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Product innovation, process innovation and export propensity: persistence, complementarities and feedback effects in Spanish firms

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ABSTRACT

Drawing on a longitudinal data of Spanish manufacturing firms, this study explores the persistence of technological innovation and exports, their potential complementary relations and feedback effects. Empirical results suggest the presence of both true and spurious state dependence in all three activities. True state dependence in technical innovation and exports implies intertemporal spillovers relevant to the evaluation of innovation and export policy measures. However, given that results also suggest spurious state dependence, firm-specific characteristics should be taken into account in promoting technological innovations and exports. In addition, we find a strong complementarity between product and process innovation both through a contemporaneous effect and via unobserved firm characteristics. However, concerning complementarity between innovation and exports, results suggests complementarity only through contemporaneous effects. Finally, we find no support for the causal link from past product and process innovations to current export activities.

KEYWORDS

Product innovation; process innovation; exports; persistence; complementarities

JEL CLASSIFICATION

O31; C23; F10; F14

1. Introduction

Innovation and exports are considered to be vital driving forces for firms' competitive advantage (Lewandowska, Szymura-Tyc, and Golebiowski 2016). Innovation has direct and indirect effects on exports (Andersson and Löf 2009; Damijan, Kostevc, and Polanec 2010). The latter stems from the role of innovation in firm productivity. Namely, innovation is the main source of firm heterogeneity in productivity, and since Melitz (2003) model, it is widely recognized that exporters are more productive than non-exporters. A direct influence of innovation on exports means that innovation increases firms' competitiveness in foreign markets, either by firms introducing product innovation and thus meeting foreign demand, or through process innovation, whereby firms gain cost advantages over their foreign competitors.

The first objective of this study investigates potential persistence of technological innovations and exports and its sources. Namely, there are two types of persistence: a) *true or genuine persistence*, whereby the decision of a firm to engage in an activity (e.g. innovation or exports) in one period in itself increases

the likelihood of that activity in the subsequent period; b) *spurious persistence*, which occurs when observed and unobserved firm characteristics that persist over time affect the likelihood of that activity in the subsequent period. Internationalization is by definition a dynamic process (Casillas, Moreno, and Acedo 2012). Moreover, innovating firms are more likely to continue innovating in the future (Clausen et al. 2011; Peters 2009). Therefore, all three activities that are in the focus of our study are dynamic in nature, but from the managerial and policy stance, it is important to identify sources of persistence. Namely, if innovation and export propensity exhibit true state dependence, then the most important decision that managers need to make is to start exporting and innovating. From the policy perspective, true state dependence implies that public support for innovation and exports has not only temporary, contemporaneous effects, but rather long-lasting impacts. If, on the other hand, persistence is spurious, then managers and policy makers should identify and facilitate those observed and unobserved firm characteristics that affect persistence in innovation and exports.

The second objective of this study is to investigate whether technological innovations and exports are complementary, i.e. whether the returns of the one activity rise because of the other. Following the cognitive theory of the firm, innovation and exports are complementary activities because firms, as learning organizations, engage in both activities simultaneously in order to accumulate knowledge, enhance capacity and thus contribute to their comparative advantage. Empirical studies that explore the decision by firms to simultaneously innovate and export are few and far between (Esteve-Pérez and Rodríguez 2013). Based on observed and unobserved firm characteristics, we assess a potential complementarity between product and process innovations, between product innovation and exports (Golovko and Valentini 2011) and between process innovation and exports.

Finally, the third objective is to report on feedback effects between innovation and exports, that is, on the extent to which participating in a given activity during the previous period increases the likelihood of the other activity in the following period. A direction of causality between innovation and exports is not clear in the literature. While traditional product life-cycle models posit that innovation affects exports, endogenous growth theories (Grossman and Helpman 1991) note that the reverse causality – from exports to innovation – might hold. As shown below, our econometric strategy considers feedback effects in all possible directions, thus making a new contribution to the literature.

Our main findings suggest a considerable degree of true state dependence in the three activities under analysis, with persistence particularly strong in the case of process innovation and in the case of exports. We also report a contemporaneous complementarity between product and process innovation, which in turn is reinforced by a positive correlation between unobservable factors that affect both outcomes. Furthermore, while being an exporter increases the likelihood of a firm being engaged in process and product innovation in the current period, we find no evidence of feedback effects from past innovation activities on the probability of firms' exporting decision.

The remainder of the study proceeds as follows. Section II discusses theoretical rationales to explain persistence in export propensity and technological innovations. In addition, a complementary nature of all three types of activities is reviewed. Section III then presents the data and provide an overview of the econometric strategy. Section IV discusses empirical findings. Section V presents conclusions, derives some managerial and policy implications and discusses the limitations of this study.

II. Theoretical rationales and hypotheses development

Persistence in exports

A dynamic nature of exports is reflected in the path-dependence view of export behaviour (Hutzschenreuter, Pedersen, and Volberda 2007), which is consistent with the resource-based view of the firm, and in particular with the dynamic-capabilities approach (Teece, Pisano, and Shuen 1997). Moreover, prior to the development of these approaches, the learning view of the international process and the evolutionary theory of multinational firms recognized the path-dependent nature of internationalization; this assumes that the process takes time, as firms learn through market experience, and this accumulated experience of past decisions affects future decisions on export participation (Casillas, Moreno, and Acedo 2012). That is, in the early stages of the internationalization process, firms' export intensity is low as they enter familiar and nearby markets. Then through the accumulation of experience and knowledge, firms become persistent exporters, their export intensity rises and they export on a global scale (Andersson and Lööf 2009).

Following dynamic models of export participation (Bernard and Jensen 2004; Melitz 2003), the source of *true state dependence* is related to sunk costs incurred when firms enter new markets (e.g. the costs of market research into foreign markets and the establishment of marketing and distribution channels) (Cassiman and Golovko 2011; Esteve-Pérez and Rodríguez 2013). In addition, past export activity might affect future propensity to export (Aw, Roberts, and Winston 2007).

Besides sunk costs, the literature on learning argues that the accumulation of export experience plays a significant role as well. Profitability in a market increases with the length of export experience, as firms accumulate knowledge about foreign markets through incremental learning (Casillas, Moreno, and Acedo 2012; Van Beveren and Vandenbussche 2010).

If, however, observed and unobserved heterogeneity and initial conditions shape a firm's current propensity to export, then the observed persistence is *spurious*. If these characteristics are persistent and correlated over time but are not controlled for by an appropriate econometric method, then the positive effect of past exporting on current activity is spurious and is due to firm characteristics, rather than to true state dependence (Esteve-Pérez and Rodríguez 2013; Peters 2009). In addition, unobserved firm characteristics influence the initial conditions for exporting (Hecker and Ganter 2014). Our choice of estimation strategy – a joint dynamic random effects probit model – is motivated by the advantage it offers of allowing us to distinguish between true state dependence and spurious one (i.e. observed and unobserved heterogeneity).

Concerning empirical evidence, Máñez-Castillejo, Rochina-Barrachina, and Sanchís-Llopis (2008) report sunk costs as a source of persistence in exports, as well as observed and unobserved firm heterogeneity in Spanish firms. Similarly, Das, Roberts, and Tybout (2007) and Aw, Roberts, and Winston (2007) found that firms face large sunk costs when they enter foreign markets, and Esteve-Pérez and Rodríguez (2013) report similar findings for Spanish firms. Thus, based on theoretical reasoning and previous empirical evidence, we expect the decision of firms on their participation in exports to be both past dependent and path dependent and accordingly we formulate the following:

H₁: Persistence in exports exhibits both true (path) state dependence as well as spurious (past) dependence.

Persistence in product innovation

Product innovations provide enterprises with a competitive advantage, by introducing a new or

significantly improved product; process innovations reduce unit costs and enhance productivity through changes in techniques, equipment and/or software (Hwang, Hwang, and Dong 2015). New products might help firms gain some market power, which could then facilitate their access to international markets.

Tavassoli and Karlsson (2015) argue that product innovation has a higher degree of persistence than the other types of innovation (process, organizational and marketing), because product innovations are the driving force for the long-run competitiveness of many industries and markets. There are several arguments supporting persistence in product innovation. The first relates to *sunk costs*, which influence investment in R&D in the long term. Because R&D is one of the key determinants of product innovation, continuous, long-run R&D investment leads to continuous product innovation. These sunk costs represent major barriers to entry and exit, because new-entrant firms need to take them into account when deciding on the price; meanwhile incumbent firms, as established R&D performers, will not recover those costs if they stop their R&D activities (Haned, Mothe, and Nguyen-Thi 2014; Triguero and Córcoles 2013).

The second argument is associated with the '*success breeds success*' hypothesis. Namely, if product innovation is successfully introduced in one period, then firms gain market power, which increases the likelihood of future successful innovation. In addition, higher market power reduces the financial constraints that firms face when they engage in product innovation. As the latter is risky and sometimes requires large investment in particular, radical innovations, firms with a record of successful previous innovation will generate the internal funds necessary to finance future innovation (Raymond et al. 2010).

The third potential explanation for the persistence in innovation is *dynamic increasing returns* (Stiglitz 1987) and *the cumulative nature of knowledge* (Crespi and Scellato 2015). Continuously innovating firms benefit from dynamic increasing returns as a result of learning-by-doing and learning-to-learn effects, which increase a firm's knowledge base and technological capabilities (Clausen et al. 2011). These learning effects are not limited to internal knowledge sources in the form of the

knowledge, skills and creativity of a firm's employees, but also include the accumulation of external knowledge through absorptive capacity. These theoretical rationales have found support in most empirical studies (e.g. Esteve-Pérez and Rodríguez 2013; Máñez-Castillejo, Rochina-Barrachina, and Sanchís-Llopis 2009).

In contrast, past dependence suggests that innovation processes are shaped only by the initial conditions and by observed and unobserved heterogeneity; this occurs in the case of *spurious persistence*.¹ Following Crespi and Scellato (2015), past dependence is in line with the resource-based view of the firm, whereby innovation persistence is a result of the intrinsic characteristics of a firm. More specifically, firms benefit from learning effects; but still persistence in innovation is fully shaped by the initial allocation of innovation capabilities.

Based on the above theoretical argument and previous empirical evidence, we hypothesize the following:

H₂: Persistence in product innovation exhibits both true (path) state dependence as well as spurious (past) dependence.

Persistence in process innovation

In relation to process innovation, the literature advances several arguments as to why this type of innovation might show persistence over time. First, as with product innovation, R&D *sunk costs* can be incurred if a new product entails the introduction of process innovation as well. However, in many industries the occurrence of R&D sunk costs is less likely in the case of process innovation than it is for product innovation, because machinery and process equipment are brought from other firms, rather than produced internally. Therefore, process innovation is likely to be less persistent than product innovation (Ganter and Hecker 2013; Hecker and Ganter 2014).

In addition, Clausen et al. (2011) note that the persistence of process innovation is conditional on the industry characteristics, i.e. it often occurs in mature industries, in which the importance of process innovation is reflected in a firm's efforts

to implement more efficient production methods, rather than new products. This source of heterogeneity would suggest a likelihood of *spurious state dependence*. We formulate the following:

H₃: Persistence in process innovation exhibits both true (path) state dependence as well as spurious (past) dependence.

Complementarity between exports and innovation

Firms usually decide on exports and innovation simultaneously (Becker and Egger 2013; Damijan, Kostevc, and Polanec 2010). Following Cassiman and Golovko (2011), product innovation has direct and indirect effects on a firm's decision to enter foreign markets. Direct effects are associated with a firm's decision to start exporting in search of greater demand for its new products or to distribute R&D costs over larger sales volumes (Esteve-Pérez and Rodríguez 2013). Indirect effects stem from the role of innovation as a productivity-enhancing investment, which motivates firms to self-select into export markets (Andersson and Lööf 2009).

In relation to the interdependence between innovation and exports, the *cognitive theory of the firm* (or the competence-based view of the firm) posits that these strategies are *complementary*. The premise of the approach is that firms, as learning organizations, adopt both strategies (innovation and exports) as mechanisms for accumulating knowledge, enhancing their capabilities and contributing to their competitive advantage. The cognitive characteristic of R&D and innovation is first recognized in Cohen and Levinthal (1989), while the same characteristic with respect to exports has only recently been recognized. The knowledge base of a firm is accumulated through exports by: (i) interaction with international competitors, (ii) expansion of the production scale, and (iii) an increase in the competitive pressure that could create incentives for innovation (Esteve-Pérez and Rodríguez 2013).

Most empirical studies exploring the interdependence between technological innovations and exports report their mutual complementarity

¹As noted by Esteve-Pérez and Rodríguez (2013, 221): 'A main challenge in the empirical analysis is to disentangle these two sources of this persistent behaviour.'

(Damijan, Kostevc, and Polanec 2010; Golovko and Valentini 2011; Máñez-Castillejo, Rochina-Barrachina, and Sanchís-Llopis 2009). In addition, Van Beveren and Vandebussche (2010) argue that the introduction of new innovations is endogenous to the export decision of a firm.² Hwang, Hwang, and Dong (2015) find that firms could improve their export performance if they carried out both product and process innovation simultaneously. Moreover, Becker and Egger (2013) confirm the previous results, implying that German firms that perform both process and product innovation have a higher probability of exporting. Their results also show that product innovation is relatively more important for a firm's propensity to export than is process innovation. However, Monreal-Pérez, Aragón-Sánchez, and Sánchez-Marín (2015) find that foreign markets selected those companies that had previously secured product or process innovation, while R&D does not increase exports among Spanish firms. Therefore, the degree of complementarity between product innovation and exports and between process innovation and exports is still an empirical question that we assess in what follows.

H₄: There is a complementary relation between (a) exports and product innovation and (b) exports and process innovation.

Complementarity between product and process innovations

When investigating the persistence of product and process innovation, their complementary nature is one of the crucial factors in identifying different patterns of persistence (Clausen and Pohjola 2013; Martínez-Ros and Labeaga 2009). Complementarity between product and process innovation was first identified by Milgrom and Roberts (1990), who noted that an increase in one innovation activity might lead to an increase in the marginal returns of the other innovation activity. Implementing new products or upgrading existing ones might render process innovation necessary. On the other hand, process innovation might allow firms to enhance the

quality of their existing products or to manufacture new products (Flaig and Stadler 1998).

Most previous empirical evidence supports the theoretical argument associated with the complementary nature of product and process innovation (Antonelli, Crespi, and Scellato 2012; Hecker and Ganter 2014; Máñez-Castillejo, Rochina-Barrachina, and Sanchís-Llopis 2009). In addition, the central finding of Van Beveren and Vandebussche (2010) is the relevance of including potential complementarities between product and process innovation when analysing export propensity. As explained, we reassess the interrelationship between process and product innovation with a new methodology that not only considers contemporaneous effects, but also feedback effects from the past. Thus, we posit the following:

H₅: There is a complementary relation between product and process innovations.

Reverse causality between exports and innovation

The literature on innovation and exports does not provide an unambiguous answer whether innovation causes exports or the opposite causation holds. The first direction of causality, from innovation to exports, is predicted by the product life-cycle theory. A product life-cycle theory suggests that product innovation should be positively associated with firm productivity, thus be indirectly linked to firms' decision on exports. Klepper (1996) argues that product and process innovations play an important role conditional on the stage of the product lifecycle. In early states of the product lifecycle, product innovation has a dominant role, while, in later stages, when produced quantities are higher and efficiency of production becomes important business strategy, process innovation is more pronounced.

The second theoretical perspective encompasses endogenous growth theories (Grossman and Helpman 1991), which suggest that the reverse causality, from exports to innovation, might hold. In these models, innovation is recognized as endogenous. The effect of exports on innovation is demonstrated through three channels: (i)

²In our empirical strategy, we take into account both arguments: (i) the simultaneous engagement in innovation and exports, and (ii) the endogeneity of innovation with respect to exports.

survey in the initial year. Those firms that exit the sample for whatever reason are replaced by newly established firms, using the same sampling procedure as in the initial year (Martínez-Ros and Labeaga 2009).

Our sample is an unbalanced panel covering the period from 2001 to 2014. It excludes the period from 1990 to 2000, because detailed information on innovation activities were first introduced in the 1998 survey (Santamaría, Nieto, and Barge-Gil 2009). The effective sample, after removing missing values, as well as losing observations from the initial period because of the estimation of a dynamic model, has 20,118 observations.

Table 1 shows variable description and descriptive statistics. Slightly less than a fifth (18.9%) of firms introduced product innovation, while a larger number (30.4%) engaged in process innovation. In contrast, two-thirds of firms are exporters. Regarding innovation activities, on average firms invest 0.6% of sales in internal R&D expenditure, and 0.2% in external R&D. More than a fifth of firms have a formal R&D department (21.5%). A modal firm has 64 employees, while the average market share is 8.9%. The average firm has been in existence for 32 years. More than a third (35.7%) of firms are part of an enterprise

group, while on average firms have two R&D personnel. Finally, the average contribution of an employee to value added is €49,125.

Model specification

Dependent variables

Our model includes three binary dependent variables measuring product and process innovations and exports as shown in Table 1.

Independent variables

Our model includes four variables measuring firms' absorptive capacity: (a) *Internal R&D intensity* which is defined as internal R&D expenditures divided by sales in period t ; (b) *External R&D intensity* defined as external R&D expenditures divided by sales in period t (Beers and Zand 2014); (c) *R&D department* equal to 1 if a firm has an R&D department in period t and zero otherwise; and d) *R&D staff* as a number of R&D personnel in period t .

Other firm characteristics controlled in the model are firm size, firm age, labour productivity, belonging to a group and market share. We control for firm size because it may influence how firms engage with innovation activities and

Table 1. Variable description and summary statistics.

Variables	Definition	Mean
Dependent variables		
Product innovation	DV = 1 if a firm introduced product innovation; zero otherwise	0.189
Process innovation	DV = 1 if a firm introduced process innovation; zero otherwise	0.304
Exports	DV = 1 if a firm is an exporter; zero otherwise	0.654
Independent variables		
Internal R&D intensity	Internal R&D expenditure divided by sales in period t	0.006
External R&D intensity	External R&D expenditure divided by sales in period t	0.002 (0.013)
Firm size	Firm size measured as the number of employees in period t	63.944
Market share	Weighted sum of the firm's market share in the markets in which it sells its products; the variable ranges from 0 to 100% in period t	8.900
Firm age	Firm age in period t	32.169
R&D department	DV = 1 if a firm has an R&D department in period t ; 0 otherwise	0.215
Group	DV = 1 if a firm belongs to an enterprise group in period t ; 0 otherwise	0.357 (0.479)
R&D staff	Number of R&D personnel in period t	1.784
Labour productivity	Value added divided by the average number of employees (in thousands of euros) in period t	49.125
High-tech industry	DV = 1 if a firm produces chemicals and pharmaceuticals or computer products, electronics and optical products; 0 otherwise	0.088
Medium high-tech industry	DV = 1 if a firm produces machinery and equipment, electrical materials and accessories, vehicles and accessories, or other transport equipment; 0 otherwise	0.176
Medium low-tech industry	DV = 1 if a firm produces plastic and rubber products, non-metal mineral products, basic metal products, or fabricated metal products; 0 otherwise	0.288
Low-tech industry	DV = 1 if a firm produces meat products; food and tobacco; furniture; textiles and clothing; leather, fur and footwear; timber; paper; printing, or other manufacturing; 0 otherwise	0.448

DV refers to dummy variable.

whether they export or not (Tsinopoulos, Sousa, and Yan 2017). The literature suggests a potential influence of *firm age* on both innovation and exports. With respect to the former, young firms might undertake riskier innovation activities, which entails larger benefits if the risk pays off and the investment is successful. In relation to the latter, the effect of firm age on exports is ambiguous (Love, Roper, and Zhou 2016). While younger firms might lack experience to export into foreign markets, older firms might suffer from inertia and inflexibility which might negatively affect firms' internationalization. To capture the efficiency of production, we include the variable *Labour productivity* measured as the value added divided by the average number of employees in period t (Tsinopoulos, Sousa, and Yan 2017). The variable *Group* is equal to 1 if a firm belongs an enterprise group in period t and zero otherwise. The variable *Market share* captures the effect whereby the failure in financial markets forces firms to rely on their own internal sources of funding, which increase with market share. To account for industry heterogeneity, the model controls for technology intensity by including dummy variables for high-technology industries, medium high-tech, medium low-tech and low-technology industries (as the base category). Finally, the model controls for the effects of time with dummy variables for each year of analysis – being 2002 the base category.

Empirical strategy

Understanding whether the processes of product innovation, process innovation and exports are simultaneously determined requires the estimation of a joint dynamic probit model. Such an empirical strategy should also account for state dependence in each of the processes and feedback effects between processes at the same time as it considers the problem of initial conditions. Feedback effects between processes render them endogenous (Van Beveren and Vandebussche 2010). Thus, we propose the estimation of a first-order Markov chain model, where product innovation (P_{it}) is the first

equation, process innovation (PR_{it}) is the second, and exports (E_{it}) is the third. Klepper (1996) notes that firms introduce product innovations in the early stages of the product life cycle, whereas process innovation is often introduced in the later stages of the cycle. Consequently, firms begin exporting after introducing product innovation (Cassiman and Golovko 2011). This theoretical argument is supported by empirical findings in Becker and Egger (2013) for German firms and Cassiman and Golovko (2011) for Spanish firms. Therefore, our empirical strategy reflects these theoretical and empirical considerations, whereby the first equation has product innovation as the dependent variable.³

We assume that companies can be characterized by a latent product innovation propensity (p_{it}^*), a latent process innovation propensity (pr_{it}^*) and a latent exports propensity (e_{it}^*). Formally,

$$p_{it}^* = \alpha_0 + \alpha_1 PR_{it} + \alpha_2 E_{it} + \alpha_3 P_{it-1} + \alpha_4 PR_{it-1} + \alpha_5 E_{it-1} + \alpha_6 Z'_{it} + a_i + k_{it} \quad (1)$$

$$pr_{it}^* = \beta_0 + \beta_1 E_{it} + \beta_2 P_{it-1} + \beta_3 PR_{it-1} + \beta_4 E_{it-1} + \beta_5 Z'_{it} + b_i + l_{it} \quad (2)$$

$$e_{it}^* = \gamma_0 + \gamma_1 P_{it-1} + \gamma_2 PR_{it-1} + \gamma_3 E_{it-1} + \gamma_4 Z'_{it} + c_i + m_{it} \quad (3)$$

where $i = 1, 2, \dots, N$ is the number of companies in our sample and $t = 1, 2, \dots, T$ is the number of periods. Furthermore, we assume $P_{it} = I(p_{it}^* > 0)$, $PR_{it} = I(pr_{it}^* > 0)$ and $E_{it} = I(e_{it}^* > 0)$ that is, binary indicator functions that are equal to 1 if the latent propensity is positive and 0 otherwise.

Note that α_3 , β_3 and γ_3 capture the degree of true state dependence of each of the processes. For example, α_3 measures the extent to which engaging in product innovation in the past (at $t-1$) increases or decreases the likelihood of current product innovation (at t). We expect these parameters to be positive. In turn, α_4 , α_5 , β_2 , β_4 , γ_1 and γ_2 are the feedback effects. This way, for example, α_4 measures the influence of past process innovation

³However, our results do not depend on this particular decision as our findings sustain when the first equation has process innovation or exports as the dependent variable. All results are available from the authors upon request.

on the probability of current product innovation. Z'_{it} is the vector of independent variables assumed to be exogenous and the corresponding α_6 , β_5 and γ_4 are vectors of parameters to be estimated.

As in the vast majority of similar studies that use longitudinal data, our panel is also affected by the problem of initial conditions. That is, we do not have information on the companies since their creation, but only a limited observational window. In order to account for the problem of initial conditions, we follow the proposal by Wooldridge (2005): we find the density of the dependent variables from $t = 1, 2, \dots, N$ conditional on the initial conditions and the explanatory variables (instead of using the whole period for $t = 0, 1, 2, \dots, N$). Formally,

$$a_i = g_0 + g_1 P_{i0} + g_2 PR_{i0} + g_3 E_{i0} + g_4 \bar{Z}_i + \varepsilon_{1i} \quad (4)$$

$$b_i = h_0 + h_1 P_{i0} + h_2 PR_{i0} + h_3 E_{i0} + h_4 \bar{Z}_i + \varepsilon_{2i} \quad (5)$$

$$c_i = j_0 + j_1 P_{i0} + j_2 PR_{i0} + j_3 E_{i0} + j_4 \bar{Z}_i + \varepsilon_{3i} \quad (6)$$

As shown, the unobserved specific effects are estimated conditional on the dependent variables in the first observed wave ($t = 0$) and the time-average of all time-varying covariates. The inclusion of \bar{Z}_i allows for a certain degree of correlation between the firm-specific random effect and the variables that change over time.

Estimates of the model's parameters are obtained by Conditional Maximum Likelihood using the software package aML. As part of the estimation process, the residuals ε_{1i} , ε_{2i} and ε_{3i} are integrated out using Gauss-Hermite quadrature. Such a strategy allows not only consistent estimates to be obtained, but also three correlations that summarize the association between the unobservable factors that determine product innovation, process innovation and exports. That is,

$$\rho_{12} = \text{corr}(\varepsilon_{1i}, \varepsilon_{2i}) \quad (7)$$

$$\rho_{13} = \text{corr}(\varepsilon_{1i}, \varepsilon_{3i}) \quad (8)$$

$$\rho_{23} = \text{corr}(\varepsilon_{2i}, \varepsilon_{3i}) \quad (9)$$

For example, if ρ_{12} is positive, it means that unobservable factors that make a company more likely

to engage in process innovation also make the same company more likely to engage in product innovation. If ρ_{12} is negative, then those unobservable factors that make a company more likely to engage in process innovation also make the company less likely to pursue product innovation. Managerial abilities, technological opportunities and risk attitudes are often identified as unobserved characteristics at the firm level (Peters 2009). We expect all correlations to be positive.

It is important to note the recursive structure of the model by which process innovation and exports measured in period t enter as explanatory variables in the first equation for product innovation. However, product innovation does not enter as an explanatory variable in the second equation for process innovation. Similarly, note that in the third equation, for exports, neither product innovation nor process innovation enter as an explanatory variable. Such a structure ensures identification, because it provides multiple exclusion restrictions (Mroz and Savage 2006). Finally, the idiosyncratic error terms (k_{it} , l_{it} and m_{it}) are assumed to follow a standard normal distribution with zero mean and unit variance and to be serially independent.

IV. Research findings

Table 2 shows the results from the joint dynamic probit model for the three activities under analysis.

Exports

First we interpret the results in relation to state dependence. In Equation 3, we report a positive and highly significant effect of lagged exports on current export propensity thus confirming true state dependence in exporting. To interpret the magnitude quantitatively, we estimate the Average Partial Effects (APEs) which we report in Table 3. Past export propensity increases the probability of current exporting by 28.9 p.p. In addition, the results suggest that initial condition positively affect current exports, which indicates that spurious dependence is likely to influence current export propensity. Concerning control variables, we find a strong positive effect of firm size on exporting, implying that larger firms are more likely to sell

Table 2. Results from a joint dynamic random effects probit model for product innovation, process innovation and exports.

	Equation 1 Product innovation	Equation 2 Process innovation	Equation 3 Exports
True state dependence			
Product innovation _{t-1}	1.160*** (0.039)		
Process innovation _{t-1}		1.032*** (0.028)	
Exports _{t-1}			1.917*** (0.057)
Feedback effects			
Product innovation _{t-1}		0.138*** (0.041)	0.006 (0.096)
Process innovation _{t-1}	-0.091** (0.037)		0.057 (0.069)
Exports _{t-1}	-0.046 (0.093)	-0.157*** (0.072)	
Current effects			
Process innovation _t	0.786*** (0.037)		
Exports _t	0.219** (0.090)	0.198*** (0.070)	
Initial conditions			
Product innovation _{t0}	0.640*** (0.052)	0.048 (0.044)	0.216* (0.113)
Process innovation _{t0}	-0.073 (0.048)	0.369*** (0.037)	0.080 (0.080)
Exports _{t0}	0.125 (0.093)	0.089 (0.073)	2.194*** (0.142)
Control variables			
Labour productivity _t	0.000 (0.001)	0.001** (0.000)	0.001 (0.001)
Firm size _t	0.210*** (0.069)	0.413*** (0.049)	0.560*** (0.095)
Firm age _t	0.186* (0.100)	-0.024 (0.094)	0.191 (0.224)
R&D staff _t	0.032 (0.034)	0.007 (0.026)	-0.054 (0.079)
Group _t	-0.073 (0.078)	0.015 (0.065)	0.010 (0.159)
Market share _t	0.003* (0.002)	0.001 (0.001)	0.001 (0.002)
R&D department _t	0.581*** (0.052)	0.357*** (0.049)	0.246* (0.146)
Internal R&D intensity _t	0.360 (0.808)	0.641 (0.941)	-0.949 (1.578)
External R&D intensity _t	4.665*** (1.583)	1.226 (1.095)	-0.091 (2.592)
High-tech industry	0.010 (0.070)	-0.098* (0.060)	0.211 (0.156)
Medium high-tech ind.	-0.053 (0.057)	-0.061 (0.044)	0.080 (0.100)
Medium low-tech ind.	-0.144*** (0.051)	-0.059 (0.038)	0.030 (0.076)
Constant	-2.144*** (0.174)	-1.632*** (0.134)	-3.761*** (0.302)
Firm-specific random effects (standard deviation)			
σ _{E1}	0.568*** (0.034)		
σ _{E2}		0.487*** (0.024)	
σ _{E3}			0.978*** (0.064)
Correlations			
ρ ₁₂		0.223*** (0.071)	
ρ ₁₃		0.088 (0.094)	
ρ ₂₃		0.143* (0.082)	
Ln-L		-17,016.89	

Standard errors in parentheses. Year dummies and time-averaged control variables included, but not reported. *** p < 0.01, **p < 0.05, *p < 0.10.

Table 3. Average Partial Effects (APEs) for true state dependence, feedback and current effects.

	Equation 1 Product innovation	Equation 2 Process innovation	Equation 3 Exports
True state dependence			
Product innovation _{t-1}	0.226	-	-
Process innovation _{t-1}	-	0.293	-
Exports _{t-1}	-	-	0.289
Feedback effects			
Product innovation _{t-1}	-	0.033	n.s.
Process innovation _{t-1}	-0.012	-	n.s.
Exports _{t-1}	n.s.	-0.036	-
Current effects			
Process innovation _t	0.125	-	-
Exports _t	0.030	0.046	-

n.s. – not significant at any conventional level.

their products in international markets than are smaller firms. We also find a marginally positive effect of absorptive capacity, proxied by the presence of R&D department. Overall findings with respect to persistence of exports provide support to

H_1 . That is, our results indicate that both true and spurious dependence drive export propensity.

Regarding the influence of product and process innovations on exporting, we find no significant feedback effects, though initial product innovation has a marginally positive effect. Accordingly, our results suggest that past product and process innovations have no effect on current exports and thus do not provide support for H_{6a} .

Product innovation

A positive and highly significant coefficient on the lagged dependent variable on product innovation suggests true state dependence. The probability of current product innovation increases by 22.6 p.p. due to past product innovation. The coefficient on the initial product innovation introduction is also positive (and significant) but is smaller than the coefficient on the lagged dependent variable, thus

indicating that persistence of product innovation is higher for more recent periods of time. Overall, these results provide support for H_2 that product innovation exhibits both path dependence and past dependence. This finding echoes Le Bas and Scellato (2014, 427): ‘Pure past dependence and pure path dependence are exceptional and unusual.’ Finally, a significant initial condition implies a substantial correlation between a firm’s initial status in product innovation and firms’ unobserved characteristics.

Second, concerning the influence of process innovation on product innovation, the current effect is positive (and statistically significant), but the feedback effect is negative. These results imply that while past process innovation has a negative effect on product innovation, its impact becomes positive in period t . That is, current process innovation increases the likelihood of product innovation by 12.5 p.p., while past process innovation reduces the probability of product innovation by only 1.2 p.p. These results establish strong evidence for a contemporaneous interrelationship between both types of innovation.

Finally, in relation to feedback effects, we find no significant effect of past export activities on the probability of product innovation, which indicates that H_{6b} is not supported. However, we do find a positive and significant contemporaneous effect that amounts to 3 p.p. Therefore, the positive impact of export activity on product innovation is simultaneous, rather than driven by the past.

Focusing on control variables, we find a positive effect of firm size and market share on product innovation, thus confirming Schumpeter’s Mark II hypothesis that large firms are more likely to introduce product innovation than are their smaller counterparts (Raymond et al. 2010). We also find a positive and highly significant effect of absorptive capacity, proxied by the existence of an R&D department. In similar fashion, we find that external R&D intensity is positively and significantly associated with product innovation, while internal R&D intensity seems not to affect the probability of product innovation. Finally, our results suggest that firm age has a marginally positive impact on product innovation, thus implying that older firms are more prone to engaging in

product innovation than are their younger counterparts.

Process innovation

A positive and highly significant coefficient of the lagged dependent variable suggests true state dependence. Thus, past process innovation increases the probability of current process innovation by 29.3 p.p. Moreover, the coefficient on the initial process innovation is also positive (and significant) but is smaller than the coefficient on the lagged dependent variable. Consequently, results support H_3 in relation to both true and spurious state dependence.

With regards to the effect of product innovation, its feedback effect has a positive influence on current process innovation. The APE is 0.033, implying that the probability of process innovation increases by 3.3 p.p. in the case of past product innovation. In relation to export activities, we find a negative feedback effect of past export activities, but a positive effect from current exports. The former suggest that H_{6b} is not supported. That is, past export activities reduce the likelihood of process innovation by 3.6 p.p., but current export activities increase the likelihood of process innovation by 4.6 p.p. Following Damijan, Kostevc, and Polanec (2010), this implies that exports may positively influence firm efficiency by facilitating process innovation when firms simultaneously export and engage in process innovation.

Focusing on control variables, we find a positive effect of firm size, absorptive capacity and labour productivity on process innovation. The latter finding suggests that process innovation, which is often associated with cost efficiency, indeed increases when labour productivity rises (probably due to the reduction in production costs).

Unobserved heterogeneity and correlations

The estimated standard deviations of the random effects and their correlations are shown at the bottom of Table 3. Standard deviations for all random effects are highly statistically significant, implying the relevance of modelling firm-specific effects in our analysis of the interrelationships between product and process innovation and

exporting. Unobserved heterogeneity shows persistence in product and process innovation and in exporting, because unobserved firm characteristics which increase the probability of product and process innovation and of exporting exhibit persistence over time.

In relation to the correlation coefficients, our results suggest a strong positive correlation between product and process innovations (ρ_{12} is positive and statistically significant). That is, unobserved factors that affect the probability of product innovation are positively associated with unobservables related to the introduction of process innovation. Hence, product and process innovations are interdependent through both observed and unobserved heterogeneity – providing even stronger evidence of their complementarity and thus supporting H_5 .

However, we find no correlation between unobservable factors related to product innovation and exports (ρ_{13}). Phrased differently, unobserved factors that make firms more likely to introduce product innovation are not associated with unobserved factors that increase the likelihood of exporting. Finally, we find a marginally positive correlation coefficient between process innovation and export activity (ρ_{23}). Accordingly, our results imply that unobserved heterogeneity that increases the likelihood of process innovation also marginally increases the likelihood of export participation. These results provide a weak partial support for H_4 , that is, (a) no complementarity between exports and product innovation but (b) weak complementarity between exports and process innovation.

As noted above, the estimated correlation coefficients also show the relevance of estimating the three equations jointly. Although the correlation coefficient between product innovation and export activity is not statistically significant, we do find a strong correlation between product and process innovations, and a marginally strong correlation between process innovation and export activity. Thus, our results hint at the importance of estimating all three processes jointly, but not as strongly as we might expect.⁴

V. Discussion and concluding remarks

Our study investigates the persistence and interdependence of exports and technological innovations, each of which is relevant for firms' productivity, growth and competitiveness. We find that exports and technological innovations are characterized by both path and past dependence. Hence, not only that all activities exhibit true state dependence, but also initial conditions and observed and unobserved firm characteristics that are persistent over time have a significant effect on these strategies.

Concerning the magnitude of true state dependence, our results indicate that exports and process innovation are the two activities that show stronger persistence. These results would suggest that sunk costs are of similar magnitude for process innovation and exports but are lower for product innovation (Esteve-Pérez and Rodríguez 2013).

Our second objective was to explore the interdependence between technological innovation and exports. Here the results are mixed. As in most previous studies, we find a strong complementarity between product and process innovation. Indeed, these innovation activities are related, particularly through a contemporaneous effect and through unobserved firm characteristics. With respect to the interdependence between technological innovation and exports, our results suggest a weak correlation in unobserved firm characteristics between process innovation and exports, but no correlation between unobservables related to product innovation and exports. These results imply that the *cognitive view of the firm* is supported in the association between product and process innovation, but not between either type of technological innovation and exports.

Concerning current effects, we find a positive and significant influence of exports on product innovation. Therefore, although exporting might not be correlated with product innovation through unobserved heterogeneity, nevertheless the current export decision is positively associated with the introduction of product innovation. In addition, we find no feedback effects of exports on current product innovation.

⁴Separate regressions overestimate state dependence and the feedback effects. Thus, our preferred model yields more conservative results and does not overestimate relationships that may not necessarily exist. These results are available from the authors upon request.

A similar pattern is found for process innovation and exports. While the current effect of exports on process innovation is positive and significant, the feedback effect is negative, i.e. past export participation reduces the probability of process innovation. Therefore, current export market participation increases the likelihood of process innovation, because firms reap higher returns to process innovation from current export participation, but lower returns from past exports.

Regarding managerial implications, our findings suggest that complementarity between product and process innovation enhances firms' knowledge accumulation and capabilities, that is, while technological innovations exhibit cognitive characteristics, it is less likely that complementarity exists between innovation and exports. Current export market participation increases the probability of both product and process innovations, but we find no such effect from the past export participation. Therefore, although all three activities exhibit true persistence, managers should not expect that past exporting activities have a contemporaneous effect on technological innovation, but rather continue to export on a regular basis if they wish to repeat the benefits of technological innovations.

Our results also provide some policy implications. Because we find evidence of true state dependence, current policy effects in promoting technological innovation and exports have not only contemporaneous effects, but a rather long-lasting influence on the decisions of firms to innovate and export. In other words, true state dependence in technical innovation and exports implies intertemporal spillovers relevant to the evaluation of innovation and export policy measures (Peters 2009; Tavassoli and Karlsson 2015). However, besides true state dependence, we also find a significant spurious dependence in all three activities, suggesting that policy makers should also focus on firm-specific factors in promoting technological innovations and exports in Spanish firms. Another recommendation is concerned with a joint provision of trade and innovation policies. Given contemporaneous effects between technological innovations and exports, policy makers might consider coordinating policy support for exports and innovation.

This study has certain limitations that could be addressed in future research. First, our study encompasses one economy. Thus, comparison with other countries – in particular, those at a similar level of innovation performance – is not possible. The availability of longitudinal data provides an opportunity for future investigations into the persistence and interdependence of innovation and exports in other European countries, and for comparison of country-specific results. Second, we do not distinguish between industries based on their technology intensity, and our sample does not include the service sector. Some empirical evidence points to heterogeneous effects on the persistence of product and process innovation, depending on the technology intensity of industries (Clausen et al. 2011). Moreover, future research might explore the issues of persistence and cross-dependence of innovation and exports in the service sector.

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References

- Andersson, M., and H. Löf. 2009. "Learning-By-Exporting Revisited: The Role of Intensity and Persistence." *Scandinavian Journal of Economics* 111 (4): 893–916.
- Añón Higón, D., and N. Driffield. 2010. "Exporting and Innovation Performance: Analysis of the Annual Small Business Survey in the UK." *International Small Business Journal* 29 (1): 4–24.
- Antonelli, C., F. Crespi, and G. Scellato. 2012. "Inside Innovation Persistence: New Evidence from Italian Micro-Data." *Structural Change and Economic Dynamics* 23 (4): 341–353.
- Aw, B. Y., M. J. Roberts, and T. Winston. 2007. "Export Market Participation, Investments in R&D and Worker Training, and the Evolution of Firm Productivity." *World Economy* 30 (1): 83–104.

- Becker, S. O., and P. H. Egger. 2013. "Endogenous Product versus Process Innovation and a Firm's Propensity to Export." *Empirical Economics* 44: 329–354.
- Beers, V. C., and F. Zand. 2014. "R&D Cooperation, Partner Diversity, and Innovation Performance: An Empirical Analysis." *Journal of Product Innovation Management* 31 (2): 292–312.
- Bernard, A. B., and J. B. Jensen. 2004. "Why Some Firms Export." *Review of Economics and Statistics* 86: 561–569.
- Casillas, J. C., A. M. Moreno, and F. J. Acedo. 2012. "Path Dependence View of Export Behaviour: A Relationship between Static Patterns and Dynamic Configurations." *International Business Review* 21 (3): 465–479.
- Cassiman, B., and E. Golovko. 2011. "Innovation and Internationalization through Exports." *Journal of International Business Studies* 42 (1): 56–75.
- Clausen, T., and M. Pohjola. 2013. "Persistence of Product Innovation: Comparing Breakthrough and Incremental Product Innovation." *Technology Analysis and Strategic Management* 25 (4): 369–385.
- Clausen, T., M. Pohjola, K. Sapprasert, and B. Verspagen. 2011. "Innovation Strategies as a Source of Persistent Innovation." *Industrial and Corporate Change* 21 (3): 553–585.
- Cohen, W. M., and D. Levinthal. 1989. "Innovation and Learning: Two Faces of R&D." *Economic Journal* 99 (397): 569–596.
- Crespi, F., and G. Scellato. 2015. "Knowledge Cumulability and Path Dependence in Innovation Persistence." In *Routledge Handbook of the Economics of Knowledge*, edited by C. Antonelli and A. Link, 116–134. New York: Routledge.
- Damijan, J. P., C. Kostevc, and S. Polanec. 2010. "From Innovation to Exporting or Vice Versa?" *World Economy* 33 (3): 374–398.
- Das, S., M. J. Roberts, and J. R. Tybout. 2007. "Market Entry Costs, Producer Heterogeneity, and Export Dynamics." *Econometrica* 75: 837–873.
- Esteve-Pérez, S., and D. Rodríguez. 2013. "The Dynamics of Exports and R&D in SMEs." *Small Business Economics* 41 (1): 219–240.
- Filipescu, D. A., S. Prashantham, A. Rialp, and J. Rialp. 2013. "Technological Innovation and Exports: Unpacking Their Reciprocal Causality." *Journal of International Marketing* 21 (1): 23–38.
- Flaig, G., and M. Stadler. 1998. "On the Dynamics of Product and Process Innovations: A Bivariate Random Effects Probit Model." *Jahrbücher für Nationalökonomie und Statistik* 217: 401–417.
- Ganter, A., and A. Hecker. 2013. "Persistence of Innovation: Discriminating between Types of Innovation and Sources of State Dependence." *Research Policy* 42: 1431–1445.
- Golovko, E., and G. Valentini. 2011. "Exploring the Complementarity between Innovation and Export for SMEs' Growth." *Journal of International Business Studies* 42 (3): 362–380.
- Grossman, G. M., and E. Helpman. 1991. "Quality Ladders in the Theory of Growth." *Review of Economic Studies* 58: 43–61.
- Haned, N., C. Mothe, and T. U. Nguyen-Thi. 2014. "Firm Persistence in Technological Innovation: The Relevance of Organizational Innovation." *Economics of Innovation and New Technology* 23 (5–6): 490–516.
- Hecker, A., and A. Ganter. 2014. "Path and past Dependence of Firm Innovation." *Economics of Innovation and New Technology* 23 (5–6): 563–583.
- Hutzschenreuter, T., T. Pedersen, and H. W. Volberda. 2007. "The Role of Path Dependency and Managerial Intentionality: A Perspective on International Business Research." *Journal of International Business Studies* 38 (7): 1055–1068.
- Hwang, Y.-S., M.-H. Hwang, and X. Dong. 2015. "The Relationships among Firm Size, Innovation Type and Export Performance with Regards to Time Spans." *Emerging Markets Finance and Trade* 51 (5): 947–962.
- Klepper, S. 1996. "Entry, Exit, Growth, and Innovation over the Product Life Cycle." *American Economic Review* 86: 562–583.
- Le Bas, C., and G. Scellato. 2014. "Firm Innovation Persistence: A Fresh Look at the Frameworks of Analysis." *Economics of Innovation and New Technology* 23 (5–6): 423–446.
- Lewandowska, M. S., M. Szymura-Tyc, and T. Golebiowski. 2016. "Innovation Complementarity, Cooperation Partners and New Product Export: Evidence from Poland." *Journal of Business Research* 69 (9): 3673–3681.
- Love, J. H., S. Roper, and Y. Zhou. 2016. "Experience, Age and Exporting Performance in UK SMEs." *International Business Review* 25 (4): 806–819.
- Máñez-Castillejo, J. A., M. E. Rochina-Barrachina, and J. A. Sanchís-Llopis. 2008. "Sunk Cost Hysteresis in Spanish Manufacturing Exports." *Review of World Economics* 144 (2): 272–294.
- Máñez-Castillejo, J. A., M. E. Rochina-Barrachina, and J. A. Sanchís-Llopis. 2009. "Self-Selection into Exports: Productivity And/Or Innovation?" *Applied Economics Quarterly* 55: 219–241.
- Martínez-Ros, E., and J. M. Labeaga. 2009. "Product and Process Innovation: Persistence and Complementarities." *European Management Review* 6 (1): 64–75.
- Melitz, M. J. 2003. "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity." *Econometrica* 71 (6): 1695–1725.
- Milgrom, P., and J. Roberts. 1990. "The Economics of Modern Manufacturing: Technology, Strategy and Organization." *American Economic Review* 80 (3): 511–528.
- Monreal-Pérez, J., A. Aragón-Sánchez, and G. Sánchez-Marín. 2015. "Do Export Markets Select the Most Innovative Producers? the Moderating Role of Productivity." *International Journal of Innovation Management* 19 (2): 1550030.
- Mroz, T. A., and T. H. Savage. 2006. "The Long-Term Effects of Youth Unemployment." *Journal of Human Resources* XLI: 259–293.

- Peters, B. 2009. "Persistence of Innovation: Stylized Facts and Panel Data Evidence." *Journal of Technology Transfer* 34 (2): 226–243.
- Raymond, W., P. Mohnen, F. Palm, and S. S. Van Der Loeff. 2010. "Persistence of Innovation in Dutch Manufacturing: Is It Spurious?" *Review of Economics and Statistics* 92 (3): 495–504.
- Santamaría, L., M. J. Nieto, and A. Barge-Gil. 2009. "Beyond Formal R&D: Taking Advantage of Other Sources of Innovation in Low- and Medium-Technology Industries." *Research Policy* 38 (3): 507–517.
- Stiglitz, J. 1987. "Learning to Learn, Localized Learning and Technological Progress." In *Economic Policy and Technological Performance*, edited by P. Dasgupta and P. Stoneman, 125–153. Cambridge: Cambridge University Press.
- Tavassoli, S., and C. Karlsson. 2015. "Persistence of Various Types of Innovation Analyzed and Explained." *Research Policy* 44 (10): 1887–1901.
- Teece, D. J., G. Pisano, and A. Shuen. 1997. "Dynamic Capabilities and Strategic Management." *Strategic Management Journal* 18 (7): 509–533.
- Triguero, A., and D. Córcoles. 2013. "Understanding Innovation: An Analysis of Persistence for Spanish Manufacturing Firms." *Research Policy* 42 (2): 340–352.
- Tsinopoulos, C., C. M. P. Sousa, and J. Yan. 2017. "Process Innovation: Open Innovation and the Moderating Role of the Motivation to Achieve Legitimacy." *Journal of Product Innovation Management* 35 (1): 27–48.
- Van Beveren, I., and H. Vandenbussche. 2010. "Product and Process Innovation and Firms' Decision to Export." *Journal of Economic Policy Reform* 13 (1): 3–24.
- Wooldridge, J. M. 2005. "Simple Solutions to the Initial Conditions Problem in Dynamic, Nonlinear Panel Data Models with Unobserved Heterogeneity." *Journal of Applied Econometrics* 20 (1): 39–54.