Competitive pressure determinants and innovation at the firm level

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ABSTRACT

This paper provides empirical evidence on the relationship between indicators of competitive pressure and innovation incentives faced by firms using panel data of Spanish manufacturing firms. The dataset we use is drawn from the ESEE (Survey of Business Strategies) for the period 1990-2006. This Survey is an annual survey that is representative of Spanish manufacturing firms classified by industrial sectors and size categories. It provides exhaustive information at the firm level on a number of production and market issues, including information on innovation activities. The sampling procedure of the ESEE is the following. Firms with less than 10 employees were excluded from the survey. Firms with 10 to 200 employees were randomly sampled, holding around 5% of the population in the base year, 1990. All firms with more than 200 employees were requested to participate, obtaining a participation rate equal to around 70% in 1990. Since then, important efforts have been made to minimise attrition and to annually incorporate new firms with the same sampling criteria as in the base year, so that the sample of firms remains representative of the Spanish manufacturing sector over time. In our empirical analysis, instead of using the standard indicators of product market competition, such as market concentration measures or firms' price cost margins, we use a number of indicators of competitive pressure (usually called the fundamentals of competitive pressure), directly related to the demand and cost conditions faced by firms. In particular, we consider that in a free entry context, enhanced competitive pressure may be captured by an increase in the degree of product substitutability, in the size of the market or in the ease of entry (a decrease in entry costs). Regarding innovation, we consider the likely different incentives to undertake product innovation *versus* process innovation efforts, and estimate a multivariate probit model for the probability of firms to introduce product innovations, process innovations or both. Our results give empirical support to the theoretical predictions of Vives (2008) for free entry. We obtain that product market substitutability, entry costs and market size significantly affect the probability to introduce product and process innovations but in a different way, that is, the effect of these determinants of competitive pressure differs among these two types of innovations. We also find different effects of enhanced competitive pressure on innovation when taking into account the efficiency level of the firm relative to the efficiency distribution within its industry.

Keywords: competitive pressure, cost-reduction, process innovations, demand-enhancing, product innovations, relative efficiency.

JEL Classification: D22, L10, L60, O31.

1. INTRODUCTION

The analysis of the effects of market competition on the innovative activity has received a good deal of attention by the economic literature, and yet, the issue is far from closed. Theoretical models are ambiguous in several ways about the effect of competitive pressure on firms' incentives to innovate. Also existing empirical studies provide diverse and often conflicting results, predicting that market competition may have either a negative or a positive effect on innovation.

The theoretical studies of competition and innovation go back to the work of Schumpeter (1943), who early related the innovative activity to market structure. Schumpeter's seminal work argued that firms with greater monopoly power have a greater incentive to innovate because they can better appropriate the returns of their R&D investment. Since then, many papers provide arguments about the negative effect of competition on this activity. Among them, Salop (1977) and Dixit and Stiglitz (1977), within the leading industrial organization models of product differentiation and monopolistic competition, deliver the prediction that more intense product market competition discourages innovation by reducing the post entry rents. Also, Gilbert and Newbery (1982), in a model of patent races, find that firms have more incentives to invest in R&D with less competition because they could still enjoy duopolistic profits in case of losing the race.

In contrast to the Schumpeterian thesis, a number of authors have stressed that competition may affect positively to the innovative activity: increased product market competition may increase the incremental profits from innovating and thus encourage firms' R&D investments. This is the so-called *escape competition* effect. This line of argument was postulated by Arrow (1962) in a context of perfect protection of the innovators' property rights. Also Porter (1990) argued that monopoly discourages innovation because firms do not need to innovate to stay in business.

According to the early theoretical contribution of Schumpeter and his followers, the first empirical models, using cross section data, found a negative relationship between competition and innovation.[1] The exception to these works was Scherer (1967), who, also using cross section analysis of firms' data, found evidence of an inverted-U shaped relationship between

[1] See Cohen and Levin (1989) for a discussion of this earlier literature.

competition and innovation. However, later empirical works on this topic, based most frequently on the estimation of linear specifications, achieve the general finding that innovation should increase with competition. In the nineties, for instance, the studies by Geroski (1995), Nickell (1996) and Blundell, Griffith and Van Reenen (1999), found this positive relationship. Consistent with Scherer's (1967) results, Aghion *et al.* (2005) present a theoretical model explaining the inverted-U shape relationship between competition and innovation, and provide empirical support for it using UK manufacturing data and using the Lerner Index (the price-cost margin, PCM hereafter) as main indicator of product market competition. Recently, a number of papers have also found empirical support for this inverted-U shape (see, for instance, Tingvall and Poldahl, 2006, for Sweden, or Kilponen and Santavirta, 2007, for Finland). However, differently to Aghion *et al.* (2005), Tishler and Milstein's (2009) model predicts a convex (U-shape) relationship between competition and innovation in oligopoly markets.

The standard measures in the empirical industrial organization literature to proxy for product market competition have been concentration measures, such as concentration ratios or the Hirshman-Herfinhdal index, firms' market shares or PCMs (see, e.g., Blundell *et al.*, 1995, Blundell *et al.*, 1999, Nickell, 1996 and Aghion *et al.*, 2005). The use of such measures of market competition has been a widely accepted practice in empirical work, in spite of their drawbacks from a theoretical point of view, as early stressed by authors as, e.g., Tirole (1988). In fact, these drawbacks may be one of the reasons behind the contradictory results obtained when analyzing the empirical relationship between competition and innovation. For example, Dasgupta and Stiglitz (1980) show that high degrees of concentration are not evidence of lack of effective competition. In relation to innovation, Scott (1984, 1993) shows that, once industry and firm effects and proxies for technology opportunities are controlled for, the effect of seller concentration on innovation becomes statistically insignificant. This result is confirmed by Levin *et al.* (1985).

Recently, new contributions to this literature have insisted on reconsidering the use of the standard indicators of product market competition in empirical work (see, e.g., Boone, 2000, Boone *et al.*, 2007, Boone, 2008, or Vives, 2008). In fact, the theoretical literature on competition and innovation considers that there are a number of parameters (also called the fundamentals of competition) capturing the competitive pressure faced by firms, which affect the degree of market competition in an unambiguous way. The degree of product substitutability or the easy of entry into the market are examples of these fundamentals: competition intensifies when goods become close substitutes (firms market power is reduced as consumers simply chose the cheapest product) and lower entry costs rise competition by increasing the number of firms into the market. Therefore, in order to approximate the degree of product market competition faced by firms these parameters should be properly captured.

However, given that most of the surveys for empirical analysis suffer from a lack of information about these fundamentals of competition, it has been standard in the empirical literature the use of concentration and/or PCM as measures of competition. A fall in concentration or PCM has been empirically interpreted as an increase in competition. Nonetheless, enhanced competition may have different effects on market structure depending on the source of the rise in competition. Boone (2000) argues that, with asymmetric firms' cost efficiency levels, there is not a simple relation between product market competition and market structure. The problem when using concentration measures as indicators of competition is that, in some circumstances, concentration may raise as a consequence of the most inefficient firms exiting the market as competitive pressure intensifies (an effect known as the *selection effect* - see, e.g., Boone, 2000, and Boone *et al.*, 2007). In addition, enhanced competition may raise the market shares of the most efficient firms at the expense of the inefficient ones, implying an increase in the Herfindahl index (the *reallocation effect,* - Boone, 2000, and Boone *et al.*, 2007). If the PCM is taken as indicator of competition, it may be the case that enhanced competition due to a more aggressive conduct by firms raises the market share of efficient firms, leading to an increase in the average PCM at the industry level. In this case, an increase in the PCM should not be interpreted as an indicator of lower market competition (Boone *et al.*, 2007). Conversely, if less competitive pressure leads to higher costs due to X-inefficiency, or lack of cost reducing innovations, the PCM will decrease.

According to Vives (2008), among others, the Lerner index or the level of concentration (and firms' R&D expenditures) should be considered as endogenous variables determined by the fundamentals of market competition. Following this author, in a free entry context enhanced competitive pressure may be captured by an increase in the degree of product substitutability, in the size of the market or in the ease of entry (a decrease in entry costs). Regarding the central question on whether enhanced competitive pressure fosters innovation, he distinguishes between the incentives to invest in process innovation (reducing variable costs of production) from the incentives to invest in product innovation (product introduction). The work of Vives (2008) is particularly interesting for the aim of this paper because of two main reasons. First, from the theoretical point of view, Vives' model of innovation and competitive pressure provides a general framework with robust results on the effects of several indicators of competitive pressure on innovation, reconciling theory with empirical results. Secondly, Vives derives specific implications for the empirical work. In the author's own words: "*Empirical analysis should consider carefully whether innovation is process or product, whether entry is restricted or not, and include as much as possible of exogenous determinants or instruments like market size, entry costs, or product substitutability variables as well as controlling for technological opportunity*" (Vives, 2008, p. 445).

The aim of this paper is therefore to contribute to the empirical evidence on the relationship between indicators of competitive pressure and innovation incentives at the firm level. In order to do so, we essentially follow the empirical recommendations of Vives' (2008), although our work does not attempt to be a comprehensive test of Vives' theoretical predictions. In particular, our empirical analysis is mainly based on the parameters/fundamentals of competitive pressure theoretically justified by Vives (2008) in a context of free entry. We use for this purpose a representative panel sample of Spanish manufacturing firms (the ESEE hereafter) for the period 1990-2006. As a first step, we perform linear regressions of the PCM measure on our set of determinants of competitive pressure, with the aim of investigating to what extent PCM is a valid measure of product market competition for empirical work, in line with the discussion above. Then, we estimate a *multivariate probit model* that allows distinguishing between the different factors affecting firms' decisions to introduce product and process innovations, focusing on the idea that the competitive pressure faced by firms affects these two decisions in a different way. We include in our estimations an extensive number of measures and indicators capturing different aspects of the competitive pressure faced by firms, such as product substitutability, market size, entry costs and technological opportunity.

In addition to Vives' predictions (as detailed in the next section of this paper), in our empirical approach we also acknowledge the predictions of a number of theoretical papers that have stressed the importance of taking into account firms' efficiency asymmetries when trying to disentangle the complex relationship between product market competition and innovation (e.g. Boone, 2000, and Aghion and Schankerman, 2004). For this purpose, we also estimate our multivariate model considering each firm's efficiency level relative to its industry's efficiency distribution. In particular, we consider if our competitive pressure variables exert a different effect on product or process innovation depending on how distant a firm's efficiency level is from that of the most efficient firm within its industry.

To our knowledge, the empirical literature that has tried to capture the relationship between innovation and competition using competitive pressure indicators capturing the fundamentals of competition is still very scarce. One exception is the work of Tang (2006), who, using a cross section data of Canadian firms for 1999, argues that firms' perceptions about their competitive environment are important drivers of innovation and better measures of firm-specific competition than the traditional ones. However, the work of Tang is not particularly linked to a theoretical model or prediction and is based on a more limited set of variables than our empirical model. As for the case of Spain, Artés (2009) has used data from the same survey than us to estimate the relationship between competition and innovation. However, Artés (2009) uses the traditional measures of competition that have been criticized by the recent literature (such as concentration ratios, PCM, firms' market share or the number of competitors in the market) to analyse the decision on whether to conduct R&D or not as differentiated from the choice on how much to invest in R&D. He finds that market concentration and other measures of monopoly power have a significant effect on the *yes/no* decision, but his results are not conclusive regarding the amount of investment in R&D.

To anticipate our main results, we obtain that product market substitutability, entry costs and market size significantly affect the probability to introduce product and process innovations but that the effect of these determinants of competitive pressure differ between these two types of innovations. Our results are consistent with the predictions of Vives (2008) for free entry. In addition, we find that the efficiency level of firms, in relation to the efficiency distribution within their industry, affects the relationship between competitive pressure and product and process innovation, as suggested by authors as Boone (2000).

Our findings are particularly important in at least two fronts. First, our results indicate that using traditional measures of market power, such as PCM, can be misleading when trying to infer the effect of competitive pressure on innovation incentives and, in particular, that a careful look at the fundamentals of competitive pressure can shed more light on the inconclusive results of the literature on competition and innovation. Secondly, our paper evidences the differential effects of competitive pressure determinants either on product or process innovation and, additionally, the different effect according to firms' efficiency levels with respect to their industry distribution. Thus, our results highlight the importance of distinguishing in the analysis the different sources of competitive pressure in the market. From these fronts we can infer some implications for research, competition policy and business strategy: empirical research on this area should take into account that results obtained without distinguishing between product and process innovations can be misleading; policy makers should consider the potential different effect of competition enhancing policies (like deregulation or trade liberalization) not only on firms' incentives to introduce process and product innovation but also on different firms according to their relative levels of efficiency; finally, from a business strategy point of view, firms' managers may be interested in acknowledging how changes in competitive pressure affect the incentives to innovate depending on the firms' position in the industries' efficiency distribution, a result that might even be used to improve their positioning in this distribution.

The rest of the paper is organized as follows. Section 2 presents an overview of the general framework which supports theoretically our empirical work. Section 3 explains the data, variables and econometric model we have used. Section 4 presents the main estimation results and, finally, section 5 concludes.

2. GENERAL FRAMEWORK

Without being our unique point of reference, the main general theoretical framework for our empirical analysis about competition and innovation relies on Vives (2008). Differently to other theoretical work in this area, which has relied on particular functional specifications for market structure and competition mode, Vives (2008) provides general results about the effects of competition on innovation that are robust to more general specifications. Additionally, with his work he tries to reconcile, within this literature, some theoretical results with the empirical evidence, not only at the industry level but also at the firm level. In doing so, he aims at providing a framework for the empirical work relating competitive pressure to innovation. However, he does not provide empirical evidence for his predictions, and this is the main purpose in our paper.

As argued by Vives (2008), firms' innovation incentives are not homogeneous and enhanced competitive pressure is likely to have a differential effect on process and product innovations. Therefore, both theoretical and empirical analysis should distinguish between product and process innovation incentives. Whereas product innovations are mainly a demand enhancing devise, process innovations are mainly cost reducing investments and, thus, the key drivers of both types of innovations are likely to differ (see, e.g., Boone, 2000, and Vives, 2008). Therefore, changes in competitive pressure may have differentiated effects on product and process innovations whenever they affect differently to firms' incentives for demand creation or cost reduction efforts. For instance, given that the rewards from unit costs reductions increase with the firm's output, any change in competitive pressure increasing per-firm output creates incentives for cost reduction expenditures and, therefore, for process innovation. In addition, changes in competitive pressure reducing the difference between the ex-post expected profits of a new product and the fixed cost of its introduction, will affect negatively the incentives for product innovation.

Endogenising market structure (what Vives considers a free entry market), Vives (2008) points to the following parameters (that he consider as fundamental variables) to measure an enhancement in competitive pressure: an increase in the degree of product substitutability (an increase in the easiness for consumers to switch among producers), an increase in the size of the market, and an increase in the ease of entry (i.e. a decrease in entry costs) for a new firm and/or a new product variety in the market. According to his general model, the empirical analysis should include as many as possible of these fundamentals that determine in an unambiguous direction the degree of competitive pressure, as well as controlling for technological opportunities. As Vives also notices, standard variables like PCM, market concentration measures, or even R&D expenditure per firm, may be explained by these fundamentals, although some of them may have an ambiguous relationship with competitive pressure.

According to Vives' (2008) model, the main three theoretical predictions, when endogenising market structure, about the parameters driving competitive pressure and their effects on product/process innovation are as follows:

> *Prediction 1*: An increase in product substitutability entails an increase in competitive pressure. It increases firms' incentives to cost reduction expenditures and, therefore, process innovation. It decreases firms' incentives for product innovation.

When firms' products are close substitutes for consumers, firms have little market power, since consumers simply buy the cheapest product. An increase in product substitutability increases firms' demand elasticity, implying that if a firm invests in cost reduction (process innovation) it could reduce prices and have a greater impact on its sales (because of the increase in the residual demand of the firm). Therefore, higher product substitutability creates incentives for process innovation. On the other hand, as firms differentiate their product, consumer preferences for a particular product or brand loyalty allow firms to raise their prices without loosing business to other firms. Thus, lower product substitutability may be considered as lower competitive pressure that increases profits to be captured by the introduction of a product innovation (a Schumpeterian argument also mentioned in Boone, 2000).

In our empirical specification, we consider that both advertising expenditures (*advertising-to-sales ratio)* and firms' promotional activities *(product promotion, branding, firm's image promotion, sales agreements, etc.)* may be used by firms to differentiate their product and, hence, to reduce product substitutability, lowering the intensity of competition (Syverson, 2004).

> *Prediction 2*: An increase in market size entails an increase in competitive pressure. It increases firms' incentives to cost reduction expenditures and, therefore, process innovation. It has an ambiguous effect on product innovation.

In industry equilibrium models under imperfect competition, an increase in market size increases the number of firms in the market and, therefore, enhances competitive pressure. However, a standard result in theoretical models of imperfect competition is that market expansion increases the number of firms in the market proportionally less than the increase in market size (see, e.g., Sutton, 1991) and, thus, rises per firm output and the incentives to cost reduction efforts (process innovation). By contrast, an increase in market size has two opposite effects on product innovation incentives. On the one hand, a larger market has a profitability-enhancing effect on product innovation (it creates "economic opportunities" for product innovation). On the other hand, it can also have a negative effect on product innovation when it increases so much the firms' effort on cost reduction and, therefore, the degree of rivalry (competition) that the expected rents from the product introduction decreases, discouraging product innovation.

In our empirical specification, we use three variables to proxy for market size. The first variable indicates the geographic size and scope of the main market served by the firm (whether it is national and international, or international only, as compared to local, regional or national only). The second one measures the firm's export intensity, and the third one indicates if the firm is facing an expansive market.

> *Prediction 3*: An increase in the ease of entry (i.e. a reduction in entry costs) for a new firm and/or a new product variety in the market entails an increase in competitive pressure. It decreases the incentives to do cost reduction efforts per variety, which is process innovation. It increases the incentives to do product innovation.

An increase in the ease of entry of new firms or new varieties into the market means enhanced competitive pressure, since competition becomes fiercer as more firms or more varieties compete in the market. The intuition behind ease of entry decreasing the incentives for process innovation is as follows. Lowering entry costs increases the number of firms in an industry by promoting entry, which implies less per-firm output and, therefore, lower incentives to undertake cost reduction efforts, that is, to introduce process innovation. However, lower fixed costs to introduce a new product increases the likelihood of firms' expected profits from the new product to be higher than the fixed cost of introducing it, increasing the incentives for product innovation.

In our empirical specification we consider two measures of entry costs (or entry barriers). On the one hand, we construct a measure of *set-up* costs following Sutton (1991), which is closely related to costs of entering and establishing a new firm within an industry. This entry barrier to the industry is expected to be more important in the case of process innovations, since it prevents the entry of new firms. On the other hand, we also introduce a variable that accounts for the speed of *obsolescence* of products as an indicator of the "costs of introducing a new product". In fact, authors as Wörter *et al.* (2010) relate slow product obsolescence to high fixed costs of introducing a new product. The idea behind this argument is that slow product obsolescence proxies for the existence of high fixed costs of introducing a new product in the market, since the firms' willingness to assume such high fixed costs is only compatible with markets where products survive for a considerable length of time. In addition, if product obsolescence is high, it may affect negatively to process innovation, since rapid product obsolescence discourages changes in the production process because it implies that the product is likely to be modified in the near future (Tang, 2006).

Besides Vives' (2008) list of parameters to be included in estimation, we also consider other variables that have been suggested in the literature and which may also shape firms' competitive pressure. These variables are *capacity utilization by competitors* and the threat of *arrival to the market of equivalent or very similar products*. Higher capacity utilization by competitors means fewer possibilities for them to react in output and, therefore, less competitive pressure for the firm. Regarding process innovation, if a firm' competitors are producing at high capacity levels, the incentives for cost reduction increase since the derived efficiency gains can be better exploited increasing the output of the firm, given that competitors cannot increase their output supply in the market. In terms of the theoretical models of market competition this would be interpreted as a decrease in the *conjectural variation* (the belief of a firm about how its opponents will react to a change in its own output level), which produces a more aggressive firm behaviour in terms of output (Boone, 2008) and, hence, a higher incentive to introduce process innovations.[2]

The arrival of firm's equivalent products into the market, either national or imported, raises competitive pressure. Tang (2006) uses the constant arrival of competing products as a measure of product market competition that creates a constant threat and promotes product innovation. According to Boone (2007), equivalent imported products will create a tougher competitive regime for domestic firms. Also in this line, Vives (2008) refers to import penetration as an exogenous determinant of market structure and competition, and Nickell (1996) and Blundell *et al.* (1999), among others, use the degree of imports penetration at the industry level as a measure of market competition.

Finally, we also acknowledge in our empirical approach that the firms' efficiency level relative to their industry's efficiency distribution may be an important determinant of the effect of enhanced competitive pressure on firms' incentives to undertake product and process innovations. A number of theoretical papers based on firms' cost asymmetries have predicted differential effects of enhanced product market competition on firms' incentives to undertake innovations. Boone (2000) and Aghion and Schankerman (2004), for instance, predict that the incentives to invest in cost reduction (process innovations) and entry (product innovations) differ for low and high cost firms.

Regarding process innovations, enhanced competitive pressure increases the incentives for process innovation in the case of firms with intermediate efficiency levels. This is explained by an *adaptation effect* of competitive pressure: firms adapt to enhanced competitive pressure by raising their productivity (Porter, 1990, Nickell, 1996, Boone, 2000, and Boone *et al.*,

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[2] Higher capacity utilization by competitors can also be taken as an indicator of stronger capacity constraints in the industry, which is likely to be associated with markets with more competition over quantities (Kreps and Scheinkman, 1983). In turn, markets competing over quantities are inherently less competitive than markets with competition over prices (Vives, 1985; Singh and Vives, 1984). The main predictions in Vives (2008) are independent of the competition mode (Cournot or Bertrand), although this topic has received considerable attention in the competition-innovation literature (see, for example, Bonanno and Haworth, 1998, or Milliou and Petrakis, 2010).

2007). Additionally, a *selection effect* of competitive pressure (Boone, 2000, and Boone *et al.*, 2007) eliminates relatively inefficient firms from the market, so that intermediate efficient firms are forced to adapt and to improve their efficiency. However, for the most efficient and the inefficient firms enhanced competitive pressure reduces their incentives for process innovations to improve efficiency. Inefficient firms know that even if they do a big effort in cost reduction the probability to survive is low. The most efficient ones know that even without doing too much effort they will survive. The intermediate efficient firms know that with enhanced competition, if they improve enough their efficiency, they have a chance to survive. Therefore, an increase in competitive pressure raises their incentives to do process innovations.

In the case of product innovations, enhanced competitive pressure raises the incentives of the most efficient firms to introduce product innovations because this rise in competitive pressure enables them to better exploit their cost advantage. In the case of the less efficient firms the argument goes in the opposite direction. This can be intuitively explained, following Boone (2000), by the Schumpeterian argument of monopoly power: as competitive pressure increases, the monopoly power and profit levels of inefficient firms are reduced and this discourages firms to undertake product innovations.

Thus, from the above discussion, we find interesting at the empirical level to analyse the effect of competitive pressure on the incentives to innovate taking into account the relative efficiency levels of firms within each industry. To the best of our knowledge, there is a lack of empirical evidence on this issue probably due to the difficulty in capturing the notion of competitive pressure at the level of the individual firm, on the one hand, and the difficulty in measuring firm's heterogeneity (asymmetry) in cost efficiency, on the other hand. The only empirical evidence we are aware of is the paper by Lee (2009). However, he does not distinguish between product and process innovation and, furthermore, instead of considering firms' asymmetries in terms of cost efficiency (as the theoretical models of Boone, 2000, 2001, suggest), relies on a measure of what he calls the firm's level of technological competence or capability relative to the world technological leader in its field. In this paper we also attempt to fill in this gap by using a cost efficiency measure which is in line with the theoretical literature.

3. DATA AND ESTIMATION ISSUES

3.1. Data and variables

The data used in this paper are drawn from the ESEE for the period 1990-2006. This is an annual survey sponsored by the Spanish Ministry of Industry and carried out since 1990 that is representative of Spanish manufacturing firms classified by industrial sectors and size categories.[3]

The ESEE provides exhaustive information at the firm level on a number of issues, including information on innovation and competitive pressure. The information on innovation includes two direct measures of innovation outcomes, such as whether or not the firm has introduced product and/or process innovations in a given year.

The particular question related to product innovations included in the ESEE is as follows: "*Indicate if during year t the firm obtained product innovations (either completely new products or with so important modifications that they are different to those produced in the past)*". For process innovations, the particular question in the survey is: "*Indicate if during year t the firm introduced some important modification of the productive process (process innovation)*". These two innovation output indicators are binary variables. For instance, the product innovation indicator equals one if the firm introduced a product innovation in year t and zero otherwise.

Table 1 reports the percentage of innovative firms in our sample. For the whole period, 66.4% of firms do not introduce any innovation, 8.6% introduce only product innovations, 15.1% introduce only process innovations and, finally, 10.0% introduce both product and process innovations. If we calculate percentages restricted to the subgroup of firms that are innovators (either of only product, only process, or both), the percentages are as follows: 25.5% of firms introduce only product innovations, 45.0% of firms introduce only process innovations, and 29.5% of firms report both types of innovations. Information about the year 1990 is not reported since the first year for

[3] The sampling procedure of the ESEE is the following. Firms with less than 10 employees were excluded from the survey. Firms with 10 to 200 employees were randomly sampled, holding around 5% of the population in 1990. All firms with more than 200 employees were requested to participate, obtaining a participation rate of about 70% in 1990. Important efforts have been made to minimise attrition and to annually incorporate new firms with the same sampling criteria as in the base year, so that the sample of firms remains representative of the Spanish manufacturing sector over time. See http://www.funep.es/esee/ing/i_esee.asp for further details.

estimation will be 1991, given that all the explanatory variables will be lagged one period in estimation. The reason for this is twofold: first, to avoid potential simultaneity problems, as it is standard in this type of models and, second, because firm/market characteristics should be observable to firms when taking their decisions in period *t* for period *t+1* and, therefore, its real effect is lagged.

[Insert Table 1 about here]

Regarding competitive pressure variables, as explained before, instead of using the standard measures of competition, such as the PCM or concentration ratios, we use a number of variables considered by theoretical models as the fundamentals driving market competition for firms in industries with endogenous market structure (see, for instance, Vives, 2008). These variables are the degree of product substitutability, the size of the market, the entry costs (which are either determined by set-up costs for a new firm to enter an industry, or the fixed costs for a firm to introduce a new product into the market) and, finally, other variables related to competitive pressure such as the capacity utilization by competitors and the price pressure from the arrival of competing products.[4]

Table 2 reports the correlation coefficients among all the variables we use to measure firms' competitive pressure. The main results in this Table are as follows. First, the product substitutability variables (*PS* in the Table) are mainly positively correlated (with the exception of *image promotion*, what could indicate that this activity is not complementary but substitutive with respect to *advertising, product promotion* or *branding*). Secondly, the three variables to proxy for market size (*MS* in the Table) are positively correlated among them and also with the *PS* variables. Thirdly, the two variables for entry costs (*EC* in the Table) are, as expected, positively correlated, because both of them indicate barriers to entry. The same reason explains why they correlate with identical signs with the other variables in the Table (in general, negative correlation with *PS*, positive with *MS*, and negative with the capacity utilization by competitors and price pressure from the arrival of competing products, what are named *OM* in the Table). Finally, the *OM* variables in the Table are

[4] The definition and the measurement procedure of the variables is presented in Appendix A.

negatively correlated among them. From this group, the *capacity utilization by competitors* is negatively correlated with the PS variables, what could suggest that when competitors are less able to react in output the firm has lower incentives to differentiate its product, and also negatively correlated with the other groups of variables. As regards the variables capturing price pressure from the arrival of competing products, they are negatively correlated between them because either firms' answer yes to one or to the other on average, but the two of them have the same correlation signs with the rest of the variables (in general, positive correlation with *MS*, negative correlation with entry costs, and mainly positive correlation with *PS*, with the exceptions of image promotion and after sales services).

[Insert Table 2 about here]

In summary, Table 2 shows in general quite low correlation among the variables measuring different aspects of competitive pressure. This suggests that our competitive pressure variables are probably capturing different aspects of competition and, therefore, they should be included simultaneously in the regressions to better capture the overall effect of competitive pressure on firms' innovation output.

We also present in Table 3 some descriptive statistics for the variables involved in estimation, differentiating among four categories of innovative firms. The justification for this is as follows. First, in a given period *t*, a particular firm may introduce none, one of the two innovation outputs or the two of them simultaneously. Second, and more importantly, there are relevant arguments in the theoretical literature analysing the effects of competition on innovation activities to separately identify these effects for product or process innovations, respectively (see sections 1 and 2). Therefore, in the estimation section we are going to be mainly interested in differentiating these effects between *only product innovation* firms and *only process innovation* firms.

[Insert Table 3 about here]

Finally, regarding the sample used for estimation, and conditioning to firms reporting information on all the variables involved, we end up with a sample of 18,735 observations, corresponding to an unbalanced panel of 2,688 firms.

3.2. Modelling and estimation

As pointed out above, in any given period a particular firm may introduce only product innovations, only process innovations, both types of innovations, or none of them. Therefore, our innovation outcome variables determine four categories of firms according to their innovation status in a given period *t*. We consider it would not be correct to estimate independently a model for each non-zero category versus undertaking none of product and process innovation (our reference innovation status group of firms, the zero-category). First, this will exclude from each one of the estimated equations, the sample of firms corresponding to the other non-zero categories different to the particular one under study. Second, the estimated probabilities of all firms' innovation statuses will not necessarily sum to unity when the model for each non-zero category is estimated independently. To avoid these problems, Tang (2006) estimates the probabilities of the non-zero categories (by reference to category zero) simultaneously with a *multinomial logit* model. In this paper we estimate a multivariate discrete choice model, but, differently to Tang (2006), our general modelling is a *multivariate probit* that avoids the typical assumption of independence of irrelevant alternatives of a *multinomial logit* model, which implies that the error terms of the different alternatives are uncorrelated.

The *multivariate probit* model we estimate in this paper is specified as follows:

$$y_{it}^{InnovStatus} = \begin{cases} 1 & if \quad \mu_t + \beta_{CompPress}^{InnovStatus} CP_{it} + \beta_{Controls}^{InnovStatus} C_{it} + \varepsilon_{it}^{InnovStatus} \geq 0 \\ 0 & otherwise, \end{cases} \tag{1}$$

where the firm innovation status in a given period (only product, only process, both or none, as defined in appendix A) depends on firm/market characteristics (CP_{it} and C_{it}), macro conditions (μ_t), and noise (ε_{it}). In our empirical application, the vector CP_{it} includes the variables measuring competitive pressure, the vector C_{it} includes control variables, and time dummies are included to control for macro conditions.

In model (1), we acknowledge the potential interdependence between the error terms of the three equations (because the status of no innovation is treated as the reference category). Taking this into account leads us to the estimation of a *multivariate probit* model allowing for the $\varepsilon_{it}^{InnovStatus}$'s of the three estimated innovation statuses (only product, only process, or both) to be freely correlated among them, and being able to estimate these correlations. The assumed distribution among the error terms is a *multivariate standard normal*.

We estimate our multivariate probit model using the *mvprobit* Stata program developed by Cappellari and Jenkins (2003).[5] This program uses simulated maximum likelihood techniques to solve the computational problem of evaluating multi-dimensional integrals.[6] In addition to including the possible correlations between the errors, the program allows implementing a pseudo simulated maximum likelihood estimator by adjusting the estimates of the parameter covariance matrix to account for arbitrary correlations between all panel observations of a given firm (see Huber, 1967, and White, 1982).

4. ESTIMATION RESULTS

The main econometric results of our analysis are shown in Tables 4 to 7 in this section. As a first step of our econometric procedure we perform linear regressions of the PCM variable on our measures of product substitutability, market size, entry costs and other competitive pressure variables and controls. These regressions are aimed at investigating to what extent the PCM is a valid measure of product market competition for empirical work. Any indicator of competition should either increase or decrease in an unambiguous way in response to more intense competition fundamentals. If an increase in competitive pressure (in the form of higher product substitutability or a fall in entry barriers, for instance) increases firms' PCM, the empirical work can not use firms' PCM as a measure of competition and, thus, cannot interpret its effect on innovation as a competition effect.

[5] This program may be obtained either at SSC public domain software archive (http://fmwww.bc.edu/RePEc/bocode/m) or inside Stata, typing 'ssc install mvprobit'.
[6] In particular, it uses the Geweke-Hajivassiliou-Keane simulator to replace multivariate standard normal probability distribution functions by their simulated counterparts, see Hajivassiliou and Ruud (1994) and Gourieroux and Monfort (1996).

[Insert Table 4 about here]

We have estimated two specifications. The first one assumes equal effect of the variables for all firms in our dataset (results reported in the first column of Table 4). The second one takes into account each firm's efficiency level relative to its industry's efficiency distribution (we use the 2-digit NACE classification, and the results are reported in the last three columns of Table 4). To take into account these relative efficiency levels we interact our competitive pressure variables with dummy variables indicating how distant is the efficiency level of the firm from that of the most efficient one within its industry (the one with the highest total factor productivity, TFP, hereafter). These dummy variables are constructed on the basis of a variable measuring within industry firms' efficiency distance to the technological frontier, which ranges from 0 (for the most efficient firm) to 1 (for the most inefficient firm). Details on the construction of this variable and of firms' TFP are given in Appendices A and B, respectively. According to this measure, firms have been defined as *efficient* if they are at most 35 % distant from the most efficient firm in their industry, as *medium-efficient* if they are between 35% and 65% distant from the most efficient firm, and as *inefficient* if they are 65% or more distant from the most efficient firm. For the sake of a parsimonious regression, control variables are not interacted with these dummies and, thus, there is only one set of estimated control variables parameters in Table 4 for this second specification.

Our interest lies on whether those variables capturing more intense competitive pressure have an unambiguous negative effect on the firm' PCM. A first group of variables in Table 4 are those that proxy for product substitutability. Given the way they are constructed (see Appendix A), an increase in these variables implies lower product substitutability and, hence, less competitive pressure. The expected sign of the estimated effects of these variables on the PCM is then positive. If we look at the group of variables that proxy for product substitutability, we observe that *product promotion, branding* and *sales agreements* exhibit significant and positive estimated coefficients in the regression corresponding to the whole sample of firms. However, the results are more ambiguous when we interact these variables with the dummy indicators of efficiency distance. In this case both positive and negative signs coefficients are obtained. This would indicate that firms' PCM may be affected by an increase in competition in a different manner depending both on the indicator of competitive pressure used and on the relative position of the firm in its industry's efficiency distribution. For medium-efficient and inefficient firms, the negative and significant sign of the effect of *after-sales services* indicates that less competitive pressure, as proxied by this variable, lowers firms' PCM. The effect, as shown in Table 4, is stronger in the case of the less efficient firms. The intuition could be that low efficient firms may use *after-sales services* to compensate for their low competitiveness in the product market. As Boone (2007, 2008) stresses, conditional on price, if a firm's costs increase over time, its PCM tends to go down, without meaning an increase in competitive pressure. This intuition is also supported by the results we present below for our *multinomial probit* estimation of product and process innovation.

The following set of variables in our analysis is that related to market size. Theoretically, an increase in market size entails an increase in competitive pressure (as explained in section 2) and, therefore, we expect a negative effect on the PCM. However, in this case we also observe different results depending on the efficiency level of firms and the variable considered. On the one hand, an *expansive market* increases unambiguously firms' PCM, a result which holds regardless of the type of firm we consider. On the other hand, the *main firm's market being national and abroad or only abroad* (as compared to local, regional, or only national) seems to exert a negative effect on the firms' PCM, although it is only significant for the group of medium-efficient firms. Finally, the *exports-to-sales* ratio seems to be negatively related to efficient firms' PCM, whereas the effect is positive for the whole sample of firms. The positive effect also appears in the case of the inefficient firms, although in this case the data does not allow us to reject the hypothesis of the coefficient being equal to zero. Since the export markets are usually associated to a higher degree of competitive pressure, the negative effect on efficient firms' PCM is thus as expected. These results can be supported by the fact that it can be the case that there are differences in difficulty and competition levels in the export markets served by more or less efficient firms, being efficient firms relatively more orientated to more difficult and highly competitive markets. This idea is supported by Mayer and Ottaviano (2007) and, for the case of Spain, by Máñez-Castillejo *et al.* (2010).

We analyse now the relationship between entry costs and PCM. Theoretically, the relationship between these two variables is unambiguous: if competition is intensified because weak entry barriers let more firms/products into the market, firms' PCM should fall. In our analysis, we use two variables as indicators of entry barriers (see Appendix A for details): the *set-up costs* measure of Sutton (1991) and a dummy variable indicating *slow product obsolescence*, which captures barriers to the introduction of new products (by incumbent firms or by new entrants into the market). Higher *set-up costs* and *slow product obsolescence* imply higher barriers of entry and then lower competitive pressure, which should be associated with higher PCM. Therefore, the expected sign of the effect of these two variables on firms' PCM is positive. However, the estimation results in Table 4 show negative estimated signs both for the *set-up costs* measure (significant for medium and inefficient firms) and for *slow product obsolescence* (significant for all firms together and for inefficient firms), indicating that firms' PCM may not reflect properly the changes in firms' competitive pressure.

Finally, we discuss about other competitive pressure variables used in our analysis such as the degree of *capacity utilization by competitors* and *product price changes due to new products or competitors in the market*. As higher *capacity utilization by competitors* means less competitive pressure, we expect a positive effect of this variable on firms' PCM. Differently, *product price changes due to new products or competitors in the market* is expected to have a negative effect, since it is related to more competitive pressure. However, the estimated effect for these variables are contrary to what we expected, that is negative for the *capacity utilization by competitors* (although only significant for medium-efficient and inefficient firms) and positive and significant for *product price changes due to new products or competitors in the market* in the case of all firms together. Thus, again in these cases the degree of competitive pressure, measured either as capacity utilization by competitors or the arrival of competing products, is not captured by the PCM variable in the expected direction.

In summary, the results in Table 4 support the critical line of arguments that has arisen in the recent literature on competition and innovation and, in particular, the idea that the PCM may be a misleading indicator of competition in empirical analysis: a higher PCM is commonly interpreted as associated with lower market competition when, in fact, it could be the result of a higher competitive pressure. Moreover, as Boone (2000) has pointed out, with asymmetric firms (firms with different efficiency levels within the industry) there is no simple relation between competition and market structure, which suggests the use of more direct measures of competitive pressure, such as those related to fundamental market demand and cost conditions.

[Insert Table 5 about here]

We turn now to the results on the effect of competitive pressure variables on innovation incentives. Table 5 reports our results for the *multivariate probit* model that estimates three equations: the first equation estimates the probability of firms' obtaining product innovations only; the second one estimates the probability of firms' obtaining process innovations only; and, the third one estimates the probability of firms' obtaining both product and process innovations. We focus on the estimates for *only product innovators* and for *only process innovators*, given that results for the category of *both* can reflect a mixture of predictions from the theoretical literature. All equations include the same set of variables, including time dummies and other controls.

As explained in the previous section, the multivariate probit model allows for correlation among the errors of the three equations, being these correlations estimated and reported at the bottom of Table 5. The estimated correlation coefficients are statistically significant, indicating that the standard multinomial logit assumption of independent equation errors would not have been valid.

A first important result is the unambiguous positive effect of our (low) product substitutability variables on product innovation. This result is robust to the several variables used in the analysis since all estimated coefficients are statistically significant and positive, indicating that the lower the degree of product substitutability (lower competitive pressure) the higher the incentives to introduce product innovations. These results are consistent with *Prediction 1* in section 2: in the case of product innovation, future returns are the main driver of innovation efforts. If a firm perceives that its clients can easily substitute its product by those of their competitors, then the future profit of innovation becomes uncertain. Thus, lower product substitution (higher values of our variables) has an *enhancing-profit* effect promoting product innovation.

Regarding process innovation we obtain that five out of six estimated coefficients of the measures of product substitutability have negative signs, although they only render statistical significance in two cases (*sales agreements* and *after-sales services*). These negative signs are also consistent with *Prediction 1*: product substitutability increases demand elasticity, what means that by investing in cost reduction expenditures (process innovation) the firm may reduce prices and enjoy a greater impact on its sales. However, *firm's image promotion* seems to have a positive impact on process innovation incentives. While *advertisement-to-sales ratio*, *product promotion* and *branding* may reduce product substitutability through product differentiation (real or perceived by consumers), *firm's image promotion* may be a competition device for those firms which do not base their market strategy on product differentiation. In fact, as already stated in the previous section, in our data image promotion is negatively correlated to product promotion, branding and advertisement, indicating that these strategies are not complementary but substitutive. Thus, our results point out that although, in principle, activities of image promotion by firms could be considered as an indicator of product differentiation reducing product substitutability (see, for example, Syverson 2004) it may be the case that, once such activities as product promotion, branding activities or advertisement are controlled for in estimation, this variable is capturing a different firm competition strategy in the market. For instance, a firm that relies on its image as a competition tool may be interested in introducing process innovations that allow the firm to be perceived by consumers as a different type of firm. Examples are those firms interested in capturing consumers environmentally concerned, or consumers interested in the security aspects of the firms' production process, etc.

Regarding market size variables, they seem to have a positive impact on innovation incentives. In the case of product innovation, the two variables indicating the geographic scope of the market and the firm's export intensity are positive and statistically significant, thus indicating that the profitability-enhancing effect of a larger market overcomes the possible discouraging effect of a higher degree of rivalry. Although *Prediction 2* (derived from Vives, 2008) states that an increase in market size has an ambiguous effect on product innovation because of the action of the two previous effects, he notices that it is more likely an increase in product innovation since the profitability-enhancing effect (a "direct" effect) is likely to dominate the rivalry effect (an "indirect" one). This result suggests that firms' internationalization and market globalization is an important stimulus for product innovation.

For process innovation, however, the relevant variable is that which accounts for the fact that the market is expanding. An expansive market means that, even if there is an increase in the number of firms, per firm output increases since the increase in the number of firms is less than proportional to the increase in market size (see, e.g., Salop, 1979, Sutton, 1991, and Vives, 2008). This result is consistent with *Prediction 2* and is reinforced by the estimated effect of *firm size* (variable included as a control in the estimation), which has a positive and significant effect on process innovation (in line with Cohen and Klepper, 1996).

Turning to our measures of entry barriers, *set-up costs* and *slow product obsolescence*, the results obtained are consistent with *Prediction 3*: lowering entry costs raises the incentives for product innovations but decreases the incentives for process innovations. For product innovations, both indicators of entry barriers have a negative and significant effect on product innovation: on the one hand, as *set-up costs* increase, the number of new firms and products entering the market go down and, on the other hand, *slow product obsolescence* also discourages the introduction of new products. In the equation for process innovation only the *set-up cost* coefficient is statistically significant and positive, the intuition being that the higher the entry cost in an industry, the lower the number of firms and thus the higher the output per firm and, hence, the higher the incentives for process innovation.

The last indicators of competitive pressure are those related to *capacity utilization by competitors*, *product price changes due to changes in prices of equivalent imported products* and *product price changes due to new products or competitors in the market*. On the one hand, the last two indicators have a positive and significant effect on firms' incentives to introduce product innovations (probably as a strategy to avoid higher competitive pressure from similar products), although they do not seem to exert any significant effect on process innovations. These results are consistent with the widespread idea that product market competition promotes product innovation (Nickell, 1996, and Blundell *et al.*, 1999), and are also in line with the empirical results in

Tang (2006). On the other hand, the positive and significant effect of an increase in the degree of *capacity utilization by competitors* in process innovation agrees with the argument already stated in section 2: the lower the capacity of competitors for reacting with their output supply, the more able is the firm to exploit the profits from a cost-reduction (process innovation) by increasing its level of output.

Finally, among the variables used as controls in the multivariate probit, we find particularly interesting the estimated effects of *firm size* (measured as *log* of real sales), which exhibit significant effects both in product and process innovation but with opposite signs: negative for product innovations and positive for process innovations. This result indicates that larger firms are more prone to invest in process innovations, a finding supported by authors such as Scherer (1991) or Cohen and Klepper (1996).

[Insert Table 6 about here]

In Table 6 we present the results following the model specification of Table 5 but for the case in which the multivariate probit model takes into account each firm's efficiency level relative to its industry's efficiency distribution. As explained for Table 4, the competitive pressure variables have been interacted with the corresponding dummy variables indicating whether the firm is efficient, medium-efficient or inefficient. Control variables are included in the model assuming equal coefficients for all types of firms.

The predictions in Boone (2000) about the differential effects of competitive pressure on innovation incentives according to firms' relative efficiency can be summarized as follows (see also section 2). For product innovation, enhanced competitive pressure increases firms' incentives in the case of efficient firms but decreases them in the case of inefficient ones. For process innovation his model predicts that an increase in competitive pressure reduces process innovation incentives both for efficient and inefficient firms, but increases them for medium efficient firms.

So far, we have analysed (following Vives' theoretical framework) how firms' incentives to product and process innovation respond to a change in competitive pressure depending on the source that drives the change in each case. As already established in section 2, competitive pressure in a market may increase as a result either from an increase in the degree of product substitutability, in market size or a decrease in entry barriers. Thus, according to Boone's predictions, an increase in these variables will imply higher incentives to product innovation if the firm has a high level of relative efficiency but lower incentives to this type of innovation if the firm is an inefficient one. As regards process innovation, an increase in the degree of product substitutability, in market size or a decrease in entry barriers will induce higher incentives in the case of medium-efficient firms, but it will reduce process innovation incentives if firms are either very efficient or very inefficient firms. Regarding product substitutability, the results in Table 6 for product innovations are in line with results in Table 5 and, thus, generally consistent with Vives (2008) predictions: a decrease in product substitutability, which entails a decrease in competition, increases product innovation. The positive and significant sign of the variables capturing product substitutability are robust to our efficiency levels classification in most of the cases but we can observe that the magnitude of the effects seem to be clearly stronger for inefficient firms in accordance with Boone (2000) predictions for product innovation.

For process innovation incentives, Vives (2008) prediction points out to a negative coefficient for the variables proxying for less product substitutability, a result that is in line with Boone's predictions for the case of medium efficient firms. Looking at the results in Table 6 for process innovation we observe that, in fact, this result is unambiguous only in the case of medium efficient firms, since they are the only ones that exhibit negative signs for all those cases whenever the coefficients are statistically significant (*advertisement to sales ratio* and *sales agreements*). This result for medium efficient firms is explained in Boone (2000) by the *adaptation* and the *selection effects* of competitive pressure: enhanced competitive pressure eliminates relatively inefficient firms from the market, forcing medium efficient firms to adapt and to improve their efficiency levels (process innovation). However, in the case of efficient and inefficient firms, our results are inconclusive regarding product substitutability variables.

If we turn now to the results for the market size variables, they are mostly in line with Vives (2008): larger market size, which entails an increase in competition, increases the incentives for product and process innovation. In the case of product innovation, the geographic scope of the market *(main market being national & abroad*) exerts a positive and significant effect on product innovation, being much more marked the higher the efficiency level of firms. This result can be interpreted in terms of Boone's prediction of higher impact of competitive pressure on product innovation in the case of efficient firms, and follows the intuition that efficient firms are better prepared to take advantage of the economic opportunities offered by a larger market.

Regarding process innovation, we find that the variable capturing that the firm is facing an *expansive market* has a positive and significant effect on process innovation for the three efficiency levels considered, but its effect is larger the lower the efficiency level. This finding seems to be pointing out that, regardless of the size of the market, firms encounter higher incentives to perform process innovation when the market is expanding. This effect is stronger for inefficient firms, maybe because they have lower pre-innovation profits (Aghion *et al.* 2005) and the expectation of a larger residual demand increases the perceived marginal profit derived from process innovation.

The estimated effects of entry costs in product and process innovation are in line with Vives (2008) predictions but only partly consistent with Boone predictions. In the case of product innovation, the effect of *slow product obsolescence* is significant and negative, and also stronger the lower the efficiency level of the firm and, therefore, contrary to Boone's prediction. Regarding process innovation our results are in line with Boone (2000): the effect of *set-up cost*s for process innovation is only significant for efficient and inefficient firms. This result is stronger for inefficient firms, what could be indicating that the protective effect of entry barriers is more relevant for this type of firms, which cannot easily cope with high entry barriers (as argued by e.g. Melitz, 2003).

Finally, other measure of competitive pressure such as *product price changes due to new products or competitors in the marke*t has a stronger effect on product innovation the higher the efficiency level of the firm. For process innovation, this variable exerts a negative and significant effect for the group of inefficient firms, supporting Boone's predictions. Regarding the variable *capacity utilization by competitors*, we obtain a significant and positive coefficient in the case of inefficient firms for product innovation, also in line with Boone (2000) prediction.

In summary, the results reported in Table 6 are consistent with the results in Table 5, but also give support to the differentiated effect of changes in competitive pressure on the incentives to innovate when the relative efficiency level of firms is taken into account, as suggested by the literature. In particular, our results are partly consistent with Boone (2000), and suggest that further research is needed in order to disentangle the role of firms' relative efficiency in encouraging product and process innovations.

[Insert Table 7 about here]

In Table 7 we present the results of two robustness checks we have carried out with our data. First, we have estimated our multivariate model controlling for firms' R&D (real) expenditure. This robustness check aims at disentangling whether our general results in Table 5 are affected by an omitted variables bias due to the potential correlation between some of our competitive pressure variables and firms' R&D investments. In fact, there is a considerable amount of empirical literature that associates R&D with innovation outputs and competition with R&D efforts. Thus, it could be argued that our results in Table 5 might not hold when firms' R&D investment is controlled for. The results obtained in this case are reported in the first three columns of Table 7. The results controlling for R&D expenditure are similar to the results in Table 5. In fact, there are only three minor differences affecting the product innovation equation. The first is the estimated coefficient of the *exports-to-sales ratio*, which in Table 5 was positive and significant at the 10% level and now is positive but not statistically significant. The second is the estimated coefficient of the *expansive-market* variable, which in Table 5 was negative and insignificant (although the associated *p*-value was slightly above 10%) and now it is negative and significant at the 10% level. The third is the estimated coefficient for *set-up costs* that in Table 5 was negative and significant at the 10% level and now is negative but non significant (although the associated *p*-value is not too further above 10%).

Secondly, to further control for the possible simultaneity between our innovation outcome measures (product or process innovation) and our explanatory variables (that could also bias our results),[7] we have run our econometric model taking 4-year averages of our explanatory variables to explain product or process innovations in the following year (the first year

[7] Notice that we have already controlled for this, at least partially, in our benchmark estimation, given that, as stated in section 3, all the explanatory variables are lagged one period.

after the 4-year period). For each of the initial dummy variables, we have defined a dummy variable taking value 1 for the category more frequently repeated during the 4-year period (the mode), ruling out cases with ties. The model also includes the R&D expenditure variable as in the previous robustness check. These results are displayed in the last three columns of Table 7. We observe that in most of the cases the coefficients keep their signs, their values are close to the ones in Table 5, but lose their statistical significance (the problem of losing statistical significance is more severe for the product innovation equation).[8]

5. CONCLUDING REMARKS.

In this paper we have provided new empirical evidence on the effects of a number of indicators of the competitive pressure faced by firms on their incentives to introduce product and process innovations. Our analysis is based on the recent strand of the literature stressing that traditional measures of competition, such as concentration ratios or PCM, may not capture properly the extent of firms' competitive pressure. We have used instead a number of indicators considered by the theoretical literature as the fundamentals of market structure, that is, indicators directly related to the fundamental demand and cost conditions faced by firms, such as product market substitutability, entry costs and market size, which are supposed to have an unambiguous relation to product market competition.

We have used a panel data set of Spanish manufacturing firms for the period 1990-2006, which is representative of Spanish manufacturing at the industry and size level. With this data and as a first step, we have estimated the effect of a number of measures of competitive pressure on firms' PCM, with the aim of showing how this measure does not unambiguously reflect the

[8] Our approach under this robustness check implies using in estimation only the waves after each 4-year group and, accordingly, discards many waves in estimation. While the full estimation sample when including R&D expenditures corresponds to 18,625 observations, our approach for this robustness check uses only 3,947 observations (see the bottom of Table 7). This important reduction in sample size could be behind the loss in significance level for the affected parameters, although its sign and value remains close to the estimates with the full sample. The loss of significance of some parameters is more severe for the product innovation equation, because as it can be seen in Table 1, only 8.6% of firms' observations correspond to the introduction of only product innovations, while 15.1% introduce only process innovations.

changes in competition induced by the changes in the fundamental variables. We have then estimated a multivariate probit model for the probability of firms to introduce product innovations, process innovations or both. Our econometric results indicate that measures of product substitutability, entry costs and market size, significantly affect the probability to introduce product and process innovations, but that the effect of these variables differs among the type of innovation introduced by firms. These results turn out to be consistent with the empirical predictions of Vives (2008) for industries under free entry (where market structure is endogenous). In particular, our results have shown, in line with Vives (2008), that product and process innovations are driven by different fundamentals of competitive pressure, and that changes in these fundamentals will affect each type of innovation in a different way. On one hand, the incentives for product innovations are determined by those fundamentals related to future returns from this type of innovation. Thus, for instance, higher product substitutability and/or lower costs associated to the introduction of a new product may be considered as enhanced competitive pressure that, by raising potential profits, encourage firms to introduce product innovations. On the other hand, the incentives for process innovations are driven by those fundamentals affecting the possibility to raise firms' output, given that a higher output per firm allows the firm to better exploit the cost reduction associated with a process innovation. Thus, in this case those fundamentals of competitive pressure affecting process innovation are those related to a larger market size and the possibility for the firm to appropriate a higher proportion of this market, such as whether the market is expansive, the use of firm's image promotion activities or a higher level of capacity utilization by competitors.

Regarding policy implications, this paper has stressed that product market competition may be captured by different indicators of competitive pressure. In addition, it has pointed out the complexity of the relationship between competition and innovation, augmented once we introduce in the analysis the distinction, according to the theoretical models of competition and innovation, between product and process innovation incentives. Recognizing these factors should be important for policy makers trying to promote innovation through measures affecting competition, as they can evaluate the different effects of acting through different competitive pressure variables on different types of innovations (either product or process innovations may be affected, and sometimes in opposite directions). Competition authorities and regulators should also be cautious about using traditional measures of competition, such as concentration and price cost margins, as measures of competition intensity on a particular industry. Further, our results have provided evidence on the importance of taking into account firms' heterogeneity in terms of efficiency when analysing the effects of competitive pressure variables on firms' incentives to introduce product and process innovations, in line with works such as Boone (2000).

APPENDIX A

Variables definition

Innovation output measures	
Process innovations only	Dummy variable taking value 1 if the firm has implemented process innovations but not product innovations, 0 otherwise.
Product innovations only	Dummy variable taking value 1 if the firm has implemented product innovations but not process innovations, 0 otherwise.
Both product and process innovations	Dummy variable taking value 1 if the firm has implemented both process and product innovations, 0 otherwise.
Product substitutability variables	
Advertisement-to-sales ratio	Advertisement expenditure normalized by sales (in %).
Product promotion	Dummy variable taking value 1 if the firm declares to perform product promotion activities.
Branding	Dummy variable taking value 1 if the firm declares to perform brand promotion activities.
Firm's image promotion	Dummy variable taking value 1 if the firm declares to perform firm's image promotion. The excluded reference category in estimation is no promotion at all.
Sales agreements with wholesalers or retailers	Dummy variable taking value 1 if the firm declares to perform agreements with wholesalers or retailers. The excluded reference category in estimation is no such agreements (either because of no agreements with them or because the firm does not sell to wholesalers or retailers).
After-sales services	Dummy variable taking value 1 if the firm declares to perform after-sales services to clients.
Market size variables	
Expansive market	Dummy variable taking value 1 if the firm declares to face an expansive market in relation to a non expansive market.
Main market is national & abroad, or only abroad	Dummy variable taking value 1 whenever the firm exports, and 0 otherwise.
Exports-to-sales ratio	Value of exports normalized by sales (in %).
Entry costs	
Set-up costs	We follow the method in Sutton (1991) for measuring set-up costs (sunk entry costs). They are measured as the output share of an industry's median-size firm multiplied by the capital-output ratio for the industry as a whole. The former part of the product is considered in Sutton (1991) as a measure for the firm's minimum efficient scale. Therefore, the total measure for set-up costs is a proxy for the amount of capital (relative to the industry's total market size) required to build such a firm. The same proxy for set-up costs is also used in Syverson (2004). See Appendix B for the used measures of firms' output and firms' capital stock in our paper.
Slow product obsolescence	Dummy variable taking value 1 if the firm declares that the type of products sold in the industry change with a frequency of more than one year, irregularly or no change, against the reference category of the type of products changing more than once in a year.
Other competitive pressure variables	
Product price changes due to changes in prices of equivalent imported products	Dummy variable taking value 1 if the firm declares that the reason for a change on its prices has been changes in prices of equivalent imported products.
Product price changes due to new products or competitors in the market	Dummy variable taking value 1 if the firm declares that the reason for a change on its prices has been the appearance of new products or competitors in the market.
Capacity utilization by competitors	Yearly weighted average of the productive capacity utilization of the other firms in the same industry (in %). The weights are given by each firm's particular sales over the total sales of the industry for a given year. The industry classification accounts for the 20 industrial sectors of the NACE-93 classification.
Traditional measure for competition	

Price cost margin (PCM)	It has been calculated as the firm's ratio of (output - labour costs - intermediate inputs costs) over output. See Appendix B for the used measures to construct this index per firm.
Control variables	
Medium-technological sectors	We follow the revised OECD [2002] industry classification, which groups industries according to their patterns of generation and acquisition of technology. According to this classification we include as med-tech food and tobacco, rubber and plastic, metallurgy, machinery and mechanical equipment, and motors and cars.
High-technological sectors	According to the revised OECD [2002] industry classification, we include as high-tech chemical products, office machines, electronic, and other transport material. The reference category is low-tech, which includes the meat industry, beverages, textiles, leather and shoes, wood, paper, printing, non metallic miner, metallic products, furniture, and other manufacturing goods.
Firm's age	Number of years since the firm was born.
Size	Log of firm's real sales. Firms' sales are in euros that have been deflated using specific industry deflators according to 20 sectors of the NACE-93 classification.
Percentage of highly-skilled labour	Ratio of the number of highly qualified workers (superior engineers and graduates) to total employment (in %).
Percentage of medium-skilled labour	Ratio of the number of medium qualified workers (technical engineers, High School Commercial Bachelors and helping people with a qualification title) to total employment (in %).
Year dummies	Dummy variables taking value 1 for the corresponding year and 0 otherwise.
Robustness variables	
Firm's R&D expenditure	Log of firm's real R&D expenditures. Firms' R&D expenditures are in euros that have been deflated using specific industry deflators according to 20 sectors of the NACE-93 classification.
Firm's distance to the technological frontier	Following Aghion *et al.* (2005), this is the ratio (not %) of the distance between the most efficient firm in the industry in a particular year (the one with the highest TFP) and the TFP for each particular firm in the same industry that year, over the TFP of the firm with the highest TFP in the industry that year. This variable has been used to classify firms in 3 different efficiency groups: efficient firms, medium efficient firms, and inefficient firms. The classification comes from a partition of the distribution of the distance to the technological frontier variable in approximately 3 thirds. Therefore, the top third of the distribution corresponds to efficient firms, the bottom third to inefficiency firms, and the intermediate third to medium efficient firms. For details on the construction of the TFP see Appendix B.

APPENDIX B

To measure productivity we use a TFP index. This is calculated at the firm level using a multilateral productivity index that is an extension of the Caves *et al.* (1982) index.[9] We deflate both output and inputs using, correspondingly, firm individual price indexes obtained from the ESEE. This allows controlling for the possibility of output and input prices not only being different or evolving differently over time for firms with different innovation outputs, but also among firms, irrespective to their innovation status. Therefore, to some extent our TFP measure reflects firm differences in market conditions.

B.1. Measurement of productivity.

In order to calculate TFP we define the following dummy variables,

$$p_{f\tau} = \begin{cases} 1 \text{ if firm } f \text{ belongs to size group } \tau \ (\tau = \text{small, large}) \\ 0 \text{ otherwise,} \end{cases}$$

$$j_{fs} = \begin{cases} 1 \text{ if firm } f \text{ belongs to industrial sector } s \ (s\text{=1,...,20, NACE} - 93 \text{ classification}) \\ 0 \text{ otherwise.} \end{cases}$$

Having a sample of N firms (f=1,...,N) for T years (t=1,...,T),[10] and assuming that observations from different firms are independent, one can calculate the TFP index for firm f belonging to size group τ and to industry s in year t, with the following expression:

$$\begin{aligned} z_{fs\tau t} = {} & \ln Y_{fs\tau t} - \overline{\ln Y_{\tau s}} - \frac{1}{2}\sum_{i=1}^{I}\left(\varpi^i_{fs\tau t} + \overline{\varpi^i_{\tau s}}\right)\left(\ln X^i_{fs\tau t} - \overline{\ln X^i_{\tau s}}\right) + \\ & \overline{\ln Y_{\tau s}} - \overline{\ln Y_s} - \frac{1}{2}\sum_{i=1}^{I}\left(\overline{\varpi^i_{s\tau}} + \overline{\varpi^i_s}\right)\left(\overline{\ln X^i_{s\tau}} - \overline{\ln X^i_s}\right), \end{aligned} \tag{B.1}$$

where $Y_{fs\tau t}$ is the production of firm f belonging to industry s with size τ in year t, $\varpi^i_{fs\tau t}$ is the cost share of input i (i=1,...,I) and $X^i_{fs\tau t}$ is the quantity of input i used. Finally, we define $\overline{m_{s\tau}} = \frac{1}{NT}\sum_{f=1}^{N}\sum_{t=1}^{T} m_{fs\tau t}\, p_{f\tau}\, j_{fs}$ and $\overline{m_s} = \frac{1}{NT}\sum_{f=1}^{N}\sum_{t=1}^{T} m_{fs\tau t}\, j_{fs}$, where $m_{fs\tau t}$ is alternatively $\ln Y_{fs\tau t}$, $\varpi^i_{fs\tau t}$ or $\ln X^i_{fs\tau t}$.

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[9] This extension was developed in Good *et al.* (1996) and Delgado *et al.* (2002). It may also be found in Máñez *et al.* (2005) and Rochina-Barrachina *et al.* (2010).

[10] In practice, we will have N_t observations for each year, i.e. we will have an unbalanced panel of firms. However, to keep the notation as simple as possible we do not show this explicitly in the formulae.

The above index measures the TFP proportional difference of a firm f from industry s and size τ in year t in relation with a reference firm. The reference firm varies according to industry. For industry s, in particular, it is defined as the firm whose outputs and inputs are equal to the geometric mean, across the sample period, of the outputs and inputs of those firms that belong to industry s and, also, as the firm whose input cost shares are equal to the arithmetic mean, during the sample period, of the input cost shares of the firms belonging to industry s.

The first component of this index (the three first terms in expression B.1), compares the output and the use of inputs for each firm in period t with those of the mean, across time, of firms belonging to the same industry and size group. This allows for transitivity in the comparisons across firms belonging to the same size group. The second component (three last terms in expression B.1), preserves transitivity in the comparison between firms belonging to the same industry but to different size groups. This second term measures the difference between TFP of a mean firm from a given industry and size group, and TFP of a reference firm (the mean firm of those belonging to the same industry, regardless its size). Finally, as we consider a different reference firm across industries, we eliminate possible differences in TFP across industries, which will also allow considering jointly firms belonging to different industries.

B.2. Construction of the variables involved in the TFP index calculation.

To calculate the TFP index we need to construct the following variables:

Output. Real output is obtained by deflating sales plus inventory changes. The price indices used are Paasche-type firm individual indices, constructed starting from the price changes on output reported by firms.

Labour. Measured as the number of hours worked (normal hours plus overtime minus lost hours).

Other intermediate inputs. Real intermediate consumption is obtained by deflating raw materials and services purchases plus energy and fuel costs. The price indices used are Paasche-type firm individual indices, constructed starting from the price changes on inputs reported by firms.

Capital. It is computed from a measure of the stock of capital obtained starting from the firms' investments in equipment goods. It takes into account the equipment price indices published by the Spanish National Institute of Statistics.

Input cost shares. For each input, the cost share is the proportion that represents that input on the total cost of inputs, where total cost is the sum of labour costs, intermediate inputs costs and the cost for capital. Labour costs are measured as the sum of wages, insurance and other labour costs paid by the firm. The cost of capital is calculated through the estimation of the user cost of capital, which is calculated as the firm's interest rate paid by long-run debt plus an industrial estimate of equipment depreciation minus the rate of change in the price index for capital goods.

Table 1. Percentage of firms engaged in innovation activities

Year	Product innovation only	Process innovation only	Both of them	None of them
1991	8.6	15.2	11.8	64.5
1992	10.0	14.5	11.7	63.8
1993	8.8	15.3	11.0	64.9
1994	9.1	15.2	10.9	64.9
1995	9.7	15.2	10.5	64.6
1996	9.1	13.7	10.4	66.8
1997	9.6	16.5	11.8	62.2
1998	9.5	19.2	10.6	60.7
1999	9.2	17.2	11.1	62.5
2000	9.5	17.4	10.7	62.4
2001	6.8	17.0	7.8	68.4
2002	6.8	13.4	8.1	71.6
2003	6.2	10.4	7.3	76.0
2004	6.8	11.1	7.8	74.4
2005	7.4	12.7	8.6	71.3
2006	7.9	15.4	6.5	70.3
Total period	8.6	15.1	10.0	66.4

Note: The numbers in this table have been obtained by upgrading the sample percentage of small and large firms to the population percentages, according to the sampling procedure in the ESEE described in section 3.

Table 2. Correlation coefficients among competitive pressure variables

	Expected sign of the variables with respect to competitive pressure													
	(-)	**(-)**	**(-)**	**(-)**	**(-)**	**(-)**	**(+)**	**(+)**	**(+)**	**(-)**	**(-)**	**(+)**	**(+)**	**(-)**
Competitive pressure variables	PS: Advert -to- sales	PS: Prod promo	PS: Brand	PS: Image Promo	PS: Sales agree	PS: After sales service	MS: Expan mark	MS: Export	MS: Export -to- sales	EC: Set-up costs	EC: Slow prod obsol	OM: Price chan import	OM: New prod/ compe	OM: Capaci use compe
PS: Advertising-to-sales ratio (Advert-to-sales)	**1.00**													
PS: Product promotion (Prod promo)	**0.19**	**1.00**												
PS: Branding (Brand)	**0.09**	**-0.10**	**1.00**											
PS: Image promotion (Image promo)	**-0.02**	**-0.46**	**-0.18**	**1.00**										
PS: Sales agreements (Sales agree)	**0.15**	**0.25**	**0.11**	**-0.11**	**1.00**									
PS: After-sales services (After sales service)	**0.01**	**0.08**	**-0.02**	**0.08**	**0.02**	**1.00**								
MS: Expansive market (Expan mark)	0.04	0.04	0.01	0.07	0.05	0.05	**1.00**							
MS: Main market is national & abroad or only abroad (Export)	0.06	0.09	0.03	0.06	0.05	0.04	**0.07**	**1.00**						
MS: Exports-to-sales ratio (Export to sales)	0.04	0.10	0.05	0.05	0.10	0.01	**0.07**	**0.60**	**1.00**					
EC: Set-up costs (Set-up costs)	-0.002	-0.005	-0.02	0.05	0.005	-0.01	0.01	0.04	0.02	**1.00**				
EC: Slow product obsolescence (Slow prod obsol)	-0.02	-0.02	-0.04	0.02	-0.05	0.02	0.001	0.004	-0.03	**0.05**	**1.00**			
OM: Changes in prices of equivalent import prod (Price chan import)	0.002	0.02	0.01	-0.02	0.01	-0.002	-0.01	0.06	0.07	-0.003	-0.04	**1.00**		
OM: New products or competitors in the market (New prod/compe)	0.04	0.04	0.0001	-0.02	0.05	-0.01	0.002	0.01	0.01	-0.03	-0.02	**-0.04**	**1.00**	
OM: Capacity utilization by competitors (Capaci use compe)	-0.03	-0.03	0.0003	-0.03	0.01	-0.08	0.08	-0.04	-0.03	-0.12	-0.02	**-0.01**	**-0.003**	**1.00**

Note: The numbers in this table have been obtained by upgrading the sample percentage of small and large firms to the population percentages, according to the sampling procedure in the ESEE described in section 3.

Table 3. Firms' descriptive statistics by type of innovation

Variables	Product innovation only	Process innovation only	Both of them	None of them
	Mean/median[a] (Std. dev.)	Mean/median[a] (Std. dev.)	Mean/median[a] (Std. dev.)	Mean/median[a] (Std. dev.)
Product substitutability variables				
Advertisement-to-sales ratio (in %)	1.66/0.62 (3.54)	0.84/0.25 (2.81)	1.58/0.58 (3.97)	0.80/0.2 (2.04)
Product promotion	0.35 (0.48)	0.19 (0.39)	0.36 (0.48)	0.18 (0.38)
Branding	0.06 (0.24)	0.03 (0.17)	0.07 (0.25)	0.03 (0.17)
Firm's image promotion	0.39 (0.49)	0.51 (0.50)	0.38 (0.49)	0.44 (0.50)
Sales agreements with wholesalers or retailers	0.27 (0.45)	0.15 (0.36)	0.31 (0.46)	0.14 (0.35)
After-sales services	0.32 (0.47)	0.22 (0.42)	0.31 (0.46)	0.24 (0.42)
Market size variables				
Expansive market	0.27 (0.44)	0.33 (0.47)	0.41 (0.49)	0.21 (0.40)
Main market is national & abroad, or only abroad	0.28 (0.45)	0.19 (0.39)	0.32 (0.47)	0.14 (0.35)
Exports-to-sales ratio (in %)	16.01/26.03 (23.41)	11.40/10.79[b] (22.16)	17.95/28.73[b] (24.68)	8.50/5.43[b] (18.83)
Entry costs				
Set-up costs	0.16/0.11 (0.17)	0.20/0.12 (0.27)	0.17/0.11 (0.19)	0.18/0.11 (0.23)
Slow product obsolescence	0.84 (0.37)	0.92 (0.27)	0.87 (0.33)	0.92 (0.27)
Other competitive pressure variables				
Product price changes due to changes in prices of equivalent imported products	0.06 (0.23)	0.03 (0.17)	0.05 (0.22)	0.03 (0.16)
Product price changes due to new products or competitors in the market	0.06 (0.24)	0.03 (0.18)	0.06 (0.24)	0.03 (0.18)
Capacity utilization by competitors (in %)	73.62/76.16 (10.68)	75.18/77.34 (9.80)	74.18/76.16 (10.30)	73.05/75.91 (11.10)
Controls				
Medium-technological sectors	0.25 (0.44)	0.29 (0.45)	0.34 (0.47)	0.27 (0.44)
High-technological sectors	0.20 (0.40)	0.11 (0.32)	0.22 (0.41)	0.11 (0.31)
Firm's age	23.65/18 (21.64)	22.03/17 (21.03)	24.23/19 (21.83)	22.45/17 (20.51)
Size	2.07/2 (1.09)	2.10/2 (1.07)	2.55/2 (1.26)	1.86/2 (1.01)
Percentage of highly-skilled labour (in %)	3.97/2 (6.13)	3.02/0 (5.16)	4.49/2.7 (6.33)	2.74/0 (5.99)
Percentage of medium-skilled labour (in%)	6.44/3.57 (9.23)	4.78/1.90 (8.86)	6.44/4.35 (8.31)	3.95/0 (7.64)
Robustness variables				
Firm's R&D expenditure	4.54/12.56[c] (5.62)	2.42/10.85[c] (4.54)	6.45/12.84[c] (5.78)	1.04/4.94[c] (3.20)
Firm's distance to the technological frontier	0.41/0.41 (0.17)	0.43/0.42 (0.16)	0.41/0.41 (0.16)	0.45/0.44 (0.16)

Notes: [a] The median has been calculated uniquely for the continuous variables; [b] Instead of the median we present the 75% percentile because of the higher amount of zeros in the distribution of this variable; [c] Instead of the median we present the 90% percentile because of the higher amount of zeros in the distribution of this variable.
The numbers in this table have been upgraded to population percentages as in Tables 1 & 2.

Table 4. Price-cost margin and competitive-pressure variables.

	All firms	Efficient Firms	Medium-efficient firms	Inefficient firms
Product Substitutability variables				
Advertisement-to-sales ratio	0.00112	0.000944	0.000678	0.00205
	(0.00125)	(0.000831)	(0.00144)	(0.00315)
Product promotion	0.0228**	0.00751	0.000384	0.0235
	(0.0111)	(0.00861)	(0.00784)	(0.0527)
Branding	0.0428***	0.00587	0.0225**	0.110**
	(0.0137)	(0.0153)	(0.0114)	(0.0483)
Firm's image promotion	0.0149	-0.00955	0.00196	0.0236
	(0.00917)	(0.00711)	(0.00611)	(0.0460)
Sales agreements with wholesalers or retailers	0.0160**	0.0154**	0.00729	0.0325
	(0.00759)	(0.00723)	(0.00683)	(0.0405)
Alter-sales services	-0.00817	0.00418	-0.0341***	-0.219***
	(0.00684)	(0.00626)	(0.00583)	(0.0724)
Market size variables				
Main market is national & abroad or only abroad	-0.00976	-0.00117	-0.0127**	-0.171
	(0.00826)	(0.00658)	(0.00629)	(0.119)
Exports-to-sales ratio	0.000535**	-0.000325**	-5.75e-05	0.000871
	(0.000220)	(0.000134)	(0.000135)	(0.00129)
Expansive market	0.0273***	0.0150***	0.0205***	0.0566**
	(0.00548)	(0.00473)	(0.00442)	(0.0273)
Entry costs				
Set-up costs	-0.00296	-0.00558	-0.0533***	-0.291***
	(0.0102)	(0.00778)	(0.0124)	(0.104)
Slow product obsolescence	-0.0188**	0.0111	-0.00765	-0.0772*
	(0.00735)	(0.00747)	(0.00708)	(0.0398)
Other competitive-pressure variables				
Product price changes due to changes in prices of equivalent imported products.	-0.0206	0.00415	-0.0177	-0.114
	(0.0127)	(0.0107)	(0.0124)	(0.0819)
Product price changes due to new products or competitors in the market.	0.0176**	-0.00200	0.00107	0.0652
	(0.00893)	(0.00894)	(0.00954)	(0.0434)
Capacity utilization by competitors	-0.000276	-0.000301	-0.00188***	-0.00430***
	(0.000984)	(0.000447)	(0.000471)	(0.000738)
Controls				
Medium-technological sectors	-0.0125		0.00667	
	(0.00847)		(0.00711)	
High-technological sectors	-0.0622***		-0.0708***	
	(0.0120)		(0.0110)	
Firm's age	0.000159		-0.000100	
	(0.000199)		(0.000166)	
Size (log of firm's real sales)	-0.00222		0.00129	
	(0.00277)		(0.00204)	
Percentage of highly-skilled labour	-1.27e-05		-0.000451	
	(0.000586)		(0.000557)	
Percentage of medium-skilled labour	0.000861**		0.000370	
	(0.000337)		(0.000307)	
Constant	0.0436		0.154***	
	(0.0820)		(0.0419)	
Root MSE	0.36309		0.23169	
Observations	20838		18930	
R-squared	0.065		0.236	

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table 5. Multivariate probit model (Benchmark)

	Only product	Only process	Both
Product Substitutability variables			
Advertisement-to-sales ratio	0.0202***	-0.00743	0.0112**
	(0.00625)	(0.00634)	(0.00560)
Product promotion	0.335***	-0.0257	0.235***
	(0.0603)	(0.0501)	(0.0571)
Branding	0.414***	-0.0544	0.269***
	(0.0825)	(0.0774)	(0.0878)
Firm's image promotion	0.129**	0.108**	0.0471
	(0.0537)	(0.0428)	(0.0497)
Sales agreements with wholesalers or retailers	0.111**	-0.137***	0.179***
	(0.0454)	(0.0416)	(0.0477)
Alter-sales services	0.141***	-0.103**	-0.000895
	(0.0446)	(0.0403)	(0.0438)
Market size variables			
Main market is national & abroad or only abroad	0.167***	-0.0279	0.135***
	(0.0595)	(0.0445)	(0.0514)
Exports-to-sales ratio	0.00185*	-0.000277	0.00209**
	(0.00111)	(0.000840)	(0.000936)
Expansive market	-0.0552	0.169***	0.191***
	(0.0339)	(0.0303)	(0.0347)
Entry costs			
Set-up costs	-0.138*	0.230***	-0.0670
	(0.0814)	(0.0616)	(0.0751)
Slow product obsolescence	- 0.306***	0.0756	- 0.206***
	(0.0649)	(0.0532)	(0.0587)
Other competitive-pressure variables			
Product price changes due to changes in prices of equivalent imported products.	0.186***	-0.0928	0.0250
	(0.0699)	(0.0669)	(0.0784)
Product price changes due to new products or competitors in the market.	0.202***	-0.0782	0.142**
	(0.0675)	(0.0612)	(0.0640)
Capacity utilization by competitors	-0.00134	0.00496*	-0.00182
	(0.00274)	(0.00261)	(0.00291)
Controls			
Medium-technological sectors	0.00514	0.0211	0.175***
	(0.0504)	(0.0430)	(0.0532)
High-technological sectors	0.143**	-0.0553	0.218***
	(0.0676)	(0.0618)	(0.0676)
Firm's age	-0.000385	-0.000641	-0.00172*
	(0.000948)	(0.000856)	(0.000955)
Size (log of firm's real sales)	-0.0425***	0.0911***	0.156***
	(0.0148)	(0.0118)	(0.0142)
Percentage of highly-skilled labour	0.00317	-0.000200	-0.000857
	(0.00316)	(0.00306)	(0.00288)
Percentage of medium-skilled labour	0.00578***	9.30e-05	0.00566**
	(0.00224)	(0.00226)	(0.00231)
Constant	-0.918***	-2.796***	-3.765***
	(0.312)	(0.277)	(0.307)

Errors correlation coefficients	ρ21	ρ31	ρ32
	-0.271***	-0.303***	-0.417***
	(0.0135)	(0.0164)	(0.0148)
Observations	18735		
Log pseudolikelihood	-19740.40		

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table 6. Multivariate probit model: Efficient vs. Non-efficient firms

	Efficient firms			Medium-eff. firms			Inefficient firms		
	Only product	Only process	Both: product & process	Only product	Only process	Both: product & process	Only product	Only process	Both: product & process
Product Substitutability variables									
Advertisement-to-sales ratio	0.0297***	-0.0131	0.0182**	0.0186**	-0.0200**	0.00601	-0.00046	0.0172*	0.0124
	(0.00989)	(0.00917)	(0.00909)	(0.00815)	(0.00899)	(0.00758)	(0.00826)	(0.00953)	(0.0104)
Product promotion	0.252**	0.00578	0.301***	0.294***	-0.0253	0.198***	0.616***	0.0567	0.0887
	(0.100)	(0.0902)	(0.102)	(0.0763)	(0.0649)	(0.0735)	(0.145)	(0.126)	(0.131)
Branding	0.334**	-0.0923	0.364**	0.392***	-0.111	0.248**	0.804***	0.204	-0.162
	(0.155)	(0.138)	(0.155)	(0.108)	(0.109)	(0.113)	(0.215)	(0.162)	(0.209)
Firm’s image promotion	0.0791	0.176**	0.0714	0.0679	0.0673	0.0435	0.425***	0.181*	0.00237
	(0.0964)	(0.0803)	(0.0885)	(0.0644)	(0.0527)	(0.0643)	(0.132)	(0.109)	(0.139)
Sales agreements with wholesalers or retailers	0.0101	-0.110	0.202***	0.178***	-0.0954*	0.246***	0.258**	-0.204**	0.0634
	(0.0792)	(0.0707)	(0.0766)	(0.0591)	(0.0570)	(0.0611)	(0.111)	(0.101)	(0.114)
Alter-sales services	0.153**	-0.0434	-0.105	0.0998*	-0.0691	0.0446	0.112	-0.462***	0.00947
	(0.0705)	(0.0637)	(0.0674)	(0.0581)	(0.0512)	(0.0569)	(0.141)	(0.129)	(0.141)
Market size variables									
Main market is national & abroad or only abroad	0.212***	-0.104	0.180**	0.143*	0.0216	0.102	0.0679	0.111	0.106
	(0.0789)	(0.0665)	(0.0796)	(0.0856)	(0.0596)	(0.0640)	(0.193)	(0.148)	(0.172)
Exports-to-sales ratio	0.000299	0.00101	0.000909	0.00278*	-5.30e-05	0.00243**	0.000153	-0.00414	0.00288
	(0.00159)	(0.00123)	(0.00144)	(0.00147)	(0.00108)	(0.00111)	(0.00335)	(0.00268)	(0.00301)
Expansive market	-0.0836	0.156***	0.170***	-0.0692	0.180***	0.224***	0.162	0.288***	0.0859
	(0.0555)	(0.0507)	(0.0575)	(0.0470)	(0.0403)	(0.0458)	(0.116)	(0.0940)	(0.109)
Entry costs									
Set-up costs	-0.175	0.234***	-0.127	-0.110	0.152	-0.142	0.0477	0.406**	0.0226
	(0.113)	(0.0722)	(0.0968)	(0.125)	(0.101)	(0.113)	(0.277)	(0.198)	(0.243)
Slow product obsolescence	-0.188**	0.0704	-0.265***	-0.371***	0.0828	-0.116	-0.389**	-0.0161	-0.567***
	(0.0939)	(0.0865)	(0.0927)	(0.0883)	(0.0701)	(0.0838)	(0.188)	(0.179)	(0.180)

Other competitive-pressure variables									
Product price changes due to changes in prices of equivalent imported products.	0.0566	-0.170	0.145	0.173*	-0.135	-0.0126	0.509**	0.0710	-0.287
	(0.118)	(0.107)	(0.130)	(0.0976)	(0.0928)	(0.0958)	(0.213)	(0.193)	(0.256)
Product price changes due to new products or competitors in the market.	0.286**	-0.136	0.326***	0.188**	-0.0370	0.203**	0.148	-0.391*	-0.119
	(0.119)	(0.100)	(0.102)	(0.0895)	(0.0821)	(0.0943)	(0.205)	(0.203)	(0.243)
Capacity utilization by competitors	-0.00140	0.00356	0.000762	-0.00408	0.00377	-0.00109	0.0106***	0.00212	-0.00145
	(0.00297)	(0.00288)	(0.00318)	(0.00293)	(0.00280)	(0.00319)	(0.00328)	(0.00294)	(0.00344)
Controls									
Medium-technological sectors	0.0261	0.0177	0.221***						
	(0.0543)	(0.0459)	(0.0572)						
High-technological sectors	0.129*	-0.0748	0.238***						
	(0.0702)	(0.0633)	(0.0726)						
Firm’s age	-0.000726	0.000576	-0.00151						
	(0.00100)	(0.00090)	(0.00101)						
Size (log of firm’s real sales)	-0.0576***	0.0833***	0.154***						
	(0.0162)	(0.0128)	(0.0154)						
Percentage of highly-skilled labour	0.00496	-0.00146	6.91e-05						
	(0.00330)	(0.00300)	(0.00312)						
Percentage of medium-skilled labour	0.00615**	0.000154	0.00432*						
	(0.00241)	(0.00222)	(0.00247)						
Constant	-0.484	-2.563***	-3.844***						
	(0.336)	(0.294)	(0.335)						
Errors correlation coefficients	ρ21	ρ31	ρ32						
	-0.270***	-0.289***	-0.419***						
	(0.0138)	(0.0168)	(0.0152)						
Observations	16918								
Log pseudolikelihood	-17773.32								

Robust standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7. Multivariate probit model: robustness checks

	Including R&D			4-year averages		
	Only product	Only process	Both: product & process	Only product	Only process	Both: product & process
Product Substitutability variables						
Advertisement-to-sales ratio	0.0182***	-0.00752	0.00579	0.0221*	-0.0178*	-0.000155
	(0.00639)	(0.00627)	(0.00536)	(0.0114)	(0.0107)	(0.00977)
Product promotion	0.322***	-0.0213	0.182***	0.331***	-0.0329	0.111
	(0.0609)	(0.0499)	(0.0573)	(0.0934)	(0.0786)	(0.0853)
Branding	0.401***	-0.0510	0.229***	0.543***	0.0528	0.136
	(0.0823)	(0.0787)	(0.0843)	(0.131)	(0.124)	(0.135)
Firm's image promotion	0.141***	0.114***	0.0340	0.0954	0.0416	0.0105
	(0.0546)	(0.0429)	(0.0501)	(0.0870)	(0.0655)	(0.0769)
Sales agreements with wholesalers or retailers	0.121***	-0.135***	0.202***	0.109	-0.225***	0.222***
	(0.0451)	(0.0417)	(0.0471)	(0.0735)	(0.0674)	(0.0705)
Alter-sales services	0.1000**	-0.0964**	-0.0454	-0.0139	-0.117*	-0.0195
	(0.0439)	(0.0406)	(0.0433)	(0.0696)	(0.0607)	(0.0662)
Market size variables						
Main market is national & abroad or only abroad	0.147**	-0.0199	0.105**	0.120	0.0459	0.113
	(0.0584)	(0.0449)	(0.0502)	(0.0940)	(0.0790)	(0.0864)
Exports-to-sales ratio	0.000799	-0.000419	0.000297	0.00192	-0.00150	-0.000799
	(0.00111)	(0.000852)	(0.000940)	(0.00186)	(0.00152)	(0.00161)
Expansive market	-0.0631*	0.171***	0.184***	-0.00128	0.296***	0.224***
	(0.0341)	(0.0304)	(0.0347)	(0.0745)	(0.0582)	(0.0639)
Entry costs						
Set-up costs	-0.126	0.229***	-0.0473	-0.0371	0.228*	0.0756
	(0.0791)	(0.0621)	(0.0719)	(0.150)	(0.124)	(0.144)
Slow product obsolescence	-0.279***	0.0814	-0.122**	-0.376***	0.134	-0.0806
	(0.0654)	(0.0527)	(0.0573)	(0.0899)	(0.0894)	(0.0860)

Other competitive-pressure variables						
Product price changes due to changes in prices of equivalent imported products.	0.174**	-0.0959	-0.0378	0.0543	-0.114	-0.455*
	(0.0703)	(0.0667)	(0.0745)	(0.196)	(0.194)	(0.237)
Product price changes due to new products or competitors in the market.	0.188***	-0.0729	0.151**	0.272	-0.0557	0.0691
	(0.0675)	(0.0610)	(0.0646)	(0.182)	(0.184)	(0.180)
Capacity utilization by competitors	-0.00172	0.00468*	-0.00209	-0.00217	-0.000565	-0.00226
	(0.00277)	(0.00266)	(0.00290)	(0.00578)	(0.00515)	(0.00586)
Controls						
Medium-technological sectors	-0.0204	0.0165	0.128**	-0.0489	-0.00870	0.122*
	(0.0499)	(0.0433)	(0.0518)	(0.0767)	(0.0617)	(0.0715)
High-technological sectors	0.0748	-0.0597	0.0978	0.185*	-0.234***	0.140
	(0.0679)	(0.0628)	(0.0670)	(0.104)	(0.0908)	(0.103)
Firm's age	-0.000584	-0.000822	-0.00272***	0.000243	-0.000621	-0.00423***
	(0.000955)	(0.000876)	(0.000942)	(0.00147)	(0.00125)	(0.00143)
Size (log of firm's real sales)	-0.0983***	0.0877***	0.0652***	-0.100***	0.0981***	0.0680***
	(0.0163)	(0.0128)	(0.0150)	(0.0242)	(0.0200)	(0.0235)
Percentage of highly-skilled labour	0.00160	-0.000518	-0.00344	-0.00449	-0.00327	-0.00674
	(0.00325)	(0.00313)	(0.00326)	(0.00493)	(0.00425)	(0.00473)
Percentage of medium-skilled labour	0.00429**	6.24e-05	0.00163	0.00326	0.000908	0.00262
	(0.00214)	(0.00230)	(0.00224)	(0.00320)	(0.00311)	(0.00305)
Log of (real) R&D expenditures	0.0368***	0.00263	0.0632***	0.0419***	0.00697	0.0731***
	(0.00440)	(0.00370)	(0.00395)	(0.00795)	(0.00663)	(0.00740)
Constant	-0.272	-2.821***	-2.714***	-0.303	-2.649***	-2.708***
	(0.284)	(0.236)	(0.265)	(0.498)	(0.427)	(0.490)
Errors correlation coefficients	ρ21	ρ31	ρ32	ρ21	ρ31	ρ32
	-0.252***	-0.340***	-0.410***	-0.223***	-0.359***	-0.458***
	(0.0134)	(0.0176)	(0.0154)	(0.0274)	(0.0325)	(0.0265)
Observations	18625			3947		
Log pseudolikelihood	-19149.37			-3896.86		

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

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