table 1
Factor correlations, means, standard deviations, and reliability indices

	Mean	SD	Cronbach's alpha	Composite reliability	1	2	3
1. Innovation outcome	4.65	0.80	0.90	0.90	1		
2. Size	4.91	1.72	—	—	0.007	1	
3. Export intensity	18.18	22.84	—	—	0.552**	0.085	1

**Correlation is significant at the 0.01 level.

and the Cronbach's alpha coefficients are highly satisfactory, all above 0.7 (Hair et al., 1998; Nunnally, 1978).

The *discriminant validity* of the model indicators was ascertained by comparing measurement models where the correlation between the constructs was estimated with a model where the correlation was constrained at 1 (thereby assuming a single-factor structure). We found that the model where the correlation is not equal to 1 improves the fit, confirming that the constructs (innovation outcome, firm size and export intensity) are distinct from each other, although it is possible that they are significantly correlated (Bagozzi, Yi, & Phillips, 1991; Gatignon et al., 2002).

4.2. Testing the research hypotheses

Table 2 shows the results of the SEM analysis. We tested two competing nested models (Hair et al., 1998): the first model (basic model) examines the three relationships we have proposed in our hypotheses; the second model (enlarged model) examines the same relationships adding experience as a control variable.

Both models show a good overall fit (Table 2). However, the basic model fits better: its chi-square statistic is non-significant ($p = 0.29$) while the enlarged model chi-square statistic is significant ($p = 0.03$) at the 0.01 level. A non-significant chi-square statistic implies that the null hypothesis of perfect fit cannot be rejected. This is the most important fit indicator with moderate samples like ours (e.g., 100–200; Shook et al., 2004; Tabachnick & Fidell, 1996). Other relevant fit indices suggest a good overall fit in both models (Bollen, 1989), but they are again slightly better for the basic model. The recommended threshold for the Normed Fit Index (NFI), the Non-Normed Fit Index (NNFI) and Goodness of Fit Index (GFI) is 0.90. The Comparative Fit Index should be close to 1. The error statistic of root mean square error of approximation (RMSEA) meets the recommended lower level of 0.03 in the basic model; it gets a higher value in the enlarged model (Dhanaraj & Beamish, 2003). The root mean square residual (RMR) is good in both models. Finally, the normed Chi-square (the ratio of the chi square to the degree of freedom) is between 1 and 2 and confirms a parsimonious fit for both models (Hair et al., 1998).

Table 2 shows the R^2 for the main equation of both models (Export Intensity $= \beta_1$*Innovation Outcome $+ \beta_2$*Size). The R^2 provides an assessment of the statistical power of the model. This indicator is slightly better in the basic model (0.368 vs. 0.335). These are acceptable values. They additionally indicate that export intensity depends on more factors that have not been taken into account in this research.

Table 2
Structural equation model analysis

Parameter	Basic model	Enlarged model (with experience as a control variable)
	$R^2 = 0.368$	$R^2 = 0.335$
Hypothesized path		
H1: Innovation outcome → export intensity	0.607 (5.175)	0.574 (5.089)
H2: Size → innovation outcome	0.095 (1.123)	0.031 (0.314)
H3: Size → export intensity	−0.082 (−0.803)	0.044 (0.427)
Control		
Experience → export intensity	—	0.021 (0.199)
Measurement model		
Innovation outcome → I_1	0.554[a]	0.566[a]
Innovation outcome → I_2	0.717 (5.783)	0.723 (5.956)
Innovation outcome → I_3	0.773 (6.034)	0.787 (6.260)
Innovation outcome → I_4	0.771 (6.029)	0.771 (6.186)
Innovation outcome → I_5	0.680 (5.599)	0.699 (5.830)
Innovation outcome → I_6	0.762 (5.988)	0.776 (6.213)
Innovation outcome → I_7	0.684 (5.616)	0.684 (5.749)
Innovation outcome → I_8	0.774 (6.041)	0.783 (6.245)
Size → S_1	0.997[a]	0.954[a]
Size → S_2	0.862 (2.465)	0.995 (9.581)
Goodness-of-fitness statistics of the structural model		
χ^2	46.55 ($p = 0.29$)	71.18 ($p = 0.03$)
d.f.	42	51
Normed chi-square	1.108	1.396
Normed Fit Index (NFI)	0.996	0.995
Non-Normed Fit Index (NNFI)	0.999	0.998
Comparative Fit Index (CFI)	0.999	0.999
Goodness of Fit Index (GFI)	0.938	0.916
Root mean square error of approximation (RMSEA)	0.030	0.057
Root mean square residual (RMR)	0.65	0.64

Parameters estimates are standardised with *t*-values shown in parentheses.
[a]The parameter was equalled to 1 to fix the latent variable scale.

The basic model has been satisfactorily tested and shows compelling evidence of a positive and significant link between innovation and export intensity in biotechnology firms. This result provides support for Hypothesis 1. Our data analysis supports the theoretical reasons according to which innovation fosters export intensity. We argue that this is especially true for a science-based industry such as biotechnology because of its globalised nature.

The relationship between firm size and export intensity is low and not significant. This finding does not imply that size is not important for the internationalisation of biotech firms, but it reveals that it is not a preponderant factor. There is a similar chance of finding small and large biotech firms doing well in the international arena. This gives support to Hypothesis 2.

According to Camisón-Zornoza et al. (2004), a number of studies examining the relationship between innovation and firm size have shown contradictory results because some were measuring firm size focusing on the number of employees while some others were focusing on the quantity of sales. For this reason, we assessed the research model using two additional measurements of firm size: (1) the logarithmic transformation of the total number of employees only, and (2) the logarithmic transformation of total sales only. We found no inconsistencies in the structural models.

The relationship between firm size and innovation is also low and not significant. Again, this result confirms that, in biotechnology, innovation depends on size-related factors (e.g. resources such as people, funds, equipments, etc.), as well as on non-size-related factors (e.g. flexibility, communication). This finding does not imply that size-related factors are not important, but it reveals that they are not preponderant. This provides support for Hypothesis 3.

Therefore, the technological setting of a firm has been found to be more important than the size factor in the case of science-based firms. Firm size has typically been regarded as an indicator of managerial and financial resources available in the firm (Dhanaraj & Beamish, 2003). However, in the particular case of science-based firms, the most important resources are technological competences, which can be effectively developed even with a small size.

Finally, our control variable *firm experience* included in the enlarged model does not seem to affect the decisions regarding exporting. This result would appear to confirm recent claims (Gabrielsson & Kirpalani, 2004; Madsen & Servais, 1997; Moen, 2002) which are based on the growing globalisation of markets and which question the relevance of experience, especially in explaining the internationalisation process of firms from a science-based industry (Yli-Renko et al., 2002). Science-based firms seem to represent an exception to conventional export development processes (Leonidou & Katsikeas, 1996). Although biotech firms are generally young, the internationalisation issue is usually solved in a nimble way through international distribution agreements that make their discoveries available to end consumers in the global market (Baker, 2003; Gans & Stern, 2004; Khilji et al., 2006).

5. Conclusions

The link between innovation, export intensity and firm size has been extensively assessed in the literature from several points of view. However, there is still an open debate on the kind of link to be expected between these three variables. Prior research has generally focused on manufacturing industries without taking into account the implications of dealing with heterogeneous technology profiles. On the contrary, this research has developed hypotheses for firms in a specific technology setting.

Previous studies have usually analysed the relationship between only two of the examined variables: innovation, export intensity and firm size. However, we have proposed and tested a research framework that appraises simultaneously these three links.

Results reveal a positive link between innovation and export intensity. This is consistent with previous literature on international business and innovation management. Our view is that this positive link can be expected to be especially strong in the case of science-based firms.

Moreover, findings confirm the importance of technology issues when analysing export performance. Some of these issues are the technological profile of an industry, the

technological capabilities of a firm, or the advantages of superior new products (Leonidou, 1998a, 1998b; López-Rodríguez & García-Rodríguez, 2005).

Regarding the role of size in innovation and export behaviour, previous empirical studies show contradictory findings. We argue that this variability in the results of previous studies is mainly due to the features of the industry. We have found that the reasons supporting a positive relationship between firm size and export intensity were founded on production efficiency rationale. Science-based industries such as biotechnology are not driven by production efficiency but by effectiveness in research. Furthermore, science-based industries are very much globalised: market information is quite accessible and the hypothetical entry barriers to export activity do not seem to be relevant. In such a science-based setting, we have found that firm size is not a determinant for innovation or for export intensity.

This paper proposes a new approach to test the relationship between innovation, export intensity and firm size: the industrial setting—the characteristics derived from pertaining to a particular technological trajectory—should be taken into account. This new approach can be useful in reinterpreting the large number of empirical studies that have been carried out so far examining innovation, exports and firm size.

Our research makes a contribution to the resource-based view of the firm. This theoretical approach predicts different behaviours in a contingent way. A main issue in the resource-based view is the identification of critical resources. Depending on which are these critical resources, the resource-based view might suggest different hypotheses. In industries in which size-related resources such as production or marketing competences are critical (Dhanaraj & Beamish, 2003; Majocchi et al., 2005), the resource-based view clearly claims a positive link between size and exports. However, in industries in which the most relevant resources is the competence to develop cutting-edge technology (Moen, 1999) such as biotechnology, the resource-based view proposes that export performance is better explained through innovation and technology issues than through size issues.

Following the resource-based view, this research suggests that biotechnology managers must carry out a number of tasks dealing mainly with developing and protecting their key resources: technology competences. While biotechnology is an industry that succeeds in effectively protecting inventions through patents (Khilji et al., 2006), protecting technology competences is a more complex issue that requires effective human resource policies to avoid key R&D employees being hired by competitors (Liebeskind, 1996).

Our findings open a new agenda for policy-makers when interpreting how they should promote innovation and exports in science-based industries. One important issue stands out: size is not the primary driver of innovation or international activity in science-based firms. Therefore, in such an industrial setting, effective policies should be focused on technology and innovation rather than on size, if they are to affect export performance. Our findings are in line with Moen's (1999) study: we have found that science-based small firms can perform satisfactorily in global markets and be competitive against large companies. Innovation has proved to be a crucial issue in competitiveness in a science-based industry: it seems to be the key to accessing global markets and obtaining outstanding export performance.

A methodological contribution of our study is in the use of a structural equations model. Previous research has typically performed regression analyses. SEM is a more sophisticated method that has allowed us to test the three hypothesised relationships simultaneously.

Our results must be viewed in the light of the study's limitations. As with all cross-sectional research, the relationship tested in this study represents a snapshot in time. While it is likely that the conditions under which the data were collected will remain essentially the same, there are no guarantees that this will be the case. Future research could undertake a longitudinal approach. This would allow testing for interaction effects between size, innovation outcome and export intensity.

Furthermore, it is interesting to note that firm experience, a usual control variable in international business empirical studies, was low and not significant. We believe this might be also due to the industry specific profile: biotechnology is quite a new business and most of biotech firms are young. We suggest that future research in this industry should try to control the experience of the firm's R&D team or the experience of its senior researcher. This time is usually much higher than the firm's age and might provide a better representation of the technological competences of biotech firms (Elmes & Kasouf, 1995).

Our results suggest that export intensity is determined by innovation and by other factors that have not been included in the analysis since our research model could not explain thoroughly the dependent variable. This constitutes a limitation of our study, and indicates that future research should include other variables. Among the determinants of export performance underscored in the literature (Leonidou, 1995, 1998a; Leonidou & Katsikeas, 1996), factors such as the above mentioned experience in R&D or management characteristics could be relevant in the context of biotechnology.

Networking capabilities might also play an important role in export performance of firms (Bonaccorsi, 1992; Gilmore, Carson, & Rocks, 2006; McCann, Arita, & Gordon, 2002; Prashantham & McNaughton, 2006). R&D networking allows biotech firms to benefit mutually from each firm R&D competences. Through networking firms can also avoid growth constraints and keep their flexibility high (Oakey & Mukhtar, 1999). Therefore, networking capabilities could enhance the innovation outcome of a firm, and thereby boost its export intensity. Future research should take into account networking capabilities when analysing export performance of biotechnology firms.

Moreover, because we have carried out a single industry analysis, our study has benefited from dealing with firms in a homogeneous technological setting. However, it must be stressed that single-industry conclusions should be considered with caution. Further research including industries with different technological features is needed to provide further empirical assessment of the industry's influence on the relationship between innovation, export behaviour and firm size.

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Appendix A. Innovation outcome measurement scale

Could you please state the performance of your firm compared to your competitors with regard to the following items? (Table A1).

Table A1

Much worse 1	2	At the same level 3	4	5	Much better 6	7
Innovation outcome						
V1. Replacement of products being phased out						1 2 3 4 5 6 7
V2. Extension of product range within main product field through technologically new products						1 2 3 4 5 6 7
V3. Extension of product range within main product field through technologically improved products						1 2 3 4 5 6 7
V4. Extension of product range outside main product field						1 2 3 4 5 6 7
V5. Development of environmentally friendly products						1 2 3 4 5 6 7
V6. Market share development						1 2 3 4 5 6 7
V7. Opening of new markets abroad						1 2 3 4 5 6 7
V8. Opening of new domestic target groups						1 2 3 4 5 6 7

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