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Complementarity among innovations for exporting in German manufacturing firms

Rosa Bernardini Papalia[1], Silvia Bertarelli[2] and Susanna Mancinelli[3]

Abstract

This paper investigates whether firms' joint implementation of product, process and organizational innovation may foster their propensity of exporting. We study the relationship of complementarity among innovation practices when exporting is the firms' objective function, through the properties of supermodular functions. We propose a unified strategy to perform multiple inequality testing implied by the properties of supermodular functions. Bootstrapping is used when innovation variables are exogenous. When endogeneity of binary variables cannot be rejected complementarity is checked through propensity score matching and instrumental variable methods. Using data from CIS4, heterogeneous incentives of exploiting complementarity among German manufacturing firms' innovation practices emerge by export destinations and when size specific conditions are satisfied.

Keywords: Export propensity, complementarity among innovations, multiple hypothesis testing, binary choice model

JEL Classification: C12, C25, F14, O31

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1. INTRODUCTION

The trade-literature has recently emphasized the role of innovation in the export-productivity relationship[4]. The linkage between firms' investment in innovation and their decision to export is explored and, through the use of micro-level data, a positive correlation between export and innovation variables is documented. This result is obtained by assuming heterogeneity of firms' productivity. The basic reasoning is the following: only more productive firms may afford the fixed costs of exporting, as well as only more productive firms may afford the fixed costs of innovating. Moreover, it is widely recognised (Griliches, 1998) the role of innovation in influencing firms' productivity patterns. Therefore innovation may imply higher productivity levels, which correspond to lower marginal costs of production. Hence innovators may charge lower prices on the goods they sell both in the domestic and in the foreign markets, and, if the foreign demand is assumed to be elastic, innovators find exporting more profitable than non-innovators.

Typically, two different kinds of firms' innovation are considered in the literature: product and process. As already emphasised (Caldera, 2010; Cassiman et al., 2010), all kinds of innovation should have positive effects on firms' exports. Through product innovation firms upgrade their products to meet foreign consumers' preferences and to adequate to foreign market standards and regulations. Through process innovations firms improve their production process receiving cost advantages; hence, they can charge lower and more competitive prices on foreign markets and expect higher profits from exports, which in turn increase their probability of exporting. Since the different forms of innovation practices are shown to be all relevant for exporting firms, some few authors (Van Beveren-Vandenbussche, 2010; Becker-Egger, 2013) have explored the combination of firms' different innovations with respect to their exporting activity.

[4] See, among others, Bustos (2011), Costantini-Melitz (2007), Cassiman et al. (2010), Van Long et al. (2011), Caldera, (2010), Aw et al. (2007, 2008), Lileeva-Trefler (2010), Becker-Egger (2013), Yeaple (2005), Van Beveren-Vandenbussche (2010).

Our aim is to move up from this literature by deepening the analysis about the relationship of complementarity among the different kinds of firms' innovation when their objective function is exporting. Following Topkis (1995, 1998), Milgrom and Roberts (1990, 1995), Milgrom and Shannon (1994), we investigate complementarity among firms' innovation practices through the properties of supermodular functions. Moreover we are interested in exploring whether firms' heterogeneity by export destinations may play a role in the analysis of complementarities among firms' innovation practices and their attitude towards exporting. In fact, as highlighted by Melitz (2003) a firm has to bear fixed costs of exporting, that involve distribution and servicing costs for each foreign market to which the firm exports. Hence the more are the foreign markets served by the firm, the larger are the fixed export costs it has to bear. Our aim is to scrutinize if exporter firms with larger fixed export costs exploit technological complementarities among different innovation practices in a stronger way than the other ones.

We investigate the issue by using a sample of 2347 German manufacturing firms from CIS4 survey, which include information about three kinds of innovation: product, process and organizational/marketing innovation[5]. Another peculiar element in our dataset is that exporters choose three different destinations for their exports: the EU markets, other foreign markets or both destinations (EU and extra EU markets), which allows us to deepen the empirical analysis about complementarities among innovation practices when heterogeneity of firms by export destinations is considered.

From an econometric point of view, a unified framework for evaluating complementarity among innovation practices for export propensity is proposed, by admitting that innovation practices can be either exogenous or endogenous.

[5] Since organizational/marketing innovation concerns new organizational or marketing methods it may play a role both in the supply of products on foreign markets and in the productive process.

In addressing the issue of complementarity, a preliminary testing procedure is adopted to distinguish the case of exogenous and endogenous innovation cases. We employ the most used methods to evaluate the properties of export propensity functions. CIS4 dataset include a rich set of instruments to be used in explaining innovation variables when the endogeneity hypothesis cannot be rejected.

In the first case (when innovation variables are assumed to be exogenous), we propose a unified strategy within the class of bootstrapping methods. More specifically, constrained and unconstrained logit and multinomial models are estimated and bootstrapping is proposed to perform joint inequality testing implied by the properties of supermodular functions. We contribute to existing literature in the sense that we directly evaluate combined hypothesis testing for more than two innovation practices, by overcoming computational problems associated to the generalization of Wald tests used by Mohnen and Roller (2005) for two practices. Indeed, regressions under inequality constraints are to be computed and the critical values of such tests are cumbersome even for dichotomously practices. For the best of our knowledge, the only paper performing complementarity testing for more than two innovation practices is Carree et al (2011). However, the authors propose an induced test procedure and argue that a combined hypothesis is accepted if all the separate hypotheses are accepted.

In the second case (when innovation variables are assumed to be endogenous), several econometric approaches estimate logit models with endogenous binary regressors and can be used for our purposes. In this study, propensity score matching and instrumental variable simulated maximum likelihood (MSL) methods are employed. In this framework, we construct binomial variables able to identify complex innovation strategies. We interpret complex innovators as a treatment group, who adopt two or more innovation practices simultaneously. The set of simple-innovators, deciding to introduce only one type of innovation, and the set of non-innovators join the control group. The estimating methods of treatment-effects models can be used to test for complementarity of innovation variables, when endogeneity is not statistically rejected.

The paper is structured as follows: section 2 analyses the relationship between exporting and complementarity among innovation practices; the theoretical framework and the research hypothesis are presented in section 2.1. Section 2.2 shows the econometric analyses and complementarity tests; then the endogeneity issue is tackled in section 2.3. Section 3 presents the CIS4 dataset and focuses on the relationship between exporting propensity and innovation activities for German firms. Section 3.3 presents and comments the econometric results about complementarity. Section 4 concludes.

2. EXPORTING AND COMPLEMENTARITY BETWEEN INNOVATION PRACTICES

In the economic literature about trade big emphasis has recently been given to the relationship among firms' attitudes to innovate and to export. Most of the analysis on the relationship innovation-trade passes through the heterogeneity of firms' productivity. The linkage is the following: only more productive firms self-select into export markets; innovation is one of the most important drivers of the firm's productivity; innovators may afford lower marginal costs of production and may charge a lower prices on the goods they sell in the foreign markets; hence, if the foreign demand is assumed to be elastic innovators' attitude to export is higher than non-innovators' attitude. Moreover, the empirical analysis is often conducted considering the correlation between investment in R&D and exporting (Aw et al, 2007, 2008; Bustos, 2011; Lileeva-Trefler, 2010;Van Long et al., 2011). Only few works (Caldera, 2010; Cassiman et al., 2010; Becker-Egger 2013; Van Beveren-Vandenbussche, 2010) have examined the direct link between firms' different innovation practices and exporting. In these works a positive correlation between firms' innovation strategies and their attitude to export is shown and product innovation seems to play a more relevant role in firms' participation in export markets than other forms of innovation. On the other hand, evidence has also shown that exporter firms adopt all kinds of innovation practices and some few works (Van Beveren-Vandenbussche, 2010; Becker-Egger, 2013) have analyzed the correlation between firms' process and product innovations and the impact on their exporting decisions. In these works firms adopt a combination of both quality improvements, by product innovation, and cost reduction, by process innovation, to ameliorate their entering export markets.

The subject that, to the best of our knowledge, has not yet received deep specific analysis is if a relationship of complementarity among the firms' different innovation practices matter when their objective function is exporting. Our aim is just to concentrate on this yet unexplored issue.

For the pursuit of our goal, this section presents the referring theoretical framework for the analysis of complementarity and our proposal of econometric testing of complementarity among the three innovation practices (product, process and organizational/marketing) when the firms' objective function is exporting.

2.1 Complementarity: concepts and methods

When a relationship of complementarity is found between two activities of a firm, this implies that if one of the two activities is increased, it is more attractive for the firm to increase also the other complementary activity. This has obvious implications on the firm's strategic decisions. In fact, the firm's change of some choice variable may have little effect if other choice variables remain unchanged.

Since the seminal applied work by Mohnen and Roller (2005), increasing attention has been devoted by economic literature to testing empirical evidence for complementarities in innovation policies. Remaining within the innovation sphere, our aim is to analyse if evidence for complementarity among some firms' innovation practices exists when their objective function is exporting.

We want to scrutinize whether innovation practices are complementary, because in such situation the firm's choice should be to implement them together in order to maximise their impact on exporting.

Since innovation practices are typically investigated in discrete settings (e.g. adopting or not, adopting at an intensity higher than the average, etc..), we study complementarity among these forms of actions through the properties of supermodular functions.

Following Topkis (1995, 1998), Milgrom and Roberts (1990, 1995), Milgrom and Shannon (1994), we state that two variables x' and x'' in a *lattice*[6] X are complements if a real-valued function $F(x', x'')$ on the *lattice* X is supermodular in its arguments. That is, if and only if:

(1) $$F(x' \vee x'') + F(x' \wedge x'') \geq F(x') + F(x'') \qquad \forall x', x'' \in X.$$

or, expressed differently:

(2) $$F(x' \vee x'') - F(x') \geq F(x'') - F(x' \wedge x'') \qquad \forall x', x'' \in X,$$

that is, the change in F from x' (or x'') to the maximum $(x' \vee x'')$ is greater than the change in F from the minimum $x' \wedge x''$ to x'' (or x'): raising one of the variables raises the value of increase in the second variable as well[7]. It is worth noting that the mathematical approach to complementarity typically considers two independent variables only. Actually the relationship of complementarity may involve more than two variables simultaneously, through a chain reaction that starts from a complementarity relationship between two variables and involves a complementarity relationship between one of the two variables and a third variable and so on (Topkis, 1978). It is

[6] More specifically, "a *lattice* $(X, \geq)$ is a set X, with a partial order ≥, such that for any $x', x'' \in X$ the set X also contains a smallest element under the order that is larger than both x' and x'' ($x' \vee x''$) and a largest element under the order that is smaller than both ($x' \wedge x''$)" (Milgrom and Roberts, 1995, p. 181). For the Euclidean space R^N, $x' \vee x'' = (\max\{x_1, y_1\}, \ldots, \max\{x_N, y_N\})$ and $x' \wedge x'' = (\min\{x_1, y_1\}, \ldots, \min\{x_N, y_N\})$.

[7] From equations (1) and (2) it is evident that complementarity is symmetric: increasing *x*' raises the value of increases in *x*''. Likewise, increasing *x*''raises the value of increases in *x*'.

sufficient to check pairwise complementarities in case the dimensions of the lattice are more than two.

In our specific case, we consider the 'Exporting function' of firm *j* $(E_j, \text{for } j = 1,2,...J)$ as the firm's objective function and we focus on the innovation practices set of firm *j*, $I_j = (I_{1j}, I_{2j},..., I_{kj},..., I_{Kj})$ [8], that can affect the firm's exporting function:

(3) $$E_j = f(I_{1j} I_{2j},...I_{Kj}, \theta_j) = E_j(I_j, \theta_j) \qquad \forall j.$$

The problem of firm *j* is to choose a set of innovation practices which maximize its *E* function. θ_j are the firm's predetermined parameters, such as the firm's foreign markets, and the firm's sector specificity and/or dimension. The maximisation problem is the same for all firms. Notwithstanding each firm is characterised by specific predetermined factors and one could be interested in how different values of the parameter θ may imply different instances of the firms' decisional problems and hence different firms' optimal choices concerning *E*.

Let the innovation practices set $I_j (I_{kj} \in I_j)$ be a set of elements that form a lattice, then complementarity between the different innovation practices may be analysed by testing whether $E_j = E_j(I_j, \theta_j)$ is supermodular in I_j.

If we consider, for example, two binary decision variables (I_{1j}, I_{2j}), there are four elements in the set I_j. If in its E_j maximizing problem, a firm chooses to adopt neither of the two practices, namely $I_{1j} = 0, I_{2j} = 0$, the element of the set I_j is $I_{1j} \wedge I_{2j} = \{00\}$. If a firm chooses to adopt both practices, we have $I_{1j} = 1, I_{2j} = 1$ and the element of the set is I_j is $I_{1j} \vee I_{2j} = \{11\}$. Including the mixed cases as well, we have four elements in the set I_j that form a lattice: $I_j = \{\{00\}, \{01\}, \{10\}, \{11\}\}$.

[8] Where *k=1, 2,…, K* denotes the kind of practice.

From the above we can assert that the two innovation practices are complements and hence that the function E_j is supermodular, if and only if:

$$(4) \qquad E_j(11,\theta_j) + E_j(00,\theta_j) \geq E_j(10,\theta_j) + E_j(01,\theta_j),$$

or:

$$(5) \qquad E_j(11,\theta_j) - E_j(00,\theta_j) \geq \left[E_j(10,\theta_j) - E_j(00,\theta_j)\right] + \\ + \left[E_j(01,\theta_j) - E_j(00,\theta_j)\right],$$

that is, changes in the firm's objective function when both forms of innovation practices are increased together are more than the changes resulting from the sum of the separate increases of the two kinds of practice.

To sum up, complementarity between the two decision variables exists if the E_j function is shown to be supermodular in these two variables and this happens when either inequality (4) or inequality (5) or other derived inequalities are satisfied[9]. Since each firm is characterized by specific exogenous parameters (θ_j), even if the maximization problem is the same for all firms, the E function may result supermodular in I_j for some firms, but not for others.

Our aim is to derive a set of inequalities (such as those explicated in equations (4) and (5)), that are tested in the empirical analysis.

[9] Since the substitutability relationship (that is, doing more of an activity reduces the attractiveness of doing more of the other activity), is the opposite of that of complementarity, we can test if a substitutability relationship exists if and only if: $E_j(11,\theta_j) + E_j(00,\theta_j) \leq E_j(10,\theta_j) + E_j(01,\theta_j)$

More specifically, through the supermodularity approach we analyse whether the probability of a firm's exporting is significantly influenced by the presence of complementarities among innovation practices.

In our analysis, we are also particularly interested in verifying whether a wider number of foreign markets served by a firm may play a role in the exploitation of complementarity relationships among innovation practices. The underlying reasoning is in line with what highlighted by Melitz (2003) that a firm has to bear fixed costs of exporting which are independent from its export volume. They involve servicing and distribution costs in foreign markets and are borne by the firm in each exporting country, hence the more the foreign markets the firm chooses to serve, the larger are the total fixed costs it has to bear.

In this view, it is worth highlighting what Milgrom and Roberts (1995) show (in their fourth and fifth results) that a firm's optimal choice related to a decisional factor may initially be zero. Nevertheless, if environmental change leads to an increase in the level of another variable (which has become more profitable), then the new optimal choice of the first variable may become positive if it shows a relationship of complementarity with the factor that has been increased. Thus, increasing both variables may become more attractive in a newly changed 'environment'. Hence the adoption of both complementary practices by a firm may be an optimal choice in some circumstances but not in others even if its behaviour is maximizing in both cases.

'Environmental changes' may be represented as both dynamic and horizontal variations. In our analysis, which is static, we consider only the second type of variations and the parameter θ_j embodies the different environments that the different firms may face.

We then empirically analyze complementarities by admitting differences between two subsamples of firms[10]: the ones that export to EU markets only (E_{EU}) and the ones that export to both EU and

[10] Actually in our sample, besides only EU markets and both EU and extra EU markets, firms choose another destination for their export that is only extra EU markets.

extra EU markets (E_B). If fixed export costs are larger for E_B than for E_{EU}, we want hence to scrutinize whether the increasing fixed export costs that the E_B subset of firms has to bear may induce them to exploit complementary innovation practices in a deeper way than the firms belonging to the E_{EU} subset.

2.2 Econometric modelling and testing strategy of the complementarity hypothesis

In this section, we concentrate on the evaluation of the complementarity hypothesis, by proposing a testing procedure developed for three different innovative activities, based on the multiple-inequality restrictions corresponding to the definition of strict super-modularity (or sub-modularity) introduced in the previous section.

The innovation practices we consider are three: product innovations; process innovations; organizational and marketing innovations. In the presence of three innovation practices of the firm, we have three binary decision variables and the elements of the lattice I are eight (that is 2^3). Specifically:

(6) $$I = \{\{000\},\{001\},\{010\},\{100\},\{101\},\{110\},\{011\},\{111\}\}$$

For each firm, $K = 3$ and, as shown in Mohnen and Roller (2005, p. 1463), the number of nontrivial inequalities is $2^{(K-2)}\sum_{i=1}^{K-1} i$, that is six nontrivial inequalities.

We can assert that for a firm j two innovation practices are complements in the presence of three practices if and only if the probability of exporting satisfies the following conditions:

- Complementarity between product and process innovation practices:

$$P(E_j | d110 = 1, \theta_j) + P(E_j | d000 = 1, \theta_j) \geq P(E_j | d100 = 1, \theta_j) + P(E_j | d010 = 1, \theta_j),$$

and:

$$P(E_j | d111=1,\theta_j) + P(E_j | d001=1,\theta_j) \geq P(E_j | d101=1,\theta_j) + P(E_j | d011=1,\theta_j),$$

with at least one of the two inequalities holding strictly[11]. We note that d_i ,with $i \in I$, is a dummy equal to one when the combination of innovation activities is i and zero otherwise, where i is an element of the lattice I, as defined in (9).

– between product and organizational/marketing innovation practices:

$$P(E_j | d101=1,\theta_j) + P(E_j | d000=1,\theta_j) \geq P(E_j | d100=1,\theta_j) + P(E_j | d001=1,\theta_j),$$

and:

$$P(E_j | d111=1,\theta_j) + P(E_j | d010=1,\theta_j) \geq P(E_j | d110=1,\theta_j) + P(E_j | d011=1,\theta_j),$$

with at least one of the two inequalities holding strictly[12].

- between process and organizational/marketing innovation practices:

$$P(E_j | d011=1,\theta_j) + P(E_j | d000=1,\theta_j) \geq P(E_j | d010=1,\theta_j) + P(E_j | d001=1,\theta_j),$$

and:

$$P(E_j | d111=1,\theta_j) + P(E_j | d100=1,\theta_j) \geq P(E_j | d110=1,\theta_j) + P(E_j | d101=1,\theta_j),$$

with at least one of the two inequalities holding strictly[13].

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[11] The first condition is verified if the third innovation practice is 0, the second condition if the third practice is 1.

[12] The first condition is verified if the second innovation practice is 0, the second condition if the second practice is 1.

[13] The first condition is verified if the first innovation practice is 0, the second condition if the first practice is 1.

Our testing procedure requires the estimation of the following logit model (Model 1):

$$(7)\quad \ln \Pr\left(E_j = 1 \middle| \theta_j\right) = a_0 + a_1 C_j + a_2 \pi_j + \sum_{s \in S} a_s D_{sj} + \sum_{i \in I} b_i D_{ij} + \varepsilon_j$$

where D_{ij} ,with $i \in I$, is a dummy equal to one when the combination of innovation activities is i and zero otherwise, where *i* is an element of the lattice *I*, as defined in (6). For example, if *i* = 111 the firm decides to adopt all three innovation practices simultaneously. Again, C_j is a dummy indicating if a firm *j* is part of a group, D_{sj} is a sector-specific dummy, and π_j is a measure of firm's relative profitability, which captures heterogeneity of firms' productivity levels.

With reference to Model 1 reported in (7), the conditions of complementarity testing are the following:

– Complementarity between product and process innovation practices:

(7.12) $$b_{000} + b_{110} - b_{100} - b_{010} \geq 0$$

$$b_{111} + b_{001} - b_{101} - b_{011} \geq 0$$

with at least one of the two inequalities holding strictly.

– Complementarity between product and organizational/marketing innovation practices:

(7.13) $$b_{000} + b_{101} - b_{100} - b_{001} \geq 0$$

$$b_{111} + b_{010} - b_{011} - b_{110} \geq 0$$

with at least one of the two inequalities holding strictly.

– Complementarity between process and organizational/marketing innovation practices:

(7.23) $$b_{000} + b_{011} - b_{010} - b_{001} \geq 0$$

$$b_{111} + b_{100} - b_{101} - b_{110} \geq 0$$

with at least one of the two inequalities holding strictly.

Inequality constraint hypotheses are to be tested with reference to the coefficients estimated in logit model (7). Since we expect that exporting firms are more likely to be involved in innovation activities, the un-weighted regression gives excessive importance to exporting firms. Given that the innovation choice is potentially endogenous, we are asked to control for potential endogeneity of the different types of innovation.

Furthermore, in the complementarity testing strategy, the innovation strategy is multinomial as a whole. That is, an unordered multinomial innovation variable MD can be easily constructed considering all dichotomous variables D_i from equation (7), with $i \in I$ (j suppressed for simplicity), that is MD=0 if D_{000}=1, MD=1 if D_{100}=1, MD=2 if D_{010}=1, MD=3 if D_{001}=1, MD=4 if D_{101}=1, MD=5 if D_{110}=1, MD=6 if D_{011}=1 and MD=7 if D_{111}=1.

Given that our treatment is multinomial we propose to simplify the procedure by referring to a pair-wise comparison of innovation strategies. This is possible by recognizing that all innovation strategies can be classified into two groups: complex innovation strategies and simple innovation strategies. In this view, we may construct a bivariate treatment from the multinomial innovation one (MD) to compare a situation where the firm introduces a simple innovation strategy to a situation where the firm chooses a complex innovation strategy from each couple of the three basic product, process and organizational innovation decisions. A complex strategy requires the simultaneous adoption of (at least) two types of innovation. Specifically, to evaluate complementarity between product and process innovation, we consider the following dummy

$$d_{12} = \begin{cases} = 1 & if \quad D_{110} = 1 \; or \; D_{111} = 1 \\ = 0 & otherwise \end{cases}$$

to evaluate complementarity between product and organizational innovation, we consider the following dummy

$$d_{13} = \begin{cases} = 1 & if \quad D_{101} = 1 \; or \; D_{111} = 1 \\ = 0 & otherwise \end{cases}$$

to evaluate complementarity between process and organizational innovation, we consider the following dummy

$$d_{23} = \begin{cases} = 1 & if \quad D_{011} = 1 \; or \; D_{111} = 1 \\ = 0 & otherwise \end{cases}$$

In these cases, we interpret complex innovators as a treatment group and the sub-group of simple innovators and non-innovators as the control group.[14]

To test the existence of endogeneity of d_{12}, d_{13} and d_{23} variables in non-linear models for export propensity, a Rivers-Vuong two stage test is applied. At the first stage, a logit model of innovation is estimated by using the instruments identified by LM and Hansen-Sargan tests. At the second stage, a logit regression for export propensity includes the predicted error term from the first stage among other regressors. Under the null hypothesis of exogeneity, the coefficient of the error term is zero[15].

When the null hypothesis of exogeneity cannot be rejected a bootstrapping is proposed; otherwise, the most used treatment effects models are considered to evaluate the presence of complementarity. The two strategies are detailed in sections 2.2.1 and 2.2.2.

2.2.1 Case I: Exogenous innovation variables

How to test inequality constraint hypotheses has largely been studied in literature; the likelihood ratio test (LRT) is generally used to test the inequality constraint hypothesis at hand. The null distribution of this test is a chi-square distribution with degrees of freedom equal to the difference between the numbers of parameters of the models under comparison. An important result from the work of Barlow et al. (1972), Robertson et al. (1988), and Silvapulle and Sen (2004) is that one of the regularity conditions of the LRT does not hold when testing inequality constraint hypotheses, consequently, the asymptotic distribution of the LRT is no chi-square distribution and its p value cannot straightforwardly be computed.

[14] For an extensive econometric and statistical analysis of causal effects, see Imbens and Wooldridge (2009).

[15] Detailed results are available upon request.

Moreover, model selection criteria, such as the Akaike's Information Criterion or Bayesian Information Criterion, cannot be used to distinguish between statistical models with inequality constraints between the parameters of interest. These criteria use the likelihood evaluated in its maximum as a measure of model fit, and the number of parameters of the model as a measure of complexity. The problem is that model selection criteria cannot distinguish between hypotheses when these hypotheses do not differ in model fit, but only in the number of constraints imposed on the parameters of interest.

With reference to the literature on complementarity testing, Mohnen and Roller (2005) apply statistical Wald tests along the lines of Kodde and Palm (1986), for dichotomously practices. Linear regression under inequality constraints are to be computed and the critical values of such tests are cumbersome. Carree et al (2011) propose a procedure arguing that a combined hypothesis is accepted if all the separate hypotheses are accepted along the lines of Savin (1980).

Our idea is to evaluate informative hypotheses (where the parameter space is restricted), by using a parametric bootstrap procedure for directly testing the combined hypotheses (7.12), (7.13) and (7.23). Bootstrapping is an approach for statistical inference falling within a broader class of resampling methods (Efron and Tibshirani, 1993).

The procedure here adopted consists of three steps. In Step 1 a parametric bootstrap from a population, in which the null hypothesis H_0 - (7.12), (7.13) or (7.23) - is true, is computed. First, parameters are estimated under H_0 using the observed data. T bootstrap samples of size n are generated. Then, parameters are estimated for each replicated data set under H_0. Further, the parameters are estimated under the alternative hypothesis H_1, similarly. The second step, is to repeat these computations conditional on the observed data set. The final step is to choose a test statistic to investigate the compatibility of the null hypothesis with the observed data. Like many previous studies (e.g., Barlow et al., 1972; Robertson et al., 1988, Silvapulle and Sen, 2004), we use the LRT for evaluating the hypotheses at hand.

This procedure is conducted for each hypothesis (7.12), (7.13) and (7.23), as previously described. For each couple of complementarity constraints, we estimate the constrained model and test them by bootstrapping. It is also checked the presence of substitutable innovation practices by replacing the ≥ sign by the ≤ sign in all inequalities.

2.2.2 Case II: Endogenous innovation variables

The dependent variable – the exporting choice - is binomial, and the true underlying regression specification is non-linear. In order to address the issue of endogeneity in non-linear models for export propensity, we can use treatment-effects models.

In the econometric literature, several approaches estimate treatment-effects models that consider an endogenous binary treatment on another binary outcome, which can be used for our purposes.

If complex innovations were assigned completely at random, we could just compare treatment and control groups. However, this is likely not to be the case. When the regression of the outcome of interest on a potentially endogenous binomial variable is not linear, applications of the standard two-stage least square (2SLS) estimator, in which nonlinearity is ignored, can lead to a consistent but biased estimate of the causal effect of the dichotomous variable on the outcome.

In this context, some methods are designed to deal with endogeneity: propensity score matching methods; IV models, such as bivariate probit and maximum simulated likelihood methods.

We first consider the propensity score matching (PSM) approach, which compares exporters and non-exporters with a very similar probability of receiving innovation treatment (propensity score) based on observables (Rosenbaum and Rubin, 1983, 1985: Heckman et al., 1998). Our objective is to estimate the average treatment effect (ATE) as the difference between the probability of exporting, conditional on having received a treatment, and the probability of exporting of the untreated (or control) group, that is the exporting probability conditional on having received no treatment, both calculated over the entire population. The idea is to compare two alternatives: one with all units exposed to the treatment and one with none exposed, where the treatment is defined as the introduction of complex innovation policies.

The PSM is a balancing method, so covariate imbalance after propensity score matching is a concern. Indeed, the PSM is very sensitive to the choice of conditioning variables and robustness can be missing in the case of misspecification of such conditioning variables (Nichols, 2007; Heckman and Navarro-Lozano, 2004). In this view, we check the presence of imbalance by calculating the reduction of the median absolute standardized bias in the observables between the treated firms and all control units versus the treated and the matched control units. Literature suggests that the remaining bias should be smaller than 20 percent (Rosenbaum and Rubin, 1985). Similarly, comparing the pseudo-R^2 of the propensity score estimation before and after matching, a drop in the explanatory power is required, indicating that there is no remaining systematic difference in observables between treated and control firms in the matched sample.

Alternatively, among all possible IV models the maximum-likelihood bivariate probit approach is the simplest way to deal with endogeneity in complex non linear models, as suggested by Freedman and Sekhon (2010)[16]. However, convergence issues emerge in some cases and bootstrap standard errors calculated for ATE estimates are very small[17]. These problems are known in the literature (Nichols, 2011). Then, another IV model employing a maximum simulated likelihood (MSL) approach is used to estimate treatment-effects models (Miranda and Rabe-Hesketh, 2006).

A simultaneous model for export propensity and innovation strategy is considered, for which latent factors are introduced to model the likely correlation structure. We present MSL estimates, by assuming that the outcome variable and the treatment are modeled via logit models.

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[16] For a survey see Nichols (2007).

[17] Results are available upon request.

The choice of the instruments used in PSM and MSL approaches are driven by the application of under-identification LM tests (to verify that the excluded instruments are relevant) and Hansen-Sargan tests of over-identifying restrictions, as we have done for the Rivers-Vuong test.

MSL latent factor coefficients represent an additional test of endogeneity of innovation variables for export propensity, which can be compared to the Rivers-Vuong two stage tests carried out in the preliminary investigation of endogeneity of innovation variables. The effect of latent factors is captured by the estimated value of a ρ parameter and the exogeneity hypothesis is not rejected when ρ is not statistically different from zero. A positive (negative) ρ means that unobserved characteristics that increase the probability of a complex innovation strategy relative to the control also lead to a higher (lower) probability of exporting for treated individuals.

2.3 Multiple market destinations

Since we are interested in exploring whether firms' heterogeneity by export destination may play a role, the analysis of complementarities among innovation practices is generalized. Theoretical explanation of differences across export strategies involves the idea that fixed costs related to distribution and servicing are to be paid for each foreign market. Hence the more are the foreign markets served by the firm, the larger are the fixed export costs (Melitz, 2003). Then it is interesting to investigate whether the incentives of innovation practices change or not when comparing alternative exporting strategies.

The dependent variable – the exporting choice - is multinomial, when export propensity is evaluated specifying which destination markets are chosen by the firm, that is if EU market alone and both EU and extra-EU markets strategies are separately studied. The testing procedure requires the estimation of a multinomial model.

When multiple exporting strategies are considered and exogenous innovation variables are assumed an exogenous multinomial model is considered (Model 2):

(8) $$\ln \frac{\Pr\left(E_j = m \middle| \theta_j\right)}{\Pr\left(E_j = No\ \exp \middle| \theta_j\right)} = a_{0m} + a_{1m} C_j + a_{2m} \pi_j + \sum_{s \in S} a_{sm} D_{sj} + \sum_{i \in I} b_{im} D_{ij} + \varepsilon_{jm}$$

with m = {EU only, extra EU only, both EU and extra EU}.

The testing procedure of the combined hypothesis of complementarity – reported for all possible pairs of innovation practices in section 2.2 – is then performed with parametric bootstrapping for each exporting strategy. It is also checked the presence of substitutable innovation practices by replacing the ≥ sign by the ≤ sign in all inequalities.

When innovation variables are assumed to be endogenous, PSM and MSL estimators are used to separately calculate average treatment effects for EU only and both EU and extra EU strategies.

3. INNOVATION AND EXPORTING OF GERMAN MANUFACTURING FIRMS

3.1 Data description

Our analysis of the relationship between exporting and innovation activities is performed by using manufacturing firm-level data for Germany given by the Community Innovation Survey 2005 (CIS4). The CIS4 dataset is a survey of innovation covering the 2002-2004 periods for all sectors of the economy. Data on turnover, exports, dimension, etc., are also available. Table 1 reports export and innovation data description by sector.

For what concerns innovation the CIS4 considers the distinction made by the Oslo manual in its 2005 revision and data are collected on three forms of innovations: product innovations; process innovations; organizational and marketing innovations.

Product innovations involve the introduction of new goods or services or significant improvement of the existing ones. Process innovations include the implementation of a new or the improvement of already existing production or delivery methods. Organizational and marketing innovations consist of the implementation of new organizational or marketing methods[18].

As for any cross-sectional dataset also CIS4 one suffers from the problems highlighted by Mairesse-Mohnen (2010). In fact, analysis about direction of causalities with innovation issues and the treatment of econometric endogenous matters should involve dynamic setting and the availability of panel data. As already depicted in the previous section, we overcome this difficulty by adequately treating the endogeneity issue with appropriate econometric techniques dealing with discrete endogenous variables. On the other hand, the sample we consider fits very well the purpose of our analysis since a great deal of firms is involved in exporting and innovation activities. As shown in table 2 more than half of the firms (68,13%) exports, with a percentage increasing in the size from 47,23% of the small firms up to 72,06% of the medium and to 86,33% of the large firms. Even a greater share of firms innovates. In fact, 86,32% of them adopts at least one of the three innovation activities (table 3). Manufacturing firms are quite homogenously distributed among the three innovation activities and also in this case size plays a relevant role, since large firms are more involved than medium and small firms in innovation.

3.2 Exporters, non-exporters and innovation

This section is devoted to the analysis of the differences between exporters and non-exporters with respect to their innovation activities and to other characteristics. Moreover the analysis goes into

[18] New organizational methods involve changes in workplace organizations, external relations and business practices. New marketing methods concern changes in product promotion or pricing, product design or packaging and product placement.

details of the two sub-samples: exporters to EU markets (henceforth E_{EU}) and exporters to both EU and extra EU markets (henceforth E_B).

We first analyze the productivity levels of exporters versus non-exporters. We consider a measure of firm's relative profitability (π_j), proposed by Aw et al. (2008), given by the log of firm's revenue share. It is calculated as the deviation from the mean log market share in the 5-digit level industry[19]. Specifically, $\pi_j = \ln\left(\frac{r_j}{I}\right) - \frac{1}{n}\sum_j \ln\left(\frac{r_j}{I}\right)$ where r_j is firm j's revenue in a reference time period and I is total market size measured in terms of total industry revenues.

Table 4 shows that exporting firms are more productive than non-exporting ones. These results are in line with trade literature (Bernard et al., 2003; Bernard et al., 2007; Melitz, 2003; Yeaple, 2005) that is the more productive firms may afford the fixed costs of exporting better than the less productive ones. Moreover, the analysis on productivity levels of innovators versus non-innovators confirms what already stated by the economic literature (Griliches, 1998), since productivity is higher for innovating firms than for non-innovating ones: only more productive firms may afford the fixed costs of innovating.

We want now to explore if it is reasonable to infer a positive correlation between innovation practices and exporting at firm-level. In fact, trade-literature (Caldera, 2010; Becker-Egger 2013; Cassiman et al., 2010; Van Beveren-Vandenbussche, 2010; Wagner, 2007) has recognized the positive effect of innovation activities on exporting. In particular, through product innovation firms adequate their products to the foreign demand preferences or to foreign market regulations and conditions. By way of process innovation firms receive cost advantages and can charge lower prices

[19] Aw et al. (2008) show that the firm's observable revenue share is strictly linked to a theoretical measure of firm's relative profitability in a dynamic model of exporting, which shares many features with Melitz (2003) and Costantini and Melitz (2007). Such relative profitability depends on firm's productivity level, capital stock, mark-up and return to scale parameters.

becoming more competitive on the foreign markets of their products. Through organizational/marketing innovation firms may improve their competitiveness both on the side of product supply and on the side of the productive process.

In table 5 exporters and non-exporters are compared in terms of innovation practices. Exporters are more innovative than non-exporters and the relative weight of all three forms of innovation is greater in exporters than in non-exporters. More specifically the relative weight of process innovation is 25,65% greater in exporters than in non-exporters, for process innovation the relative weight is 17,34% bigger in exporters than in non-exporters and for organizational and marketing innovation the relative weight is 15,30%. Exporters adopt all types of innovation activities.

In the sample we analyze three different destinations for firms' exports: EU markets, other foreign markets and both destinations (EU and extra EU markets). We are particularly interested in analysing the two subsets of firms: the ones that export to EU markets (E_{EU}) and the ones that export to both markets (E_B). The main reason is in line with what highlighted above in section 2.4 and concerns the higher fixed costs of exporting incurred by the firms with larger foreign markets to serve (Melitz, 2003). We want to scrutinize whether this element of heterogeneity implies different behaviour of exporters with respect to their attitude to innovate.

Data in table 5 support our intuition, since the share of E_B that do not innovate are sensitively less than the share of E_{EU} firms that do not innovate (5,92% versus 9,36%) and the percentages of E_B that adopts each of the three kinds of innovation are always larger than the percentages of E_{EU}.

As a first step of the analysis of the relationship among firms' innovation activities and exporting, we estimate a logit model to identify exporting determinants.

Given the unobservable intensity of exporting E_j^* for any firm *j*, we can model it as follows:

(9) $$\ln \Pr\left(E_j = 1 \middle| \theta_j\right) = a_0 + a_1 C_j + a_2 \pi_j + \sum_{s \in S} a_s D_{sj} + b_1 I_{1j} + b_2 I_{2j} + b_3 I_{3j} + \varepsilon_j$$

where C_j is a dummy indicating if the firm *j* is part of a group, D_{sj} is a sector dummy and I_{kj} , k = 1, 2, 3, are innovation dummies reported by firm *j* and related to product, process and organizational/marketing practices, respectively. Again, π_j is a measure of firm's relative profitability as in Aw *et al*. (2008). It is calculated as the deviation of the log of the firm's revenue share from the mean log market share in the industry. Table A2 reports the list of variables we use in this study and descriptive statistics.

In order to evaluate the effects of environmental conditions on innovation strategies, a different framework is asked for. When a firm chooses between exporting toward EU countries only or selling to all (both EU and extra EU) countries, it takes into account different trade costs connected to all exporting alternatives, as suggested by Melitz (2003). Then it is interesting to investigate whether the incentives of innovation practices change or not when comparing these different environments. Thus, let consider a multinomial logit model:

$$(10)\quad \ln \frac{\Pr\left(E_j = m \mid \theta_j\right)}{\Pr\left(E_j = No\ \exp \mid \theta_j\right)} = a_{0m} + a_{1m}C_j + a_{2m}\pi_j + \sum_{s \in S} a_{sm}D_{sj} + b_{1m}I_{1j} + b_{2m}I_{2j} + b_{3m}I_{3j} + \varepsilon_{jm}$$

where m = {EU only, extra EU only, both EU and extra EU} and each outcome is compared to the no exporting group.

Before applying our methodology of complementarity testing to Model 1 and Model 2, exogenous logit estimates for both specifications (9) and (10) are presented in table 6. First of all, the positive link between productivity and exporting is confirmed. The coefficients on the productivity are positive and highly significant. More productive firms are more likely to export. For what concerns innovations the coefficient on the product innovation is for all firms positive and highly significant at the 1 percent. Firms that adopt product innovations are more likely to export. Going into details, the coefficient on product innovation is still positive and strongly significant for firms of small and medium size. Process and organizational innovations, instead, don't seem to have effects on the likelihood of firms' exporting. In fact, results show a positive significant coefficient only on process innovation for large firms[20].

Results on innovations are quite in line with what already emphasized by the literature (Becker and Egger, 2013; Caldera, 2010; Cassiman et al., 2010) that the effects of product innovations appear to weight more on exporting than those of other kinds of innovation. The stronger effects of product innovation may be explained as a necessary step which a firm has to deal with in order to serve foreign markets. Actually, firms do have to adjust their products to foreign markets regulations or to meet foreign demand and to differentiate from foreign competitors. On the other hand, process and organizational innovations imply firms' cost advantages that can have effects not so much on the likelihood of exporting but rather on the probability of surviving in foreign markets.

However, as previously highlighted (table 5), large percentages of exporters (both E_B and E_{EU}) adopt also process and organizational innovations in our sample. Moreover, data in table 7 show that the largest share of exporters (both E_B and E_{EU}) adopt all three forms of innovation jointly. We believe that the relationship between innovation and export deserves a deeper analysis.

More specifically, we next scrutinize if a relationship of complementarity among the three kinds of innovation exists when exporting is the firm's objective function.

3.3 Results on testing complementarity among innovation practices

In this section, we apply the testing procedure explained in sections 2.2-2.3 with the objective of evaluating the presence of complementarity among innovative activities for German firms.

Some preliminary checks have been performed. Data are heteroskedastic, therefore robust estimates have been calculated for all methods. Moreover, since large differences emerge across firms by

[20] Results on the two subsets of exporters (E_{EU} and E_B), available upon request, do not appear significantly different.

dimension, the analysis of complementarity is separately performed for small, medium and large firms groups.

To test the existence of endogeneity in non-linear models for export propensity, a Rivers-Vuong two stage test has been applied as detailed in section 2.2. The choice of the instruments used in PSM and MSL approaches has been driven by the application of under-identification LM and Hansen-Sargan tests. All instruments come from the CIS4 data set: public funding of innovation, cooperation arrangements on innovation activities, acquisition of machinery, training, sources of information on innovation, hampering factors, effect of organizational innovation. Detailed description is given in table A2 in Appendix.

When assuming exogenous innovation practices, for each couple of complementarity constraints, we estimate the constrained (exogenous) logit model (Model 1) and test them by bootstrapping. It is also checked the presence of substitutable innovation practices by replacing the ≥ sign by the ≤ sign in all inequalities. As to Model 2 with multiple market destinations (exogenous multinomial logit model), the same methodology is applied for each exporting strategy. Summary results are reported in table 8 for small, medium and large firms.

When assuming endogenous innovation practices, complementarity results are obtained by propensity score matching (PSM) and maximum simulated likelihood (MSL) methods. They are calculated in terms of average treatment effects (ATE), which are differences between the probability of exporting, conditional on having received a complex innovation treatment, and the probability of exporting of the untreated group. As to the PSM approach, we apply radius matching, where each treated firm is compared to all firms within a radius equal to 0.05 around its propensity score. Robustness of the method is checked by considering a smaller radius and alternative matching estimators (nearest-neighbor and kernel matching) in the sensitivity analysis. Imbalance is also tested. Detailed results for PSM effects are reported in table 9 and for MSL in table 10. In addition, table 10 shows tests on coefficients of the latent factors calculated in MSL estimates. The results confirm our preliminary investigation of endogeneity based on Rivers-Vuong test in many cases.

Table 11 summarizes all the results on complementarity and substitutability tests, indicating which cases do not reject the hypothesis of exogenous innovation variables and which ones do not reject the hypothesis of endogenous innovation variables.

Our analysis confirms what already emphasized by the literature: the adoption of innovation strategies by a firm improves its probability of exporting. Moreover, while previous works have identified product innovation as the main driver of firms' probability of exporting, our analysis gives more details of the relationship between firms' innovation and exporting. In fact the results confirm our preliminary intuition that the coexistence of different innovation strategies in exporting firms suggests the presence of various complementarities: exporters tend to adopt two or more practices together because their joint adoption leads to a higher probability of exporting than the sum of the probability from their individual adoption. As shown in table 13, supermodularity of innovation variables for export propensity is detected. Complementarities are found for medium and large firms between product and process innovation, between product and organizational/marketing innovations for medium firms and between process and organizational/marketing innovations for large firms.

Results confirm also our second intuition, that is firms that incur higher fixed costs of exporting, because of the higher number of foreign markets they serve (Melitz, 2003), exploit complementarities among innovation strategies in a deeper way than the other firms. In fact, as relationships of complementarities are frequent for firms exporting two both EU and extra EU markets, they are completely absent for firms exporting to EU markets only. Complementarity among innovation practices allows firms to better afford the fixed costs involved in an enlargement of destination markets. Results about complementarity are particularly evident for large firms exporting to both EU and extra EU markets. For this subset of manufacturing firms, complementarity arises between product and process innovations, between product and organizational innovations and between process and organizational innovations (all three pairs of innovations).

On the other hand, relationships of substitutability arise just for firms exporting to EU markets only and concern product/process and product/organizational innovations in small firms. For this subset of firms the three kinds of innovation are maybe considered as substitute pathways for investment spending and small manufacturing exporters to EU markets channel their investment spending into only one of the innovation strategies.

4. Conclusions

The focus of this paper was on the investigation of the relationship of complementarity among innovation practices when exporting is the firms' objective function through the properties of supermodular functions.

Three specific contributions have been reached in this study.

First, the main message of our study was that product, process and organizational-marketing innovations jointly matter for firms' export propensity. The issue of complementarity was addressed theoretically by studying the properties of supermodular functions and exploring firms' heterogeneity by export destinations.

Second, we provided a unified strategy to perform multiple inequality testing implied by the properties of supermodular functions, evaluating the potential endogeneity of binary variables in non linear models. Propensity score matching and instrumental variable methods were introduced as flexible tools for answering research questions about complementarity in the case of endogenous innovation regressors. The proposed econometric strategy considered either exogenous or endogenous innovation variables in the model specification of export propensity. The main advantage of using bootstrapping hypothesis testing in the former case and PSM/MSL treatment effects models in the latter one was the possibility to apply it to large data sets.

Third, we illustrated and tested the usefulness of the proposed strategy by using data from CIS4 for the 2002-2004 periods, in order to analyze the presence of heterogeneous incentives of exploiting complementarity among German manufacturing firms' innovation practices, by export destination and size. We showed that heterogeneous incentives of exploiting complementarity among German manufacturing firms' innovation practices emerge by export destinations and when size specific conditions are satisfied. Specifically, large firms exploit complementarity among all three forms of innovation. Furthermore, export strategies oriented to multiple market destinations require a stronger coordination among innovation activities. In fact evidence of complementarity relationship is found particularly for firms that export in both intra and extra EU markets.

Ongoing research will be focused on methodological issues related to the ideas of: (i) studying whether complementarity of innovation variables arises for services sector firms; (ii) and exploring other approaches for the treatment of endogenous discrete regressors in non linear models, such as Deb and Trivedi (2006) and entropy based semi-parametric methods, with reference to the multiple hypothesis testing cases implied by the properties of supermodular functions.

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Table 1: Export and Innovation data description , by sector

	Exporters		*Product innovation*		*Process innovation*		*Organiz/marketing innovation*		*Total*	
Nace rev. 1.1 sectors	Frequency	Percentage (%)	Frequency	Percentage (%)	Frequency	Percentage (%)	Frequency	Percentage (%)	Frequency	Percentage (%)
DA	70	2,98	84	3,58	69	2,94	100	4,26	147	6,26
DB	76	3,24	60	2,56	47	2,00	68	2,90	106	4,52
DC	15	0,64	11	0,47	9	0,38	8	0,34	22	0,94
DF_DG	148	6,31	160	6,82	123	5,24	153	6,52	207	8,82
DH	107	4,56	92	3,92	74	3,15	108	4,60	148	6,31
DI	53	2,26	59	2,51	40	1,70	57	2,43	92	3,92
DK	245	10,44	215	9,16	149	6,35	205	8,73	284	12,10
DL	332	14,15	358	15,25	230	9,80	310	13,21	443	18,88
DM	125	5,33	108	4,60	95	4,05	124	5,28	149	6,35
DN	64	2,73	58	2,47	46	1,96	64	2,73	102	4,35
20_21	77	3,28	64	2,73	66	2,81	76	3,24	136	5,79
22	39	1,66	64	2,73	75	3,20	99	4,22	125	5,33
27	75	3,20	50	2,13	64	2,73	64	2,73	92	3,92
28	173	7,37	141	6,01	141	6,01	161	6,86	294	12,53
Total	**1599**	**68,13**	**1524**	**64,93**	**1228**	**52,32**	**1597**	**68,04**	**2.347**	**100,00**

Sector description is reported in table A1 in Appendix

Table 2: Export data, by firm size

	total sample		*Small firms*		*Medium firms*		*Large firms*	
	Frequency	Percentage (%)	Frequency	Percentage (%)	Frequency	Percentage (%)	Frequency	Percentage (%)
Exporting firms	1599	68.13%	384	47.23%	552	72.06%	663	86.33%
Non exporting firms	748	31.87%	429	52.77%	214	27.94%	105	13.67%
Total	2347	100%	813	100%	766	100%	768	100%

Table 3: Innovation data, by firm size

	total sample		*Small firms*		*Medium firms*		*Large firms*	
	Frequency	Percentage (%)	Frequency	Percentage (%)	Frequency	Percentage (%)	Frequency	Percentage (%)
Product	1524	64.93%	420	51.66%	462	60.31%	642	83.59%
Process	1228	52.32%	294	36.16%	361	47.13%	573	74.61%
Organizational and marketing	1597	68.04%	452	55.60%	503	65.67%	642	83.59%
At least one of the 3	2026	86.32%	633	77.86%	654	85.38%	739	96.22%

Table 4: Productivity levels of exporters and innovators

	Mean	St. Dev.
Exporters	0.48	2.07
Non-exporters	-1.03	1.79
Innovators	0.31	2.12
Non-innovators	-0.99	1.72
All firms	0	2.11

Table 5: Innovation and exporting by market destination (frequency and percentage)

	Total	No innovation	Product	Process	Org/marketing
All firms	2347	321	1524	1228	1597
Exporters	1599	146	1169	925	1166
EU only	*748*	*70*	*456*	*373*	*505*
Extra-EU only	*115*	*10*	*75*	*50*	*77*
Both	*1115*	*66*	*854*	*675*	*850*
Non-exporters	748	175	355	303	431
All firms	100,00%	13,68%	64,93%	52,32%	68,04%
Exporters	100,00%	9,13%	73,11%	57,85%	72,92%
EU only	*100,00%*	*9,36%*	*60,96%*	*49,87%*	*67,51%*
Extra-EU only	*100,00%*	*8,70%*	*65,22%*	*43,48%*	*66,96%*
Both	*100,00%*	*5,92%*	*76,59%*	*60,54%*	*76,23%*
Non-exporters	100,00%	23,40%	47,46%	40,51%	57,62%
Difference between Exp and Non-exp		*-14,27%*	*25,65%*	*17,34%*	*15,30%*

Table 6: Marginal effects of product, process and organizational/marketing innovations

	Export propensity		
	Product innovation	Process innovation	Organizational/marketing innovation
All data	0.130*** *0.037*	-0.010 *0.037*	0.034 *0.038*
Small firms	0.142***	-0.024	0.031
	0.049	*0.051*	*0.049*
Medium firms	0.115**	-0.016	0.017
	0.045	*0.045*	*0.047*
Large firms	0.010	0.080**	-0.016
	0.034	*0.034*	*0.032*

Logit estimates; *** 1%, ** 5%, * 10% significant coefficients; standard errors in italics

Table 7: Innovation strategies (frequency in numbers and %)

	Total	000	001	010	100	110	101	011	111
All firms	2347	321	240	91	194	144	364	171	822
Exporters	1599	146	134	51	140	96	254	99	679
EU only	556	70	66	21	42	47	90	46	174
Extra-EU only	81	10	8	4	7	4	19	2	27
Both	962	66	60	26	91	45	145	51	478
All firms	100%	13,68%	10,23%	3,88%	8,27%	6,14%	15,51%	7,29%	35,02%
Exporters	100%	9,13%	8,38%	3,19%	8,76%	6,00%	15,88%	6,19%	42,46%
EU only	*100%*	*12,59%*	*11,87%*	*3,78%*	*7,55%*	*8,45%*	*16,19%*	*8,27%*	*31,29%*
Extra-EU only	*100%*	*12,35%*	*9,88%*	*4,94%*	*8,64%*	*4,94%*	*23,46%*	*2,47%*	*33,33%*
Both	*100%*	*6,86%*	*6,24%*	*2,70%*	*9,46%*	*4,68%*	*15,07%*	*5,30%*	*49,69%*

Table 8: Tests on complementarity/substitutability, bootstrapping for exogenous logit

	Export propensity			**EU market only (E_{EU})**			**EU and extra EU markets (E_B)**		
	product &process	product &organiz	process &organiz	product &process	product &organiz	process &organiz	product &process	product &organiz	process &organiz
Small firms	S			S	S		S		C
Medium firms									
Large firms	C		C	C			C	C	C

The letter S states that the hypothesis of substitution between two innovation practices cannot be rejected at 5%, the letter C indicates that the hypothesis of complementary innovation practices cannot be rejected at 5% and no letter is used when there is no significant relationship.

Table 9: Tests on complementarity/substitutability, MSL method

	Small firms				Medium firms				Large firms			
	ATE	Std. Err.	ρ	Std. Err.	ATE	Std. Err.	ρ	Std. Err.	ATE	Std. Err.	ρ	Std. Err.
Product&Process												
Export propensity	0.072***	0.001	-0.120	0.157	0.139**	0.078	-0.270*	0.154	0.081*	0.060	0.071	0.231
EU only	-0.001***	0.0004	0.059	0.178	0.110***	0.0011	-0.183	0.185	-0.095***	0.008	0.508***	0.131
Both	0.296	0.876	-0.707***	0.002	0.160***	0.052	-0.224	0.175	0.157***	0.066	-0.097	0.193
Product&Organiz												
Export propensity	0.081***	0.001	-0.045	0.115	0.162**	0.079	-0.299**	0.145	0.096	0.091	-0.251	0.165
EU only	0.046***	0.013	0.015	0.140	0.150***	0.005	-0.294	0.187	0.004***	0.0002	-0.073	0.254
Both	0.084*	0.064	-0.144	0.155	0.180***	0.042	-0.242	0.162	0.140**	0.074	-0.220	0.165
Process&Organiz												
Export propensity	0.041***	0.001	-0.016	0.130	0.076***	0.030	-0.148	0.131	0.080	0.038	0.022	0.201
EU only	0.001***	0.0003	0.096	0.154	0.079***	0.0027	-0.128	0.155	-0.128***	0.012	0.501***	0.183
Both	0.066*	0.045	-0.093	0.174	0.093***	0.014	-0.052	0.139	0.180***	0.005	-0.268*	0.158

***, ** and * indicate 1%, 5% and 10% significant average treatment effects and latent factor coefficients, respectively

Table 10: Tests on complementarity/substitutability, PSM method

	Small firms						Medium firms						Large firms					
	Radius 0.05		**Pseudo R^2**		**Mean bias (%)**		**Radius 0.05**		**Pseudo R^2**		**Mean bias (%)**		**Radius 0.05**		**Pseudo R^2**		**Mean bias (%)**	
	ATE	Bootstr. Std. Err.	Raw	Matched	Raw	Matched	ATE	Bootstr. Std. Err.	Raw	Matched	Raw	Matched	ATE	Bootstr. Std. Err.	Raw	Matched	Raw	Matched
Product&Process																		
Export propensity	0.032	0.044	0.005	0.001	18.1	3.7	0.060*	0.034	0.009	0	23.3	9.4	0.110***	0.047	0.026	0.008	38	32.4
EU only	0.024	0.036	0.007	0.003	10.8	2.4	0.004	0.039	0.013	0	11.7	5.7	0.007	0.049	0.029	0.017	22.8	18.3
both	0.007	0.034	0.007	0.003	10.8	2.4	0.068*	0.036	0.013	0	11.7	5.7	0.126***	0.059	0.029	0.017	22.8	18.3
Product&Organiz																		
Export propensity	0.112*	0.059	0.02	0.004	34.5	24.9	0.068*	0.035	0.015	0	28.7	13	0.017	0.040	0.009	0.004	23.3	6.4
EU only	0.042	0.050	0.015	0.003	17.1	9.4	-0.012	0.038	0.019	0.001	15.5	6.7	-0.077*	0.040	0.033	0	38.7	20.2
both	0.047	0.055	0.015	0.003	17.1	9.4	0.087***	0.035	0.019	0.001	15.5	6.7	0.107***	0.047	0.033	0	38.7	20.2
Process&Organiz																		
Export propensity	0.139***	0.071	0.002	0.014	12	5.5	0.115***	0.057	0.003	0.019	13.4	1.1	0.068***	0.033	0.019	0.001	32.1	16.8
EU only	0.131***	0.065	0.003	0.031	7.3	4.9	0.165***	0.075	0.008	0.057	9.3	7.4	-0.023	0.037	0.027	0.006	27.7	16.5
both	0.025	0.058	0.003	0.031	7.3	4.9	-0.010	0.060	0.008	0.057	9.3	7.4	0.117***	0.047	0.027	0.006	27.7	16.5

***, ** and * indicate 1%, 5% and 10% significant average treatment effects, respectively

Table 11: Tests on complementarity/substitutability, summary results

	Export propensity			EU market only			Both EU and extra EU markets		
	Product and process	Product and org/marketing	Process and org/marketing	Product and process	Product and org/marketing	Process and org/marketing	Product and process	Product and org/marketing	Process and org/marketing
Small firms	B: S	B: /	B: /	B: S	B: S	B: /	MSL: / PSM: /	B: /	B: C
Medium firms	MSL: C PSM: C 10%	MSL: C PSM: C 10%	B: /	B: /	B: /	B: /	B: /	B: /	B: /
Large firms	B: C	B: /	B: C	MSL: S PSM: /	B: /	MSL: S PSM: /	B: C	B: C	MSL: C PSM: C

Endogeneity tests of innovation variables are based on MSL latent factor coefficients and Rivers-Vuong procedure
B: Bootstrapping testing for exogenous logit and multinomial logit; MSL: maximum simulated likelihood method; PSM: propensity score matching.
The letter S states that the hypothesis of substitution between two innovation practices cannot be rejected at 5%, the letter C indicates that the hypothesis of complementary innovation practices cannot be rejected at 5% and the symbol ‘ / ‘ is used when there is no significant relationship.

Appendix

Table A1: Description of NACE rev. 1.1 sectors

Sectors	Description
DA	Food products, beverages and tobacco
DB	Textiles and textile products
DC	Leather and leather products
DF-DG	Coke, refined petroleum products and nuclear fuel; chemicals, chemical products and man-made fibres
DH	Rubber and plastic products
DI	Other non-metallic mineral products
DK	Machinery and equipment n.e.c.
DL	Electrical and optical equipment
DM	Transport equipment
DN	Manufacturing n.e.c.
20-21	Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials; pulp, paper and paper products
22	Publishing, printing and reproduction of recorded media
27	Basic metals
28	Fabricated metal products, except machinery and equipment

Table A2: Explanatory variables for exporting and innovation propensities

Variable	Description	Mean	Std. Dev.	Min	Max
π_j	Relative profitability of firm j	0.00	2.10	-5.84	7.81
gp	Enterprise part of a group	0.65	0.48	0	1
fun	Public funding of innovation	0.19	0.39	0	1
co	Cooperation arrangements on innovation activities	0.23	0.42	0	1
rmac	Engagement in acquisition of machinery	0.58	0.49	0	1
rtr	Engagement in training	0.47	0.50	0	1
roek	Engagement in other external knowledge	0.22	0.42	0	1
hprior	No innovation activity due to prior innovations	0.72	0.92	0	3
sins	Sources of information on innovation from consultants, commercial labs or private R&D institutes	0.55	0.78	0	3
suni	Sources of information on innovation from Universities or other higher education institutes	0.69	0.90	0	3
sgmt	Sources of information on innovation from Government or public research institutes	0.43	0.72	0	3
spro	Sources of information on innovation from Professional and industry associations	0.67	0.83	0	3
hdom	Hampering factor: Market dominated by established enterprises	0.39	0.79	0	3
hmar	No innovation activity due to no demand for innovations	0.88	1.03	0	3
hper	Hampering factor: Lack of qualified personnel	0.44	0.80	0	3
hfout	Hampering factor: Lack of outside funds	0.44	0.88	0	3
eforqu	Effects of organizational innovation: Improved quality of goods/services	1.29	1.24	0	3
eforco	Effects of organizational innovation: Reduced costs per unit output	0.99	1.11	0	3
efored	Effects of organizational innovation: Reduced time to respond to customers' needs	1.27	1.26	0	3