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Endogenous Innovation and Export Performance in Firms

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Abstract:

We investigated whether export activity is correlated with innovation in a large sample of European companies. We explicitly considered five types of innovation: a) process innovation; b) product innovation; c) process and product innovation; d) product innovation new to the firm; and e) product innovation new to the market. We considered innovation as endogenous and determined by R&D through a process characterized by the regional technological environment. Our analysis enabled us to propose an integrated model incorporating R&D, innovation, and export in a scheme of simultaneous decisions which considers their mutual correlations.

Econometric results showed that product and process innovation positively affect the export intensity of manufacturing firms in Europe. The results also indicated complementarity effects between process and product innovation. The average effect on export intensity from engaging in process innovation is larger than that found for product innovation, except in cases where the product is new to the market. When both types of innovation have been carried out, a larger effect results than that observed for product or process innovation alone. Furthermore, the average marginal effect on export intensity from innovation of any kind is highly positive and significant.

Keywords: European firms; R&D; innovation; export; endogeneity issue; fractional response model.

JEL Classification: O30, O31; F13; C36.

Introduction

The interaction between innovation and export outcome has stimulated considerable academic interest in studies of the economics of innovation and global trade (Altomonte et al., 2016; Bıçakcıoğlu-Peynirci et al., 2019). Empirical innovation literature evidence has shown that R&D activities positively affect firms' competitiveness and has reported a consistent positive marginal return on R&D investment (Chan et al., 2001). Moreover, since R&D may benefit companies in terms of competitiveness, this supplies them a stimulus to participate in international business contexts.

This study supplies an empirical analysis of the influence that different forms of innovation have on export intensity in a large sample of European manufacturing firms. The analysis considers four types of innovation: *a*) process innovation; *b*) product innovation; *c*) process and product innovation; *d*) product innovation new to the firm; and *e*) product innovation new to the market. The methodology is based on a fractional response probit model with endogenous innovation. Section 1 illustrates insights from recent literature on the links between innovation and exports. Section 2 presents the methodology and describes the data used. Section 3 presents our conclusions.

1. Research Background and Objectives

It is commonly acknowledged that innovative companies have highly competitive capabilities, which help them succeed in international markets (Harris and Li, 2009; Aw et al., 2011). At the macro level, export is viewed as vital to economic growth. According to the European Commission (2013), "Trade has never been more important for the European Union's economy", and "boosting trade is one of the few ways to bolster economic growth". European Union trade policies are designed to emphasize the interrelation between three factors through which a company's competitiveness may support economic growth and employment: export, investment, and innovation.

This issue has been extensively studied by international trade scholars (Harris & Li, 2009; Aw et al., 2011, among others). However, unequivocal evidence explaining the role of research in export has yet to be produced. At the same time, competition in global markets increases firms' innovative capacity through technological spillovers or "learning by exporting". This results in reverse causality from export to R&D. It is argued that decisions on whether to engage in research and whether to export are made concomitantly by firms (Harris & Li, 2011). This leads to simultaneity arguments between R&D and export as well as a possible self-selection process on the part of firms engaged in R&D moving into international trade. The idea is that innovative companies extend overseas to seek the best returns on their expenditures in innovation projects.

In the following sections, we summarize four common ideas from the economic literature upon which this work was based.

The Innovation–Export Link

A recent insight emerging from innovation–export analysis concerns the idea that the outcome of innovation effort influences decisions about entering and being successful in international business. Tavassoli (2018) argued that focusing on input for innovative activities (measuring innovative activity on the basis of effort and resources such as R&D expenditure) can lead to an incomplete understanding of how a company's innovation impacts its export performance.

However, many empirical analyses have found no significant evidence of the relation between research activity and export (Harris & Li, 2009; Aw & Roberts, 2011). Conversely, other studies have used input factors typically employed in the knowledge production function to express a proxy for innovation output but with inconclusive results (Van Beveren & Vandenbussche, 2010).

Few recent studies investigating factors affecting export performance have made a distinction between innovation inputs and outputs and implemented econometric setups involving models of structural equations aimed at testing the sequence of the following relations: a) R&D (along with other factors) → innovation output; and b) innovation output → export performance (Ganotakis and Love, 2011; Tavassoli, 2018).

The Research–Innovation–Export Link

This aspect has been amply explored from a theoretical perspective. The notion of a knowledge production function finds its foundation in Griliches (1979), who underlined the role of transformation of technological activities into original and remunerative valuable knowledge. R&D is acknowledged to be the most crucial input of the innovative process. Empirical evidence in this respect is scarce. However, more recent econometric research (Conte & Vivarelli, 2014; Medda, 2020) has corroborated the beneficial influence of research on firms' innovation, with diverse conclusions as to the differentiation between product and process innovations. The relation of innovation–export activity has garnered much interest. Highly innovative firms expand into international markets, searching for a higher premium on their technological projects and seeking to counterbalance potential sunk costs (Zhang and Zhu, 2016).

In particular, product innovation via the generation of novel and more technologically sophisticated commodities and assortment of product supply can give firms an incentive to penetrate or reinforce their position in international markets (Cassiman & Golovko, 2011; Tavassoli, 2018). An important aspect of recent insight deriving from innovation–export research is that the output of innovation activity affects the propensity to enter (and prosper in) global markets. At the same time, it is acknowledged that companies improve their technology as a result of selling their products abroad (Chen et al., 2018). Competition in the global context improves innovativeness thanks to spillovers from the wider knowledge acquired. Furthermore, companies can acquire technological knowledge by operating in a larger and richer environment, increase their reception of inputs that are not available in the home market (Aghion et al., 2018), and learn by exporting (İpek, 2019).

Heterogeneity in Innovation

Empirical studies have shown that one reason for the fragmentation of results is the great heterogeneity in firms' innovation activities, which is related to factors including variation in industrial sectors (Altomonte et al., 2016), countries' economic and institutional environments (Ganotakis & Love, 2011), and the nature of the innovation (Dohse & Niebuhr, 2018). In particular, attempts to unravel the effect of innovation on exports by distinguishing between process, product, and organizational innovation, as well as incremental or radical innovation in terms of the company or the market, have received little attention.

The outcomes of innovation processes can generally be classified as product innovations or cost-contracting process innovations. These two forms differ in the actions and investment required and with respect to the choice of technological partnerships, and they have different outcomes on firm performance.

According to the Oslo Manual (OECD, 2005), process innovations relate to the creation of new or significantly upgraded techniques, so they are meant to promote productivity. They provide a cost advantage over potential competitors, turning into a higher markup. Product innovations concern commodities or services which are novel or have substantial upgraded characteristics, compared to similar items on the market. Exploration of the innovation behaviour of companies has seldom focused on the direct impact of research on product and process innovation. There is often a propensity to assume that findings from literature on product innovations can be adapted to process innovation (Un and Asakawa, 2015).

However, product and process innovations mutually affect each other. Empirical and theoretical studies are now available showing this complementarity. Hullova et al. (2016) investigated cases where cost-reducing innovation necessitated the evolution of new products. In the same way, the manufacture of a new product may require adjustments in the process of production. Companies can choose to implement these two types of innovation jointly. Empirical research has highlighted noticeable gains when product and process innovations are carried out together (Guisado-González et al., 2017, for Spanish firms; Carboni & Russu, 2017, for firms in seven EU countries).

Among the few studies that have investigated how distinct forms of innovation affect firms' export outcomes, Ayllón & Radicic (2019) reported that both product and process innovation exert beneficial effects on the propensity to export, with complementary relations between the two channels of innovation. Cassiman et al. (2010), employing a panel of Spanish manufacturing firms, found evidence that product innovation, and not process innovation, affects productivity and stimulates small non-exporting firms to enter the international market. Becker and Egger (2013) concluded that companies engaged in both process and product innovation have a higher probability of exporting than firms that do not innovate. However, when implemented alone, product innovation is more important than process innovation in firms' exporting decisions. Dohse and Niebuhr (2018) showed that incremental product innovations speed up exports, whereas entirely novel products exert no prompt action.

Two Econometrics Aspects: The Endogeneity Issue and the Fractional Response Model

It is argued that choices about whether to engage in innovation activities and in those related to export are possibly made jointly by firms. The reverse causality (from export to innovation) has been pinpointed (Damijan et al., 2010). However, in determining the causal influence of technological activity on innovative outcomes, existing empirical research has generally not considered the endogeneity problem (Un et al., 2010; Berchicci, 2013). A key concern in literature on innovative behaviour is that the decision to commit to research projects is influenced by persistence and by unobservable factors that affect other crucial firm decisions (Crepon et al., 1998; Raymond et al., 2010). This may be a source of sizeable distortion in econometric estimates.

From a methodological perspective, this is relevant to endogeneity arguments establishing the link between innovation and exportation (Aw et al., 2011; Becker & Egger, 2013; Tavassoli, 2018). Well-established evidence shows that companies involved in innovative projects self-select in export activities. Aw et al. (2008) presented a framework where companies decide to carry out innovative activities with the aim of competing in international markets. Analysing a sample of Taiwanese companies, their results provided evidence of interactions between firms' decision to invest in innovativeness and their export activity level.

Studies aimed at estimating the intensive innovation margin effect on export performance have considered exports as a proportion of total turnover (Bıçakcıoğlu-Peynirci et al., 2019). As a result, in these models the dependent variable is in the range [0, 1], with a large cluster at zero, corresponding to non-exporting companies. With such cases, traditional linear models are unsuitable due to a number of methodological issues, such as the inconsistency of estimates and meaningless interpretation of results (Wooldridge, 2010).

For instance, the bounded nature of such variables and the potential probability distribution accumulating at one or both boundaries prevent standard linear estimation to ensure that the predicted values of the observed variable are confined to the unit range. Even ad hoc adjustments such as logit transformation are subject to conceptual or practical difficulties when a substantial number of observations lie at either 0 or 1, as is the case for zero-exporting sales firms in our dataset (Ramalho et al., 2011). In some cases, Tobit models have been used. However, the Tobit approach may lead to inconsistent results when the observable variable is limited on both the left and right border and, most importantly, the limited dependent nature of variables analysed in these models is assumed by a censoring mechanism; that is, the researchers do not observe values beyond certain boundaries. This is not the case when a variable is a fraction which is, by nature, confined to the 0–1 limit. A better alternative is a fractional response model, which is more appropriate for dealing with dependent variables specified as proportions (Papke & Wooldridge, 1996; Wulff and Villadsen, 2020).[1]

The econometric setup of this work was based on a fractional response probit model with endogenous innovation. This allowed us to take account of the bounded nature of exports, which, in our dataset, was expressed as exports over total sales. The analysis was carried out for five European countries over the three-year period of 2007–2009. This also distinguishes our work from existing studies based on single-country samples.

Our results may inform organizations seeking to shape technological schemes oriented at ameliorating export outcome, firm organizational apparatus, synergies, and performance. Our results can also be useful for policymakers in shaping government technological programmes at both national and European levels. Companies ought to be seriously concerned with their research engagement, as this occupation heavily impacts innovation, which, in turn, favours export activity. Moreover, innovation is systemic, embracing multiple interactions involving workers, firm organization, and the external environment. Firms which can take full advantage of their technical engagement might gain complementary know-how in other lines of activity. To establish and define opportunities, companies are required to scrutinize newly available knowledge and build suitable capabilities (Atzeni & Carboni, 2004; 2006). Such competencies include the capability to forecast demand, the evolvement of industries, and awareness of possible responses of supplier and rivals. Perception of such dimensions of innovation and R&D is vital to ameliorate firms' long-term international activity.

2. Data and Research Methodology

The information employed in this research covered five countries (Germany, France, Spain, Italy, and the UK) and was derived from the EU-EFIGE/Bruegel survey, which collected qualitative and quantitative data on the features and business of companies relative to the three-year period from 2007 to 2009. The final sample included responses from 13,621 European firms (Table 1), 22.1% of which were from Italy, 21.5% Germany, 21.7% France, 19.8% Spain, and 14.9% the UK.[2]

Table 1. Descriptive statistics

Countries	Obs.	Firms that have exported	Export intensity	Firms that have undertaken R&D	Firms that have carried out innovations				
					Process innovations	Product innovations	Process & Product innovations	Innovations new to the firm	Innovations new to the market
France	2,957	1,429	29.6%	1,499	1,115	1,311	757	436	875
%	21.7%	48.3%		50.7%	37.7%	44.3%	25.6%	14.7%	29.6%
Germany	2,929	1,308	31.3%	1,578	1,170	1,459	742	609	850
%	21.5%	44.7%		53.9%	39.9%	49.8%	25.3%	20.8%	29.0%
Italy	3,004	1,962	35.9%	1,655	1,346	1,478	797	449	1,029
%	22.1%	65.3%		55.1%	44.8%	49.2%	26.5%	14.9%	34.3%
Spain	2,699	1,360	26.6%	1,208	1,392	1,231	754	631	600
%	19.8%	50.4%		44.8%	51.6%	45.6%	27.2%	23.4%	22.2%
UK	2,032	1,174	30.4%	1,075	944	1,180	763	292	888
%	14.9%	57.8%		52.9%	46.5%	58.1%	37.5%	14.4%	43.7%
Total	13,621	7,233	31.2%	7,015	5,967	6,659	3,793	2,417	4,242
%	53.1%		51.5%		43.8%	48.9%	27,8%	17.7%	31.1%

The variable of observation in this study was exports over sales. Over half of the firms in the survey (53.1%) declared sales to other countries of some (or all) of their own products/services in 2008, with the maximum

[1] When the observations at one or both boundaries display too large a frequency, it may be preferable to use two-part models.

[2] The original dataset also contains information about Austria and Hungary; however, given the numerous missing observations that prevented us from generating our core variables, these two countries were excluded from the study.

proportion in Italy (65.3%) and the minimum in Germany (44.7%). The average export intensity recorded for exporting firms was 31.2%, with the maximum, again, found in Italian firms (35.9%) and the minimum pertaining to Spanish companies (26.6%). Just over half the companies were engaged in research, while 27.8% carried out both process and product innovation (43.8% and 48.9%, respectively). Product innovation was rated as "new to the firm" for 17.7% and "new to the market" for 31.1% of the companies. The section below illustrates the variables employed in the analysis and provides the theoretical background.

2.1 Estimation Strategy

The econometric design employs an integrated model incorporating R&D, innovation, and export in a scheme of simultaneous equations which consider their possible reciprocal interrelations. We studied the impact of innovation on firms' export intensity, considering that innovation, in turn, depends on external and internal factors. Recent studies have emphasized that what matters for success in international markets is the output of innovation processes rather than their input (Ganotakis & Love, 2011; Tavassoli, 2018). Special emphasis is placed on R&D efforts, which are commonly identified as the main source of innovation (Griliches, 1979), and the role of the technological environment. Thus, we attempted to shed light on the R&D–innovation link and the regional technological spillover literature (Jaffe, 1986; Rodríguez-Gulías et al., 2020). The regional technological environment represents a critical component affecting the choice to engage in technological activities. We used this information together with the lack of appropriate financing for innovation activity as instrumental variables, which we employed in the framework for the system of equations. To the best of our knowledge, our framework is among the few first of its kind (Altomonte et al., 2016; Mancusi et al., 2018).

Moreover, given the substantial heterogeneity in innovation, we explicitly distinguished between the following: *a*) process innovation; *b*) product innovation; *c*) process and product innovation; *d*) product innovation new to the firm; and *e*) product innovation new to the market. This allowed us to obtain a more focused picture of their specific effects on export and differentiates our analysis from existing studies which used generic innovation variables (among others, Ganotakis & Love, 2011; Tavassoli, 2018).

The analysis considered innovation as endogenous and determined by R&D through a process influenced by the regional technological context. In this section, we describe an integrated model incorporating R&D, innovation, and export, in a scheme of simultaneous equations. The objective of our estimation method was to supply an empirical inquiry on the complex R&D–innovation and export link, emphasizing the potential non-linearity of the relationship. We argued that simultaneity may be at the base of such decisions. We regarded companies' choice to undertake R&D decision as an endogenous mechanism.

We also examined the elements possibly influencing firms' commitment to research. An interesting aspect of firms' knowledge production function is that innovation output may be affected by unobservable factors that also affect firms' R&D. Endogeneity issues also arise in the innovation–export relationship: several studies have shown that choices about whether to engage in innovation activities and in those related to export are made jointly by firms (Aw et al., 2011; Becker & Egger, 2013). However, in their survey of empirical literature, Wu et al. (2021) found that less than half of innovation–export empirical analysis accounts for endogeneity, claiming that this approach may lead to contrasting estimates of the magnitude and direction of the impact of innovation on companies' export outcome.

We considered endogeneity in the relationship between research and innovation by studying factors that may affect firms' propensity for R&D, with a particular focus on the role regional technological surroundings might play. For this purpose, we identified the regional (NUTS-2 level) technological environment as a determining component in incentivizing firms to engage in research.

The econometric strategy of this study considered the themes in the literature discussed above and employed a three-equation model, as follows: (1) estimation where the dummy R&D variable is endogenous and determined by the regional technological background, expressed by the regional R&D/GDP ratio; (2) estimation where the dummy innovation variables are endogenous and dependent on R&D and other controls; and (3) estimation of the impact of innovation intensity on export intensity. This latter indicator was a proportion with bounds [0, 1], thus, as suggested by Wooldridge (2010) and Wulff & Villadsen (2020), we employed a fractional probit response model. In detail, the model we propose is as follows:

$$\text{DUMMY\_R\&D} = \alpha_0 + \alpha_1\ \text{REGIONAL\_TECH\_CONTEXT} + \alpha_i\ \text{CONTROLS} + \varepsilon_1; \quad (1)$$

$$\text{DUMMY\_INNOVATION} = \beta_0 + \beta_1\ \text{DUMMY\_R\&D} + \beta_i\ \text{CONTROLS} + \varepsilon_2; \quad (2)$$

$$\text{EXPORT\_INTENSITY} = \gamma_0 + \gamma_1\ \text{DUMMY\_INNOVATION} + \gamma_i\ \text{CONTROLS} + \varepsilon_3. \quad (3)$$

The DUMMY_R&D variable indicates whether a firm has carried out R&D. DUMMY_INNOVATION is a set of dummy variables indicating whether different kinds of innovation have been undertaken, namely process innovation, product innovation, both product and process innovation together, and finally, product innovation new to the company or new to the market. EXPORT_INTENSITY expresses the percentage of annual turnover represented by export activities. REGIONAL_TECH_CONTEXT is measured by Eurostat statistics on regional (NUTS-2 level) R&D spending over GDP. CONTROLS features conventional variables used to capture the significant heterogeneity in companies' characteristics (Altomonte et al., 2016; Coad, 2018).

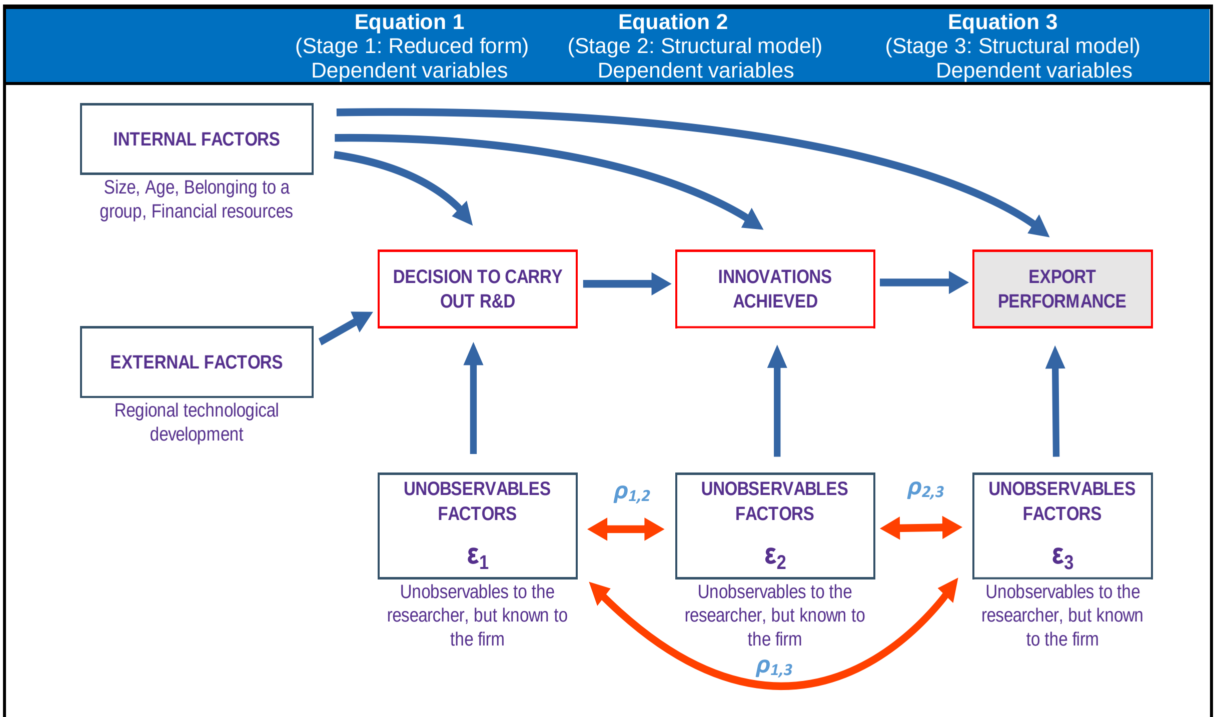
As suggested by Wooldridge (2010), equations (1) and (2) do not need to be correctly specified and are estimated by linear models, while equation (3) is analysed using a fractional probit response design. We assumed (and tested) the following:

$$E(\varepsilon_1) = E(\varepsilon_2) = E(\varepsilon_3) = 0;$$

$$E[\varepsilon_1\ \varepsilon_2] = \sigma_{1,2} \neq 0; \qquad E[\varepsilon_1\ \varepsilon_3] = \sigma_{1,3} \neq 0; \qquad E[\varepsilon_2\ \varepsilon_3] = \sigma_{2,3} \neq 0. \tag{4}$$

We made use of the Stata conditional mixed-process estimator (CMP) command (Roodman, 2011) and used the delta method to compute average marginal effects. The econometric methodology applied in this work was supported by tests and revealed the existence of unobservable elements that influence export, innovation, and R&D. Chart 1 illustrates the econometric setup. The methodology and mechanism by which regional effects entered the estimation strategy are described in Figure 1 below.

Figure 1. Estimation scheme



INTERNAL FACTORS: - Age of firm (log of years from establishment); - Size (log of number of employees); - Dummy = 1 if the firm exported prior to 2008; - Dummy = 1 if the firm belonged to a group; - Dummy = 1 if the firm was head of the group; - Lack of appropriate financing as a factor hampering innovation (INSTRUMENTAL VAR).	DECISION TO CARRY OUT R&D: DUMMY R&D: Did the firm undertake R&D? (yes = 1; no = 0)	INNOVATION ACHIEVED: 5 types of innovation variables: (yes = 1; no = 0): 1) Process; 2) Product; 3) Process & Product; 4) New to the firm; 5) New to the market; Did the firm carry out any (type of...) innovation?
EXTERNAL FACTORS: - Country dummy variables; - Industry dummy variables at NACE 2-digit level; - Average R&D expenditure over GDP by NUTS-2 regions (INSTRUMENTAL VAR.)	- Error terms: $\varepsilon_1, \varepsilon_2, \varepsilon_3$; - Error correlations: $\rho_{1,2}; \rho_{2,3}; \rho_{1,3}$.	EXPORT PERFORMANCE: - Export sales over total turnover.

2.2 Control Variables

There is a consensus that export performance by firms is positively correlated with size. Due to consistent differences in manufacturing systems, firm dimension may be helpful for comprehension of the heterogeneity observable in the conduct of firms. The size of the organization is also a critical aspect in deciding innovativeness and the possibility of finding the financial assets required for tangible investment. We considered companies' dimension as the number of workers expressed in logarithm terms.

The age of organizations (expressed in years since their foundation) was also considered in the estimation analysis. The rationale is that older companies are likely to possess superior production skill gained with time, giving them a possible market advantage. Organization age was also accounted as influencing technological propension, on the grounds that young companies devote greater energy in research with respect to older ones, although documentation for this is diverse (García-Quevedo et al., 2014).

A binary indicator, referring to whether firms had exported anterior to 2008, was also considered. The key role of experience in international business is commonly recognized. Returns from exports can be employed to finance internal investment. This may be crucial if firms depend heavily on their own financing. Being active in the world context may also affect companies' innovation capacity: international organizations are asked to stress proficiency at high standards. At the same time, world business fosters the potentiality to acquire technological spillovers from overseas (Altomonte et al., 2013).

Two binary variables expressing if the company was part of a business group and if it was the principal of a group were included in the estimation (Wu et al., 2021). Being part of a group may enable companies to internalize externalities from research projects and possibly mitigate financial restrictions (Guzzini & Iacobucci, 2014).

An indicator of financial constraints was also designed into the model. These provide an approximate proxy of credit market efficiency and are generally suitable to argue under-investment in technology. They are commonly considered a major factor constraining innovation (Hall et al., 2016; Chen et al., 2018; Nemlioglu & Mallick, 2020; Kou et al., 2020). A shortage of financial resources may hamper or delay a company's decision about whether to implement R&D projects. The rationale is that the possession of financial assets eases investment by lowering the hazards deriving from external loan use. This strongly impacts the costs of financing. R&D investment is arguably riskier in general, and both sunk costs and market failures are generally associated with this idea. In light of this, we included lack of appropriate financing for innovation activity among the controls (equal to 1 if the company acknowledged a shortage of finance as the major factor constraining innovation, 0.5 if this shortage was rated as the second factor, and 0 otherwise). This information is employed as an instrumental variable in the econometric estimates. It is incorporated in R&D equations 1 and 2 since it is supposed to influence R&D and innovation, but it is excluded from equation 3 as it does not impact export directly.

We controlled for the heterogeneity of firms' innovative activity between regions. The spatial technological context was proxied by the regional average R&D spending over gross domestic product (similar to Rodríguez-Gulías et al., 2020, Carboni & Medda, 2021(a, b). This variable was built using Eurostat data from 2007 and was matched to the EFIGE dataset. We followed the idea that the technological context plays an important role in encouraging companies to engage in research and has an impact on the level of its intensity. Consolidated literature starting with Jaffe (1986) has shown the existence of localized technological spillover and that firms benefit from neighbours' innovative activities (Bengoa et al., 2017; Lòpez-Bazo & Motellòn, 2018; Coad, 2019; Rodríguez-Gulías et al., 2020). This information is used as instrumental variable in the econometric estimates.

The R&D dichotomy variable was constructed according to the information contained in the survey about companies' research activity in the triennium 2007–2009. Research activity refers to four modes: (1) invested in R&D; (2) acquired R&D from companies within the same group; (3) acquired R&D from other firms/consultants; and (4) acquired R&D from universities and research centres.

The following types of innovation were considered: a) process innovation; b) product innovation; c) process and product innovation; d) product innovation new to the firm; and e) product innovation new to the market; the dummy variable was constructed according to the information gathered in the survey.

Finally, the analysis included country and industry controls to check for potential country and industry-specific effects (manufacturing sectors, defined by two-digit NACE Rev. 1 codes) in research, innovation, and export behaviour.

2.3 The Role of Regional Innovation

Consolidated literature since Jaffe (1986) has demonstrated the existence of localized technological spillover (Lòpez-Bazo & Motellòn, 2018; Coad, 2019; Audretsch & Belitski, 2020). Firms benefit from the innovative activities of neighbouring companies and adjust their R&D decisions on the basis of the local technological environment and opportunities (Bengoa et al., 2017). Even though we could not deepen the analysis of themes relating to geographical aspects, we controlled for significant internal heterogeneity in firms' innovative activity between regions (countries).

In accordance with regional technological innovation literature, we hypothesized that the surrounding context might influence firms' R&D choices (a relevant condition for an instrumental variable (IV); Ketokivi and McIntosh, 2017; Angrist & Krueger, 2001), but they are not correlated with the residuals of the structural equation, where firm export intensity is employed as a dependent variable. The regional surrounding affects companies' technological outcomes through its influence on each firm's internal R&D (exclusion condition), as well as on other inputs in firms' knowledge production function (Griliches, 1979). We separated inputs from the outputs of firms' innovative activity (Hagedoorn & Cloodt, 2003; Ganotakis & Love, 2011), considering the local technological environment as a crucial factor (Roper & Love, 2017; Holl, Peters & Rammer, 2022).

The spatial technological context was proxied by total regional R&D spending over gross domestic product (Rodríguez-Gulías et al., 2020, and Carboni & Medda, 2021a). This information together with the lack of appropriate financing for innovation activity represented our IVs. It is worth noting that our framework required exclusion of the instrumental variables from the structural equation. Finally, we checked the validity of our IVs following the guidelines proposed by Ketokivi & McIntosh (2017), although, as argued Angrist & Krueger (2001) the assumption beyond the exclusion restriction is formally untestable. In the second stage, we estimated the structural equation where the research variable was included to test its effect on innovation outcomes.

2.4 Estimation Results

The estimated results of equation (3) are given in Table 2. All estimates confirmed our hypothesis that innovation positively and highly significantly impacts exports. The average marginal effect of innovations on export intensity of any kind among the firms studied here was between 67.2% (for the general product innovation dummy) and 72.7% (for the new-to-the-market product innovation dummy). The average effect on export intensity from process innovation was larger than that found for product innovation, except for cases where the product was new to the market.

Table 2. Innovation and export

Dependent variable: Export intensity	(1)		(2)		(3)		(4)		(5)	
	dy/dx	s.e.	dy/dx	s.e.	dy/dx	s.e.	dy/dx	s.e.	dy/dx	s.e.
Log of employees	-0.028***	0.002	-0.018***	0.002	-0.029***	0.003	-0.010***	0.003	-0.012***	0.002
Log of age	0.007***	0.002	0.003	0.002	0.007***	0.003	-0.006*	0.003	0.007***	0.002
Belongs to a group?	0.005	0.006	0.019***	0.006	0.010	0.006	0.012	0.007	0.012*	0.006
Is at the head of a group?	-0.005	0.012	-0.038***	0.012	-0.016	0.013	-0.004	0.015	-0.037***	0.012
France	0.040***	0.007	0.044***	0.007	0.054***	0.008	-0.014*	0.008	0.056***	0.007
Germany	0.033***	0.007	0.036***	0.007	0.069***	0.008	-0.048***	0.008	0.070***	0.007
Italy	0.015**	0.007	0.059***	0.007	0.070***	0.007	-0.004	0.008	0.064***	0.007
Spain	-0.033***	0.007	0.047***	0.007	0.047***	0.008	-0.072***	0.009	0.098***	0.007
Process innovations	0.689***	0.001								
Product innovations			0.672***	0.003						
Process & Product innovations					0.722***	0.002				
Product inn. new to the firm							0.684***	0.003		
Product inn. new to the market									0.727***	0.002
N	13,621		13,621		13,621		13,621		13,621	
Wald chi2	447.829***		186.593***		89.551***		140.313***		90.326***	
Insig_1	-0.779***	0.003	-0.778***	0.003	-0.779***	0.003	-0.779***	0.003	-0.779***	0.003
Insig_2	-0.747***	0.005	-0.735***	0.014	-0.854***	0.008	-0.975***	0.007	-0.802***	0.013
atanhrho_12	-0.123***	0.033	-0.418***	0.035	-0.211***	0.032	-0.071***	0.020	-0.380***	0.033
atanhrho_13	-0.237***	0.009	-0.352***	0.010	-0.273***	0.009	-0.081***	0.009	-0.303***	0.009
atanhrho_23	-1.655***	0.086	-0.868***	0.044	-1.353***	0.064	-2.524***	0.112	-0.995***	0.047

Note:* p<0.10.** p<0.05.***p<0.01; Includes 10 industry dummies. A joint test for significance Chi2 reveals p<0.001 in all models; dy/dx for factor levels is the discrete change from the base level.

It is worth noting that the effect was highest in the case of product innovations new to the market (0.727). Moreover, in line with Ayllón & Radicic (2019), a complementarity effect was found between product and process innovation: when product and process innovations occur together, the effect on exports (0.722) is greater than when either is carried out alone (0.689 and 0.672, respectively). This might be a sign that firms performing both types of innovations are tout court technology-oriented and, for this very reason, more related to international markets. This somewhat contradicts conventional wisdom considering that product innovation has a major role in export outcomes (Becker & Egger, 2013). However, Bıçakcıoğlu-Peynirci et al. (2019) argued that process innovation can significantly improve productivity, which is a crucial factor in international markets. Furthermore, as in Aw, Roberts & Xu (2008), exporting companies invest in new products which might be more successful in the international context.

Being part of a business group has positive effects for product innovation. This might indicate that the interaction between these two aspects has a role to play, probably due to the presence of internal spillovers within the group. The coefficient is non-significant for process, product, and process innovation. Size generally exerts a negative impact on export. This is also corroborated by the negative coefficient for firms that are the head of a group (which are commonly large in size). It is worth noting that the period covered by the dataset coincided with financial crises where large exporting firms suffered the most. Concerning the age of firms, our estimations did not supply clear evidence.

Table 3 shows the results for the three-equation system estimation. In the first stage (eq. (1) at the top of the table), the binary R&D decision was the dependent variable. It is worth highlighting that the technological regional context variable was found to have a positive effect on R&D, suggesting the relevance of geographical spillovers. The size of firms asserts a positive impact on decisions to carry out R&D, particularly for those at the head of a group. It also emerges that being part of a group itself does not have a significant effect on research. Past export experience positively impacts R&D. However, it is not easy to state whether this is due to structurally persistent characteristics of firms which push them to enter and remain in the international market, or whether it is the result of reverse causality between export and innovation. Interestingly, the credit constraint variable is positively correlated with the probability of engaging in research. However, the firms in the sample desiring more credit spent more on R&D with respect to those not desiring more credit. This suggests that such firms, even if financially constrained, had a more technology-oriented attitude compared to their counterparts, and that possibly they would have committed more to research had they had access to more financing.

The second stage (eq. (2)) involved the five types of innovation as dependent variables. From the estimations, it emerged that small organizations innovate in terms of products. Conversely, in terms of process, large firms appear to be more performant. Concerning the research variable, the results suggest that commitment to R&D impacts overall the probability of product innovation (the coefficient was double that for process innovation). This is not surprising given that to generate innovations in the process of production, along with the intensity of research commitment, it is also important to realize organizational changes. The latter are widely acknowledged as being crucial to keep a competitive position in a speedily changeful environment and also beneficial for efficient implementation of technical product and process innovations (Carboni & Russu, 2017). The results also confirm the value of financial collateral in the innovation process (Hall et al., 2016; Nemlioglu & Mallick, 2020).

In the third panel of Table 3 (eq. (3) at the bottom of the table), the variable of observation is export intensity, and the five types of innovation are the explanatory variables. All forms of innovation produce a positive and highly significant influence on export. The estimated effect of size was negative overall, while belonging to a group or being at the head of a group was observed to have positive effects on export intensity in the product innovation equation only. Significant industry-specific effects were detected. In the same manner, country fixed effects suggest the presence of structural differences among countries, possibly related to the specific regulatory system and to the national economic and institutional environment that firms belong to.

Finally, tests of the model's validity corroborated the approach used: the *atanhrho* statistics were all highly significant, revealing correlations between the error terms of pairs of equations. These values were different from zero in all the specifications.

The excluded instrumental variables asserted a highly significant and positive impact on R&D propensities, as reported in equation (1) and (2) regressions. Particularly, this finding is aligned with studies that stress the geographical dimension as a cause of the considerable heterogeneity in firms' innovation outcomes (Lychagin et al., 2016; Hu et al., 2020) and confirms the crucial role of local public commitment to innovation (García-Vega and Vicente-Chirivella, 2020; Carboni & Medda, 2021a). The results corroborate the validity of the instruments employed, which was also confirmed by highly significant chi-square test results. The latter enabled us to reject the null hypothesis of variable coefficients jointly equal to zero. Although this does not represent a full solution, we reasonably believe that the endogeneity bias was sensibly mitigated.

Table 3. Three equation model

	(1)		(2)		(3)		(4)		(5)	
	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.
eq. (1). dep. variable: has undertaken R&D?										
Log of employees	0.078***	0.004	0.077***	0.004	0.078***	0.004	0.078***	0.004	0.078***	0.004
Log of age	-0.006	0.005	-0.007	0.005	-0.006	0.005	-0.006	0.005	-0.007	0.005
Did export in the past?	0.260***	0.009	0.261***	0.009	0.260***	0.009	0.260***	0.009	0.260***	0.009
Belongs to a group?	0.009	0.011	0.008	0.011	0.009	0.011	0.009	0.011	0.009	0.011
Is at the head of a group?	0.044**	0.022	0.045**	0.022	0.045**	0.022	0.044**	0.022	0.045**	0.022
France	-0.020	0.014	-0.017	0.014	-0.019	0.014	-0.021	0.014	-0.019	0.014
Germany	-0.027**	0.014	-0.024*	0.014	-0.026*	0.014	-0.028**	0.014	-0.027**	0.014
Italy	-0.008	0.014	-0.002	0.014	-0.006	0.014	-0.009	0.014	-0.005	0.014
Spain	-0.071***	0.014	-0.066***	0.014	-0.069***	0.014	-0.073***	0.014	-0.069***	0.014
Lack of appropriate financing	0.061***	0.010	0.046***	0.010	0.057***	0.010	0.065***	0.010	0.056***	0.010
Regional R&D/GDP	0.006***	0.002	0.007***	0.002	0.007***	0.002	0.006***	0.002	0.008***	0.002
Cons	0.089***	0.025	0.089***	0.025	0.089***	0.025	0.089***	0.025	0.087***	0.025
eq. (2). dep. variable:	Process innovations		Product innovations		Process & Product inn.		Product inn. new to the firm		Product inn. new to the market	
Log of employees	0.032***	0.006	-0.013**	0.006	0.024***	0.005	0.005	0.004	-0.017***	0.006
Log of age	-0.013***	0.005	-0.002	0.005	-0.011**	0.004	0.008**	0.004	-0.010**	0.005
Belongs to a group?	0.000	0.012	-0.016	0.012	-0.006	0.011	-0.012	0.009	-0.005	0.012
Is at the head of a group?	-0.011	0.024	0.031	0.023	0.003	0.022	-0.002	0.019	0.034	0.023
France	-0.080***	0.014	-0.092***	0.014	-0.096***	0.013	0.019*	0.010	-0.108***	0.013
Germany	-0.068***	0.014	-0.080***	0.014	-0.124***	0.013	0.062***	0.011	-0.139***	0.014
Italy	-0.015	0.014	-0.092***	0.014	-0.106***	0.013	0.011	0.010	-0.098***	0.014
Spain	0.089***	0.014	-0.056***	0.015	-0.058***	0.013	0.100***	0.011	-0.151***	0.014
Lack of appropriate Financing	-0.021***	0.004	-0.022***	0.008	-0.022***	0.005	-0.008***	0.002	-0.029***	0.007
Has undertaken R&D?	0.388***	0.032	0.794***	0.035	0.463***	0.029	0.130***	0.015	0.664***	0.031
Cons	0.180***	0.026	0.290***	0.027	0.118***	0.025	0.081***	0.021	0.211***	0.026
eq. (3). dep. variable: export intensity										
Log of employees	-0.115***	0.010	-0.075***	0.010	-0.120***	0.010	-0.034***	0.010	-0.052***	0.010
Log of age	0.031***	0.010	0.011	0.010	0.029***	0.010	-0.021*	0.011	0.029***	0.010
Belongs to a group?	0.021	0.025	0.079***	0.025	0.041	0.026	0.040	0.025	0.050*	0.026
Is at the head of a group?	-0.023	0.050	-0.161***	0.049	-0.066	0.053	-0.015	0.051	-0.161***	0.053
France	0.165***	0.029	0.183***	0.029	0.219***	0.031	-0.049*	0.027	0.239***	0.031
Germany	0.136***	0.029	0.149***	0.029	0.278***	0.031	-0.165***	0.029	0.302***	0.031
Italy	0.062**	0.029	0.245***	0.029	0.285***	0.031	-0.013	0.027	0.275***	0.031
Spain	-0.137***	0.030	0.197***	0.030	0.192***	0.031	-0.245***	0.030	0.421***	0.031
Process innovations	2.053***	0.004								
Product innovations			2.092***	0.007						
Process & Product innovations					2.296***	0.011				
Product inn. new to the firm							2.645***	0.019		
Product inn. new to market									2.248***	0.010
Cons	-0.785***	0.060	-1.482***	0.061	-0.824***	0.063	-0.391***	0.057	-1.254***	0.063
N	13,621		13,621		13,621		13,621		13,621	
Wald chi2	447.829***		186.593***		89.551***		140.313***		90.326***	

lnsig_1	-0.779***	0.003	-0.778***	0.003	-0.779***	0.003	-0.779***	0.003	-0.779***	0.003
lnsig_2	-0.747***	0.005	-0.735***	0.014	-0.854***	0.008	-0.975***	0.007	-0.802***	0.013
atanhrho_12	-0.123***	0.033	-0.418***	0.035	-0.211***	0.032	-0.071***	0.020	-0.380***	0.033
atanhrho_13	-0.237***	0.009	-0.352***	0.010	-0.273***	0.009	-0.081***	0.009	-0.303***	0.009
atanhrho_23	-1.655***	0.086	-0.868***	0.044	-1.353***	0.064	-2.524***	0.112	-0.995***	0.047

Note:* p<0.10.** p<0.05.***p<0.01; Includes 10 industry dummies. A joint test for significance Chi2 reveals p<0.001 in all models

Conclusion

In this work, we investigated the nexus between export performance and innovation. Given the marked heterogeneity associated with innovation, we explicitly distinguished between a) process innovation; b) product innovation; c) process and product innovation; d) product innovation new to the firm; and e) product innovation new to the market. Such heterogeneity relates to various internal and external factors, including industrial sectors and the economic and institutional environment.

The empirical analysis was based upon a sample of 13,621 European manufacturing companies in Germany, Italy, Spain, France, and the UK. This is a noteworthy target, especially in consideration of the scarcity of unequivocal empirical documentation at hand and considering the EU's trade strategy, which is strongly focused on the function of research and innovation for employment and economic growth.

The analysis developed an integrated model incorporating R&D, innovation, and export, in a scheme of simultaneous equations. We considered the decision to commit to research as an endogenous mechanism and analysed the elements which may affect R&D engagement. Moreover, it is possible that choices about whether to engage in research and innovation activities and in those related to export are made jointly by firms. Hence, we employed a recursive system of regression equations which allowed us to consider whether companies choose R&D, innovation, and export strategies simultaneously.

We also considered the fact that firms may benefit from neighbouring companies' technological activity and adapt their R&D decisions to surrounding knowledge opportunities. For this purpose, we used total regional R&D spending over regional gross domestic product as a proxy for the geographical technological context. This information, and the lack of appropriate financing for innovation activity, represented our instrumental variables in the econometric setting. Finally, given the bounded nature of the dependent variable and the possibility of values at the boundaries, we made use of fractional specification. Only a limited number of empirical investigations have considered this issue, which has potentially led to biased estimates.

Although the cross-sectional nature of the survey prevented the computation of long-term effects, the enquiry produced worthwhile insights on the nexus between export performance and product and process innovation. We found that process innovation has a larger average effect on export intensity relative to product innovation. However, when product innovations are new to the market, their effect is stronger, and this is also the case when they are carried out together with process innovations, in which case significant complementarity effects arise.

The relevance of innovation and its interplay with research and export activity has valuable policy indications. Firms ought to capitalize upon R&D while attempting to ameliorate their export outcome. Concurrently, they ought to concentrate on innovation directly associated with their research and export actions. This circular process embraces several crucial internal and external aspects. The innovation process is, in fact, systemic and has a complex interplay embracing workers, the organization of the company, and the exterior background. Firms capable of taking full advantage of their technological commitment may profit from complementary competences in other branches of their activity. Recognition of such dimensionality is vital and can be very helpful for firms developing their export design.

To select and frame opportunities, firms ought to constantly search for technologies and markets and build suitable skills and competences. This implies a commitment to technological research, comprehension demand, markets, and competitors dynamics. Constructing (and progressively honing) related skills helps firms make appropriate decisions and achieve better long-term export performance. This is particularly true as product innovation supports the continuous upgrade of firms via the interrelationship with internal abilities which, in turn, strongly depend on technological effort and commitment.

One limitation of this research derives from the cross-section structure of the data (although the dataset was large and related to multiple countries). As more complete information is collected, future enquiries should concentrate on the dynamic sequence of companies' decisions about R&D, innovation, and export. This would allow a more accurate portrayal of exporting designs from a sequence-of-facts perspective. Another limit of this work is that it does not consider the possible presence of public interventions aimed at supporting exports (e.g., trade liberalization) or policies oriented at stimulating innovation through tax schemes. Further enquiry can investigate how the contraction of trade tariffs can affect companies' success in global business.

Credit Authorship Contribution Statement:

We state and recognize the roles and contributions to this research as follows: Oliviero A. Carboni: data curation, formal analysis, software, supervision, methodology, funding acquisition and resources; Giuseppe Medda: review, editing, conceptualization, investigation, methodology.

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Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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