Export, R&D and New Products.
A Model and a Test on European Industries

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Abstract

In this article we extend the model developed by Bogliacino and Pianta (2013a, 2013b) on the link between R&D, innovation and economic performance, considering the impact of innovation of export success. We develop a simultaneous three equation model in order to investigate the existence of a 'virtuous circle' between industries' R&D, share of product innovators and export market shares. We investigate empirically – at the industry level – three key relationships affecting the dynamics of innovation and export performance: first, the capacity of firms to translate their R&D efforts in new products; second, the role of innovation as a determinant of export market shares; third, the export success as a driver of new R&D efforts. The model is tested for 38 manufacturing and service sectors of six European countries over three time periods from 1995 to 2010. The model effectively accounts for the dynamics of R&D efforts, innovation and international performances of European industries. Moreover, important differences across countries emerge when we split our sample in a Northern group – Germany, the Netherlands and the United Kingdom – and a Southern group – France, Italy and Spain. We find that the 'virtuous circle' between innovation and competitiveness holds for Northern economies only, while Southern industries fail to translate innovation efforts into export success.

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1. Introduction

Technological efforts and international competitiveness are at the root of successful economic performance in advanced economies. Moreover, they are widely seen as key factors for the ability of European countries to return to growth after the 2008 crisis. In this article we develop a model for the structural relationships between R&D efforts, innovation success and export performance, and we carry out an empirical test for 38 manufacturing and service sectors of six major European countries. The theoretical framework moves from the model developed by Bogliacino and Pianta (2013a, 2013b) and extends it to international competitiveness – captured by industries' export market shares. We use a model of simultaneous equations exploring feedbacks and structural linkages between our key variables. First, the ability of industries' R&D to lead to successful innovations is explored, combining supply push and demand pull drivers. Second, the determinants of export shares are identified, considering both the role of technological competitiveness and cost competitiveness factors (Soete, 1981; Fagerberg, 1988; Montobbio, 2003). Third, we investigate the feedbacks of export success and profits on further sectoral R&D efforts.

Conceptually, our model allows for the presence of diversity in innovation in a number of ways. We take into account the uncertainty of technological change, considering R&D efforts as distinct from the actual success in introducing new products. Innovation is seen as the result of both demand pull and technology push factors (Schmookler, 1966; Scherer, 1982; Kleinknecht and Verspagen, 1990 and Lucchese, 2011). The contrast between technological and cost competitiveness strategies pursued by firms and industries is put at the centre of international competitiveness (Pianta, 2001) and the broader links between technology and exports are fully addressed (Dosi et al. 1990).

In a recent set of contributions, there has been an effort to break down the innovation-performance nexus, into different constituent phases, in order to identify empirically its structural parameters. Usually, three equations are put forth: the decision to invest in R&D, the relationship between innovative inputs and outputs and the effect of R&D on economic performance (Crépon et al. 1998; Parisi et al. 2006). However, little attention has been devoted to the temporal structure and to feedbacks among such variables.

As to the link between innovation and international performance, a wide literature has already investigated, both theoretically and empirically, the relation between technology and competitiveness (see among others Dosi et al. 1990; Amendola et al., 1993, Carlin et al., 2001; Landesmann and Pfaffermayr 1997). In recent decades, trade has moved towards a greater relevance of intra-industry and intermediate input flows, and several studies have highlighted the role of the technological content in shaping such more complex trade patterns (Bas and Strauss-Kahn, 2010; Colantone and Crinò, 2014). In our model we integrate such aspects of international trade in the simultaneous and recursive explanation of innovation dynamics and export success.

To the best of our knowledge, Bogliacino and Pianta (2013a) is the first contribution which explores the feedback effect of the innovation-performance nexus, including the relevance of profits, leaving aside, however, the role of export. This article fills in this conceptual gap and investigates empirically the regularities and differences across Europe in such relationships, using a simultaneous three equations model (3SLS). Data cover 21 manufacturing and 17 service sectors (two-digits NACE classification) and are drawn from STAN and WIOD databases for production and demand variables, and from the Community Innovation Surveys (CIS hereafter) for innovation variables. Our model and econometric strategy allows for greater efficiency by controlling for correlation among errors belonging to different equations, while identifying the impact of endogenous regressors through the instrumental variables technique. As a result, it is possible to estimate the role of feedbacks and loops in an efficient and statistically parsimonious way.

This article is organized as follows. The next section is dedicated to a theoretical overview of the issues, considering separately each equation of the system. In the third section data are illustrated and some descriptive evidence is provided. In the fourth section the econometric strategy is described. In the fifth section, the results are presented and we provide additional findings on the contrast between patterns in Northern and Southern countries. Section six offers some concluding remarks.

2. Theoretical framework

At the root of our work there is the circular loop of self-reinforcing relations between R&D, new products and profits (Bogliacino and Pianta, 2013a, 2013b). The extension proposed here has the following dynamics: R&D efforts lead to successful innovations; new products drive the acquisition of export market shares; strong exports (together with profits) enhance R&D efforts. In the following subsections we first present the advantages of an analysis at the industry level, and we then illustrate the theoretical basis of each equation and the linkages with the existing literature.

2.1 The industry level approach

Studies on the topics addressed above have been carried out both at the firm and at the industry level. It is important to emphasise the differences between these two approaches and the specific value of industry level analysis.

Firm level studies have attracted increasing attention as a consequence of the emphasis on micro units of analysis that has emerged both in mainstream microeconometrics addressing causality issues, and in evolutionary approaches focusing on the heterogeneity of economic actors. While we share both concerns, we argue that firm level approaches cannot account for a number of explanatory factors in the analysis of innovation and performance that only emerge when the industry level is considered (Bogliacino and Pianta, 2013a).

(a) In most cases, the small number of firms often included in panel based firm level studies is not representative of the universe. Moreover, these studies are usually focused on manufacturing alone, without taking into account service activities. Furthermore, when a panel is followed over a certain time span, it excludes firms exiting and entering the market – events where innovation, or the lack of it, is likely to play a major role. Therefore, the results of firm level studies are relevant only for the firms included in the analysis, and can rarely be generalized to other firms, or assumed to be relevant for the whole economy. On the contrary, an industry level approach identifies the changes in the structure of the economy and the links to macroeconomic patterns because sectoral data account for the totality of activities in a given sector, allowing leveling off gains and losses that may occur at the firm level (Bogliacino and Pianta, 2013a).

(b) The specificity of technological trajectories and sectoral systems of innovation is at the heart of Neo-Schumpeterian and evolutionary approaches, which have widely documented the importance of industry level analysis. In this light, firms belonging to an industry are likely to share – to a large extent - the same technological opportunities, nature of knowledge, appropriability conditions and market structure (Dosi, 1982, 1988; Pavitt, 1984; Breschi et al. 2000, Malerba, 2004). Technological heterogeneity of sectors is therefore effectively identifiable by an industry level approach, while in firm level studies such heterogeneity is generally expressed in a limited way by inadequate indicators of industries' technological characteristics, or is generally left uncharted and wrapped with all sorts of other factors in industry dummies.

(c) The consideration of the role of demand determines the emergence of another fundamental asymmetry between industry and firm-level approaches. At micro level, a perfectly elastic demand can be assumed, since an individual firm can always grow and increase its market share at the expense of competitors. On the contrary, an industry's demand has a downward slope and results from the part of aggregate demand directed to the products and services of that industry. Therefore, a fundamental difference emerges: at the firm level the relationship between innovation and improved economic performance can easily be found while, without a simultaneous expansion of demand, this relationship is much less identifiable at the industry level (Bogliacino and Pianta, 2013a).

These fundamental differences between firm and industry level studies imply that the results obtained at one level cannot be automatically generalized at a more aggregate level.

2.2 Innovation and export success: concepts and literature

The state of the literature addressing the three relationships we investigate - the determinants of R&D efforts, innovation and export success – shows different degrees of consensus.

(a) Building on evolutionary approaches, R&D is considered here as a path dependent process because the development of knowledge and technology is closely related to the relevant paradigm and trajectory of technological change, making the process of search eminently localized (Atkinson and Stiglitz, 1969; Nelson and Winter, 1982; Dosi, 1982, 1988). In the R&D equation of our model, we account for such persistence of commitments by including lagged R&D among the explanatory variables. The influence of technological factors on R&D operates on the one hand through the nature of the industrial structure, reflected in average firm size and, on the other hand, on the potential for new markets - two additional factors we consider in our model.

A second variables affecting R&D efforts is related to demand (Piva and Vivarelli, 2007). Exports are the most dynamic component of demand in advanced countries and they lead to new demands for knowledge and competences required for international competition (Dosi et al, 1990; Carlin, 2001). Moreover, export success, together with Schumpeterian profits, plays a key role in providing the resources required for R&D. A large literature has shown that R&D is financially constrained (Hall, 2002; Cincera and Ravet, 2010; Bogliacino and Gomez, 2010) due the intangible nature of R&D, which is difficult to collateralize and also due to informational problems, namely the "radically uncertain" nature of research and the asymmetric distribution of information (Stiglitz and Weiss, 1981). As a result, successful economic performance – expressed by both exports and profits – represents a vital source of resources for financing industries' R&D.

(b) The relationship between R&D and innovative performance is the least controversial one. A large literature on both firms and industries – using a variety of models and approaches - has found that greater research efforts are generally associated to better innovative outcomes (for instance, Griliches, 1979, 1995; Crépon et al., 1998; Mairesse and Mohen, 2010; Loof and Heshmati, 2006; Parisi et al., 2006 for firm level studies; Crespi and Pianta, 2007, 2008a, 2008b and Bogliacino and Pianta, 2013b for industry approaches). Patterns of innovation are jointly affected by demand pull (Schmookler, 1966; Scherer, 1982) and technology push factors. According to the former perspective, innovation is brought to the market when firms anticipate strong demand; in the latter view innovation is supported by science-related developments and is triggered by relative prices in a feasible production set. Moreover, innovation is persistently characterized by the presence of specific technological and production capabilities (Pavitt, 1984; Dosi, 1988; Malerba, 2002; Metcalfe, 2010). On the technology side, in our analysis we build on the Schumpeterian distinction pointed out by Pianta (2001) between product and process innovation that helps identify heterogeneity in the determinants of innovative success. More precisely, we rely on the concepts of *technological* and *cost competitiveness* summarizing strategies focusing either on new markets, new products and R&D, or on efforts directed at labor saving innovation, new machinery, efficiency gains and cost reductions. Technological and cost competitiveness are proxied in our equations by specific variables accounting for R&D efforts on the one hand and new machinery on the other. On the demand side, the demand pull effect on the development of new products is accounted for by a detailed consideration of the different components of demand, including internal demand for intermediate and final goods, and exports. In this way a more comprehensive explanation of the drivers of innovative success is provided

(c) Today a wide agreement exists on the importance of innovation for international competitiveness of industries and countries. This has not always been the case. Traditional neoclassical trade theory disregarded differences in technology in explaining trade flows between countries, supposing that every country has access to the same technology set, while concentrating on factor endowments and hence on factor prices

instead. For a long time this has led economists to concentrate on price as the only aspect of competitiveness (Dosi et al. 1990, Amable andVerspagen, 1995). With the New Trade theory, also the mainstream has started to stress the importance of non-price factors in determining international competitiveness. This approach has pointed out the importance of product differentiation and quality on the supply side and of preference for variety on the demand side (Krugman, 1990). Innovation is crucial to both, leading to new products, while technology becomes a strategic variable to maintain market shares. R&D and innovation have also become important in growth theory where comparative advantages become endogenous and research policy and trade influence specialization and growth (Grossman and Helpman, 1991; Aghion and Howitt 1992, 1998).

Similar arguments had been developed before in the Post Keynesian literature emphasising non-price factors in countries' performances (Thirlwall, 1979; Kaldor, 1981); explanations of international competitiveness and specialisation have later explicitly included R&D and technology (Fagerberg, 1988; Archibugi and Pianta, 1992, Fagerberg et al., 1997). In evolutionary approaches technological differences among countries and industries have been considered as the basis for trade and for dynamic competition (Dosi et al. 1990, Amendola et al. 1993, Verspagen, 1993).

The recent developments of international production and trade, however, have led to a greater international integration and to more complex trade patterns of intermediate inputs, shaped by global value chains (Feenstra and Hanson, 1996; Hummels et. al, 2001; Backer and Yamano, 2012; Timmer at al. 2013). Imported intermediate inputs on the one hand may embody advanced technology and therefore increase the quality and variety of products and their technological competitiveness. On the other hand, they provide low cost inputs when production is outsourced to low wage countries, increasing in this way industries' cost competitiveness (Daveri and Jona-Lasinio, 2007; Bas and Strauss-Kahn, 2010; Colantone and Crinò, 2014). This complexity in the ways innovation affects international competitiveness has to be taken into account in modelling such relationships.

2.3 The R&D equation

The first equation of the model explains the determinants of R&D efforts:

$$R\&D_{ijt} = \beta_0 + \beta_1 * R\&D_{ijt-1} + \beta_2 * DEMPULL_{ijt} + \beta_3 * SIZE_{ijt} + \beta_4 * EXPSH_{ijt-1} + \beta_5 * PROF_{ijt-1} + \varepsilon_{ijt} \quad (1)$$

Where, *i* stands for sector at two digits level, *j* for country and *t* for time. The R&D variable is expenditure for research and development per employee (in thousands of euros); due to its path dependent nature, lagged efforts play a key role is shaping current R&D. DEMPULL stands for the potential for the introduction of new products, captured by the objective of opening up new markets reported by firms in innovation surveys (CIS). Following Schumpeterian insights, we expect that greater SIZE – average number of employees in industries' firms – would go along with higher R&D efforts. EXPSH is the lagged export market share of industries, computed (following Carlin et al., 2001) as the ratio between sector *ij*'s real exports and the sum of real exports for that industry and period for all the countries included in the sample; we expect higher export shares to be associated with greater technological efforts. PROF is the lagged growth rate of gross operating surplus - average annual compound rate of change in profits in the previous period – and is considered as a key source for internal R&D financing. The last term is the standard error term.

In discussing the determinants of R&D, a short digression is needed on the so called 'Schumpeterian hypothesis'. According to this strand of literature it is possible to identify an effect of firm size on R&D (Cohen and Levin, 1989; Cohen, 2010). Since the introduction of the Schumpeter Mark II model, the concentration of R&D expenditures in larger firms has been identified as a stylized fact. However, this line of research has been criticized for being unclear on whether it is innovation input or output that is affected by size and for the risk of endogeneity, given that both market structure and innovation are codetermined by the

fundamental features of the sector (appropriability, cumulativeness and the knowledge base, as explained by Breschi et al. 2000). Relying on the contributions which have stressed the importance of past economic performance as a main driver of R&D investments (Schumpeter, 1976; Brown et al. 2009), we emphasize the role of the incumbent position in export markets as a key element in determining R&D efforts in European countries. Industry level data make it possible to overcome the controversial evidence emerging from firm level studies (Greeve, 2003) about the association of past economic performances and R&D efforts. From this point of view, considering lagged export market share as a performance variable allows us to take into account both the commitment of firms to exploit and reinvest the results of their past performances, and the perspectives of higher external demand as drivers of R&D. This allows including size as a control variable without incurring into the risk of endogeneity via omitted variable.

2.4 The product innovation equation

The specification of the product innovation equation, the second of the system, is the following:

$$NEWPROD_{ijt} = \beta_0 + \beta_1 * R\&D_{ijt-1} + \beta_2 MACH_{ijt} + \beta_3 * EXPGR_{ijt} + \beta_3 * DEMGR_{ijt} + e_{ijt} \quad (2)$$

where NEWPROD stands for the share of firms that are product innovators in the sector – an accurate indicator of the relative success in introducing new products in markets. Its first determinant is lagged R&D input (estimated in the first equation); the ability of new R&D expenditure to lead to successful innovations takes time and for this reason the R&D variable is inserted with one period lag. In terms of innovation dynamics, we consider the complementary effect – or, possibly, the contrasting role - of innovation in processes, proxied by MACH – innovation related expenditure for machinery and equipment, in thousands of euros per employee. The success in the introduction of new products is also affected by demand factors; EXPGR is the compound annual growth of exports and DEMGR reflects the dynamics of internal demand, split into the growth rates of final demand and of demand for intermediate goods produced by the industry; ε the usual error term.

The demand pull perspective and the literature on structural change (Pasinetti, 1981) emphasize the positive effect that a strong demand dynamics has on the development and diffusion of new products. This is a complementary approach to the Schumpeterian analysis on the way major innovations change the economy. However, not all demand components may play the same role; when an economy – or an industry - operates in the Walrasian (or equilibrium) "circular flow", without major innovations, current demand for standard products may reduce the incentive to develop new products and delay their introduction. Therefore we need to identify on the one hand the more 'dynamic' components of demand - such as exports - that match current technological change and support the introduction of new products in a virtuous circle among capabilities, innovations and markets (as in the "learning by exporting" hypothesis assessed by Crespi et al., 2008). Conversely, demand that is related to the activity of industries where a "circular flow" prevails – such as demand for consumption and for intermediate goods – may lead to fewer incentives for the introduction of new products.

2.5 The export market share equation

The specification of the market share equation, the third of the system, is the following:

$$EXPSH_{ijt} = \beta_0 + \beta_1 NEWPROD_{ijt-1} + \beta_2 MACH_{ijt} + \beta_3 ULC_{ijt} + \beta_4 INTERM_{ijt} + \eta_{ijt} \quad (3)$$

where success in international competitiveness is proxied by EXPSH - the export market share of sector i in country j with respect to the total of the exports of the same sector for the whole sample. For the method of calculation we rely on the one used in Carlin et al. (2001):

$$EXPSH = \frac{EXP_{ijt}}{\sum_j^{j\in\{1,..,6\}} EXP_{ijt}} \quad (4)$$

$$i \in \{NACE\}, j \in \{Ger, Sp, Fr, It, Nl, Uk\}$$

We considered the export market shares computed in (4) as a reliable measure of relative competitiveness of our sample's countries and industries since their position is highly stable; an extensive analysis of the reliability of this variable as a proxy for export performances is provided in the Appendix.

Competitive success is expected to result from both technological and cost competitiveness. The former is reflected in NEWPROD - the share of product innovators among the firms of sector i (in our system is the variable estimated in the product innovation equation). Efforts in process innovation may strengthen competitiveness in various ways and is proxied by MACH - expenditure in thousands of euros per employee for innovation related machinery and equipment. The major source of cost competitiveness is related to labour costs, and is proxied by the compound average annual rate of change of unit labour cost (ULC), defined as follows (Carlin at al., 2001):

$$UNITLC_{ijt} = \frac{(W_{ijt} \,/\, EMP_{ijt})}{(VA_{ijt} \,/\, ENG_{ijt})} \quad (5)$$

where the numerator is the wage per employee in real terms and the denominator is the ratio between the industry's value added and the number of total engaged – a measure of productivity. Finally, the complexity of current patterns of trade flows requires the consideration of the role different intermediate inputs (INTERM) may play in contributing to an industry's competitive success. In our equation we distinguish them on the basis of both their origin (domestic or imported) and their technological content (based on the revised Pavitt categories[1]: high when inputs are provided by Science Based and Specialized Supplier sectors, and low when they are provided by Scale Intensive and Supplier Dominated sectors, see the Appendix). The four variables accounting for the role of intermediate inputs therefore include the following: domestically sourced inputs of high technological content; domestically sourced inputs of low technological content; imported inputs of high technological content; imported inputs of low technological content. Indicators are computed as the sum of the expenditure devoted by each industry to the acquisition of different types of inputs, divided by the total production of each user sector (Yamano and Ahmad, 2006). We expect that competitive success is driven by a greater use of inputs with higher technological content and of international origin.

Equation (3) is the crucial one in our model since it highlights the differences in terms of relevance of technological and cost competitiveness. Moreover, the estimated coefficients of this equation within our simultaneous system may allow identifying different types of relationships between innovation and international performance that will be examined later by splitting the sample between a group of 'Northern' and 'Southern' countries.

The full system is:

$$\begin{cases} R\&D_{ijt} = \beta_0 + \beta_1 * R\&D_{ijt-1} + \beta_2 * DEMPULL_{ijt} + \beta_3 * SIZE_{ijt} + \beta_4 * EXPSH_{tij-1} + \beta_5 * PROF_{tij-1} + \varepsilon_{ijt} \\ NEWPROD_{ijt} = \beta_0 + \beta_1 * R\&D_{ijt-1} + \beta_2 MACH_{ijt} + \beta_3 * EXPGR_{ijt} + \beta_3 * DEMGR_{ijt} + e_{ijt} \quad (6) \\ EXPSH_{ijt} = \beta_0 + \beta_1 NEWPROD_{ijt-1} + \beta_2 MACH_{ijt} + \beta_3 ULC_{ijt} + \beta_4 INTERM_{ijt} + \eta_{ijt} \end{cases}$$

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[1] An extensive description of the revised Pavitt taxonomy proposed by Bogliacino & Pianta (2010) and used in this paper is provided in the Appendix

3. Data and descriptive evidence

3.1 The database

The database used in this paper is the Sectoral Innovation Database (SID) developed at the University of Urbino[2] that combines different sources of data at the two-digit NACE classification for 21 manufacturing and 17 service sectors; all data refer to the total activities of industries. For innovation variables data are from three European Community Innovation Surveys - CIS 3 (1998-2000), CIS 4 (2002-2004) and CIS 6 (2006-2008). Economic variables are obtained from the OECD-STAN database; demand, trade and intermediate inputs variables are drawn from the World Input Output Database (WIOD) (Timmer, 2012). The country coverage of the database includes six major European countries – Germany, France, Italy, Netherlands, Spain, and United Kingdom - that represent a large part of the European economy. The selection of countries and sectors has been made in order to avoid limitations in access to data, due to the low number of firms in a given sector of a given country, or to the policies on data released by national statistical institutes.

The time structure of the panel is the following. Economic and demand variables are calculated for the periods 1995-2000, 2000-2005 and 2005-2010. The export market shares variable is computed for each industry for the final year of each period – the years 2000, 2005 and 2010. Innovation variables refer to 1998-2000 (linked to the first period of economic variables); 2002-2004 (linked to the second period of economic variables) and 2006-2008 (linked to the third period of economic variables). The variables used are listed in Table 1.

Table 1. List of Variables

Variable	Unit	Source
In-house R&D expenditure per employee	Thousands euros/empl	CIS
New machinery expenditure per employee	Thousands euros/empl	CIS
Share of product innovators	percentages	CIS
Share of firms innovating with the aim of opening new markets	percentages	CIS
Average firm size	Number empl. per firm	CIS
Rate of growth of Exports	Annual rate of growth	WIOD I-O Tab.
Rate of growth of Intermediate Demand	Annual rate of growth	WIOD I-O Tab.
Rate of growth of Final Demand	Annual rate of growth	WIOD I-O Tab.
Rate of growth of Imported Interm. Inputs (high and low-tech)	Annual rate of growth	WIOD I-O Tab.
Rate of growth of Domestic Interm. Inputs (high and low tech)	Annual rate of growth	WIOD I-O Tab.
Rate of growth of Wages	Annual rate of growth	STAN Isic Rev.3
Rate of growth of Profits	Annual rate of growth	STAN Isic Rev.3

All economic variables are deflated using the sectoral Value Added deflator from OECD-STAN (base year 2000), corrected for PPP (using the index provided in Stapel et al. 2004). For the performance variable we compute the compound annual growth rate that approximates the difference in log; for innovation we use the shares of firms in the sector or expenditure per employee; this can be justified considering innovative efforts as dynamic and capturing the change in the technological opportunities available to the industry.

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[2] Pianta et al. 2011 provide a comprehensive description of the database. CIS innovation data are representative of the total population of firms and are calculated by national statistical institutes and Eurostat through an appropriate weighting procedure (A detailed description of the procedure is provided in Bogliacino and Pianta 2013a).

The dataset is a panel dataset over three periods covering a time span from 1995 to 2010 across six major European countries. This kind of industry level-dataset accounts for the complexity of innovation at the sectoral level, as well as for consideration of both supply and demand determinants of economic and innovative performances. A summary of the strengths of this dataset is provided below:

➢ The industry level detail of the dataset allows to identify the specificity of industries in terms of their innovation patterns and growth trajectories, considering both manufacturing and service sectors;

➢ The detailed nature of CIS data offers the possibility to take into account different innovation strategies (cost and technological competitiveness) as well as different aims of innovation;

➢ Input-Output data allow to distinguish the intermediate inputs used by a sector on the basis of their technological intensity (identified by the two digit NACE sector of origin of the inputs) and of their domestic or imported origin;

➢ The availability of consistent export data allows for the construction of reliable competitiveness indicators by industry.

In order to use these data in panel form, we need to test that the sample design or other statistical problems in the gathering of data are not affecting their reliability. Besides considering the time-effects capturing macroeconomic dynamics, we have examined the stability of the database. The following table reports the main descriptive statistics:

Table 2. Descriptive statistics

Variables	Mean	SD Overall (Whole sample Variability)	SD Between (Var. across industries)	SD Within (Var. across country and time)
In-house R&D expenditure per employee	2.65	4.86	4.36	2.07
New Machinery expenditure per employee	1.70	2.69	2.51	1.44
Share of product innovators	35.03	43.15	61.83	13.28
Share of firms innovating with the aim to open new markets	25.58	15.88	13.36	9.33
Average firm size	0.364	1.90	1.51	1.38
Rate of growth of Export	2.07	26.25	18.97	18.17
Rate of growth of Intermediate Demand	0.77	8.89	5.41	7.06
Rate of growth of Final Demand	0.09	17.19	11.12	13.13
Export Market Shares	0.16	0.14	0.13	0.04
Rate of growth of operating surplus	3.72	17.25	16.2	8.01
Rate of growth of Unit Labor Cost	-0.63	8.49	4.38	7.28

3.2 Some descriptive evidence

As we anticipated, one of the main objectives of this work is to analyze the connections and the feedbacks between innovation, labour cost and economic performances in terms of export market shares, with a specific attention to the North-South divide in Europe. Table 3 contains data at the country level for the key economic and innovation variables used for the subsequent econometric analysis, providing information on national competitiveness. The figures also provide a first snapshot of the North-South divide within the EU, highlighting the dynamics of technological and cost competitiveness across EU countries. Looking at R&D expenditure, Spain and Italy lag behind the rest of the countries in the sample. Regarding product innovation, the differences between Germany and the South are striking, and are paralleled by the distance in export

market shares. Unit labour cost figures show an increasing trend in Italy, the Netherlands and the UK, with the opposite trend in the other countries.

Table 3. Economic and Innovation Variables, descriptive statistics by country (averages 1995-2010)

Country	R&D per empl. (%)	Mach. Exp per empl. (%)	New Products (%)	New Market Obj. (%)	Unit Labour Cost (%)	Export Market Share (%)
Germany	3.87	3.84	60.05	35.32	-3.05	0.29
Netherlands	3.08	1.19	36.79	26.50	1.90	0.12
UK	2.06	2.35	25.23	33.94	0.11	0.23
North	3.06	2.71	41.08	33.00	-0.34	0.64
Spain	0.99	0.68	25.23	16.79	-1.49	0.08
France	4.84	0.80	36.60	26.89	-2.15	0.14
Italy	1.37	1.42	29.04	16.00	0.88	0.14
South	2.38	0.99	30.24	19.85	-0.92	0.36

Notes: Labour Cost is the compound average annual rate of change of the indicator computation shown in (6), Export Market Shares is the average over the sample period, and totals for 'Northern' and 'Southern' groups are the sum of countries' shares. All the variables are in euros and in real terms. R&D expenditure and Process Innovation (Expenditure for Machineries and Equipments) are in thousands of euros for employee. New market objectives is a share variable computed dividing the respondents who declared that opening a new market is their main aim to innovate over the whole population of firms.

The Italian case deserves a particular attention. Italy has maintained a significant market share despite a weak performance in new products and processes and a rise in unit labor costs higher than in most countries. The complexity of the patterns involved – including the role of intermediate inputs, non price competitiveness and product quality – are relevant in the explanation of such outcome; a similar investigation has been carried out by Tiffin (2014) in a recent IMF paper exploring the "Italian productivity puzzle". In the Appendix a more detailed descriptive analysis of the variables is provided.

4. Econometric Modelling Strategy

The estimation strategy adopted is the following. First, in order to verify the validity of the hypothesized relationships, we implement a WLS estimation equation-by-equation, carrying out all the needed diagnostic tests. Second, in order to identify the feedbacks and self-reinforcing loops among our variables, we use a model suitable for the estimation of systems of equations. We have chosen the Three Stages Least Squares model (3SLS) since it allows estimating a simultaneous system of equations addressing at the same time all the endogeneity issues. Third, we replicate the 3SLS estimation adopting the interaction terms technique in order to assess the extent of a divergent dynamics between Northern and Southern countries.

The 3SLS method generalizes the two-stage least squares (2SLS) method to take account of the correlations between equations in the same way that Seemingly Unrelated Regression (SUR) generalizes OLS. 3SLS requires three steps: first-stage regressions to get predicted values for the endogenous regressors; a two-stage least-squares step to get residuals to estimate the cross-equation correlation matrix; and the final 3SLS estimation step. The 3SLS method goes one step beyond the 2SLS by using the 2SLS estimated moment matrix of the structural disturbances to estimate all coefficients of the entire system simultaneously. The method has full information characteristics to the extent that, if the moment matrix of the structural disturbances is not diagonal (that is, if the structural disturbances have nonzero "contemporaneous" covariances), the estimation of the coefficients of any identifiable equation gains in efficiency as soon as there are other equations that are over-identified. Further, the method can take account of restrictions on parameters in different structural equations (Zellner and Theil, 1962).

Two further methodological points must be addressed: the choice of weights and the choice of instruments. As it is well known, industry level data are grouped data of unequal size, thus we cannot expect all industries to provide the same contribution in terms of information; as a result, the consistency of the estimation is affected. Following Bogliacino and Pianta (2013a, 2013b) we achieve consistency using the weighted least

squares estimator (WLS) that allows taking the relevance of industries into account (Wooldridge, 2002, Ch. 17). The use of a correct weight becomes crucial and the choice is usually limited to value added and number of employees. Statistical offices tend to use the latter since the former is more unstable and subject to price variations, and we follow them in the use of employees as weights.

In order to control for endogeneity, our baseline strategy is to use the lag structure; since our time lags are of three to five years, the autoregressive character of variables is considerably softened but not eliminated, which makes them suitable instruments. Moreover 3SLS is a proper estimation technique to account for endogeneity when dealing with systems of equations. Anyway, there is always a trade-off between consistency and efficiency in choosing an estimator. Due to modest sample size (inevitable with industry level data), we solve the trade-off relying on consistency instead of efficiency. In fact, with 3SLS we only have to care about orthogonality inside each equation, without taking care of what is happening elsewhere in the system (ibid., 199). As a result, we can focus on the choice of instruments equation by equation in order to guarantee identification. We identified four endogenous variables: SIZE in the first equation, EXPGR in the second, MACH and INTERDEM in the third. The set of instruments we used include the rate of change of lagged value added, lags of the endogenous variables, country, Pavitt and time dummies. Additional endogeneity tests – carried out equation by equation - and the instruments validity tests are discussed in detail in the Appendix. Moreover, we controlled for the presence of multicollinearity and heteroscedasticity. All tests confirm the robustness of the approach we have followed.

5. Results

The results of our estimates are presented separately for each equation in the three tables below. We implemented the model on all manufacturing and service industries (38 sectors, Nace Rev. 1), with two different specifications: a baseline estimation and a model with country and technology dummies; in the latter we control for country specificities and technological intensity – as well as for differences in technological trajectories among sectors - using dummies for the revised Pavitt taxonomy (Bogliacino and Pianta, 2010). In principle, the use of rate of change is assumed to clear fixed effects at country and industry level, but dummies may capture differences in terms of trend across them.

5.1 The Weighted Least Squares Estimations

We first provide some comments over diagnostic tests. Multicollinearity is not an issue; we have conducted the VIF test over each of the three equations, obtaining respectively the following factors: 1.32 for the first equation, 1.26 for the second and 2.55 for the third. Since the critical value for the VIF statistic in order to detect multicollinearity among regressors is near to ten (Kleinbaum et al.,1988, p. 210), we can exclude the presence of multicollinearity in our regressions. Moreover, the results of the Breusch-Pagan test for heteroskedasticity reject for each equation the null hypothesis of constant variance. As a result, we carried out all the estimations with robust standard errors. The results of the R&D equation contained in Table 4 suggest that the theoretical framework developed in Section 2 is supported by the empirical results. Both the baseline and the model with country dummies show that R&D efforts are explained by the cumulative nature of R&D, identified by the coefficient of lagged R&D expenditure. The *demand pull* factor, proxied by the importance of firms innovating with the aim of entering new markets is not significant; a possible explanation could be found in the major role played by lagged profit and export market share. The latter in particular can easily capture the motivation to invest in R&D related to the opening of new markets making the *New Markets Objective* variable less relevant.

Table 4. The R&D equation

Dependent Variable: In-house R&D expenditure per employee.

WLS with robust standard errors and weighted data (weights are the numbers of employee).
t-stat in brackets.
* significant at 10%, ** significant at 5%, *** significant at 1%.

	(1) Baseline Model	(2) Baseline with dummies
Lagged R&D expenditure	0.58 [8.35]***	0.51 [6.90]***
Firm Size	11.42 [6.66]***	12.05 [6.98]***
New Markets Obj.	0.03 [1.64]	0.02 [0.93]
Profits (first lag)	0.026 [2.25]**	0.03 [2.26]**
Export Market Share (first lag)	3.68 [1.68]*	4.04 [1.71]*
Country dummies		Yes
Pavitt dummies-industry groups		Yes
Constant	-1.01 [-0.94]	-1.88 [-3.06]***
N.observations	179	179
R2 (Adj)	0.73	0.73

Supporting the Schumpeterian assumption of R&D efforts driven by large firms able to earn monopolistic profits, the *Size* variable is significant and positively related to the dependent variable in both the baseline and the country dummy equation. Moreover, *lagged profits* have an important role in determining new R&D investment. Finally, the *lagged export market share* is significant and positive in both estimations.

Regarding the dummy variables inserted in the second equation, *country dummies* do not seems to play a clear role in the case of R&D efforts, while *Pavitt dummies* are both positive and significant for Science Based and Specialized Supplier sectors. The interpretation of the coefficients associated to *Pavitt dummies* is straightforward since we can expect that sectors characterized by an intensive use of technological inputs are also those where R&D efforts are relatively higher. Including country dummies in our baseline model does not harm the significance of the estimated coefficients, so we can proceed to analyse the New product equation.

The results in Table 5 show that innovative performances are mainly driven by research efforts. The coefficient associated with past R&D efforts is positive and significant in both the baseline and the country/Pavitt dummy equation. On the contrary, the coefficient associated to process innovation - *Expenditure for new machinery and equipment*, a proxy for cost competitiveness strategies - is negative and is significant in the country dummy specification only. This result may suggest that at the industry level product and process innovation are more substitute than complement; industries tend to be characterised either by a prevalence of the search for new products, or by efforts to introduce new processes; this further supports our distinction between technological and cost competitiveness.

Among demand variables the impact on innovation of the *rate of growth of exports* is always positive, although it is not statistically significant. The internal demand for final consumption and intermediate goods has negative and significant coefficients that could be explained by the lack of dynamism and innovative content of domestic demand with respect to exports. Such a result is in line with the previous findings of Bogliacino and Pianta (2013b) where in an analogous specification they found that only exports, out of the complete set of demand components, are able to explain innovative performances.

Table 5. The New Product Equation

Dependent Variable: Share of firms carrying out product innovation.

WLS with robust standard errors and weighted data (weights are the numbers of employee).
t-stat in brackets.
* significant at 10%, ** significant at 5%, *** significant at 1%.

	(1) Baseline Model	(2) Baseline with dummies
Lagged R&D expenditure	1.57	1.60
	[6.23]***	[6.28]***
Expenditure for Mach. & Equipments	-0.45	-1.16
	[-0.69]	[-1.73]*
Demand for Final Consumption (Rate of Growth)	-0.28	-0.24
	[-0.38]	[-0.33]
Demand For Interm. Goods (Rate of Growth)	-0.55	-0.47
	[-2.88]***	[-2.49]**
Exports (Rate of Growth)	0.01	0.009
	[0.70]	[0.41]
Country dummies		Yes
Pavitt dummies-industry groups		Yes
Constant	37.79	30.04
	[11.14]***	[6.75]***
N.observations	286	286
R2 (Adj)	0.55	0.57

Dummy variables point out some divergent trends in this case. In the country dummy specification Germany and the Netherlands have a positive and strongly significant role in explaining innovative performances in our sample; these results begin to delineate the divergent dynamic between Northern and Southern countries. Looking at *technology dummies*, Science Based and Specialized Supplier sectors have - as expected - a positive and significant impact on innovative performances.

Table 6. The Export Market Share Equation

Dependent Variable: Export Market Share.

WLS with robust standard errors and weighted data (weights are the numbers of employee).
t-stat in brackets.
* significant at 10%, ** significant at 5%, *** significant at 1%.

	(1) Baseline Model	(2) Baseline with dummies
Lagged Product Innovation	0.0015	-0.0004
	[2.88]***	[-0.03]
Expenditure for Mach. & Equipments	0.014	0.01
	[2.41]***	[1.83]*
Unit Labour Cost (Rate of Growth)	-0.005	-0.004
	[-3.39]***	[-3.07]
Domestic Interm. Inputs, low tech (Rate of Growth)	-0.012	-0.12
	[-3.51]***	[-3.80]***
Domestic Interm. Inputs, high tech (Rate of Growth)	-0.004	-0.002
	[-1.43]	[-0.81]
Imported Interm. Inputs, low tech (Rate of Growth)	0.002	0.003
	[1.02]	[1.77]*
Imported Interm. Inputs, high tech (Rate of Growth)	0.015	0.011
	[5.31]***	[3.98]***
Country dummies		Yes
Pavitt dummies-industry groups		Yes
N.observations	287	287
R2 (Adj)	0.79	0.81

The results of Table 6 show that industries' export market shares are supported by both technological and cost competitiveness, confirming the view developed in the theoretical framework of Section 2. In the baseline equation, lagged new products, new processes and lower labour costs are all significant factors in strengthening exports shares. However, including country dummies in the second specification of the model leads to a loss in significance of product innovation and labour costs, as country specificities do play a key role in shaping national competitiveness. The intermediate input mix is also relevant to explain performances of sectors. Industries' export performance is supported by the imports of inputs from high-technology sectors, that improve the quality and variety of goods produced, improving technological competitiveness. Conversely, domestic low-tech inputs have a negative impact on export shares as industries more dependent from such factors are left out of innovation dynamics; this result is in line with the findings of authors who have already analyzed the relation between imported inputs and export performance (Bas and Strauss-Kahn, 2010; Colantone and Crinò, 2014).

The included dummies are all significant and, also in this case, the coefficient associated to Germany has the highest positive impact on the dependent variable In the next subparagraph the results of the full system estimation and the test for the presence of the North-South divide are reported.

5.1 The system of equation for R&D, New Products and Export Market Shares

This section provides the results of the structural 3SLS estimations. Table 7 contains the results for the whole sample estimation while in Table 8 the results from the model with separate estimations for Northern and Southern countries are shown.

The estimated coefficients and goodness of fits are consistent with the previous regressions and – in the first two equations - with the version of the model developed in Bogliacino and Pianta (2013a, 2013b). In the R&D equation (column 1) past R&D, past profits and export market shares – with strongly significant coefficients - support R&D efforts, that are also 'pulled' by the presence of a potential market for new products and 'pushed' by the importance of firm *size*, confirming the "Schumpeter Mark II" perspective. R&D expenditures are driven by the presence of high techological opportunities, extensive profit-based financial resources and high export market power.

In the product innovation equation (column 2), the importance of new products is the result of past R&D - with a positive and significant impact – confirming the close relationship between technological inputs and outputs. The introduction of new processes appears here to play a complementary role to new products, with a positive and significant coefficient. Demand variables have - as expected - different effects on new products: export growth is associated to a higher presence of product innovators, in line with the "learning by exporting" hypothesis (Crespi et al. 2008); a large growth of final consumption and intermediate demand, conversely, is associated to lower product innovation (a result already detected in the simple OLS estimation); an increase in such components of demand may lower the need to introduce new products, a relationship that is typical of "traditional" industries and services with little R&D, more standard goods and less international openness.

Finally, export market shares (column 3) are positively explained by product and process innovation (again showing complementarity) and, negatively, by unit labor costs; competitive success is therefore driven by both technological and cost competitiveness. Firm size has a negative impact on export market shares, suggesting a greater dynamism of small firms, especially in sectors more open to trade and with higher technological intensity. The relevance of size in influencing high R&D efforts (found in equation 1) is then lost when such technological efforts have to be turned into success in international markets. Considering the intermediate input mix, we find that - as already detected in the WLS single equation estimation - a growth in imported high tech intermediate inputs has a positive and significant impact on export performances, as it may improve the technological competitiveness of an industry's output. Conversely, a negative and significant link is found with domestic low tech intermediate inputs; they may help reduce production cost,

but are of no use in gaining foreign markets. The other two types of intermediate inputs do not have significant effects.

Table 7. The system of equations for R&D, New Products and Export Market Shares
Three Stage Least Squares. Standard Errors in brackets, * significant at 10%, ** significant at 5%, *** significant at 1%.

	Equation 1 R&D per employee	Equation 2 Share of Product Innovators	Equation 3 Export Market Share
R&D per employee (First lag)	0.57 [0.61]***	**0.5** **[0.28]*****	
Rate of growth of profits (First Lag)	0.03 [0.01]***		
New Market Objective	0.05 [0.02]**		
Size	10.02 [1.65]***		-0.14 [0.08]*
Export market share	**4.64** **[2.69]*****		
Rate of growth of export		0.93 [0.32]***	
Rate of growth of final consumption		-0.047 [0.06]	
Rate of growth of intermediate demand		-0.49 [0.20]**	
Share of Product Innovators			**0.0034** **[0.0006]*****
New machinery per employee		2.26 [0.70]***	0.028 [0.006]***
Rate of Growth of Unit Labour Cost			-0.006 [0.001]***
Rate of growth of Domestic Interm. Input (low-tech)			-0.0081 [-0.004]*
Rate of growth of Domestic Interm. Input (high-tech)			-0.005 [0.003]
Rate of growth of Imported Interm. Input (low-tech)			0.004 [0.003]
Rate of growth of Imported Interm. Input (high-tech)			0.009 [0.003]***
Country dummies	Yes	Yes	Yes
Pavitt dummies-industry groups	Yes	Yes	Yes
Obs	172	172	172
RMSE	2.40	13.14	0.09
Chi-2	870.78	1741.75	1594.93
(p-value)	(0.00)	(0.00)	(0.00)

The variables in bold in Table 7 are the key drivers of our system of feedbacks and circular loops. Coherently with the 3SLS estimation technique, the dependent variables estimated and instrumented in the first steps are then used as regressors in the next steps. Such technique allows us to increase estimation consistency and highlights the role of R&D, new products and export marker shares as engines of the recursive relationships we investigate.

An additional test has been carried out in order to check the robustness of our estimations controlling for path dependent technology factors; in a separate estimation we also included time dummies in the R&D equation, but the results are unchanged, and the dummies are not significant. Indeed, the use of long differences, industry level data, average rate of change, and autoregressive specification is a satisfactory strategy to account for a time varying production possibilities frontier.

Once detected this system of feedbacks between R&D, innovation and export performance we can go a step further and investigate the existence and magnitude of two divergent loops affecting the Northern and Southern European countries (with the obvious constraint represented by the limited number of European countries that we consider in this analysis, due to the lack of data).

Table 8. The system of equations for R&D, New Products and Export Market Shares for Northern and Southern countries
Three Stage Least Squares. Standard Errors in brackets, [*] significant at 10%, [**] significant at 5%, [***] significant at 1%.
Group of countries: NORTH (Ger, Nl, Uk), SOUTH (Sp, It, Fr)

Variables		Equation 1 R&D per employee	Equation 2 Share of Product Innovators	Equation 3 Export Market Share
R&D per employee (First lag)	**NORTH**	1.17. [0.13][***]	**1.85** [0.36][***]	
	SOUTH	0.58 [0.06] [***]	**1.45** [0.32] [***]	
Rate of growth of profits (First Lag)	NORTH	0.01 [0.01]		
	SOUTH	0.04 [0.01][***]		
New Market Objective -	NORTH	.006 [0.01]		
	SOUTH	0.07 [0.018][**]		
Size	NORTH	4.39 [2.23] [**]		-0.07 [0.16]
	SOUTH	10.69 [4.91] [**]		-0.05 [.09]
Export market share	**NORTH**	6.53 [2.53] [**]		
	SOUTH	4.88 [2.64] [*]		
Rate of growth of export	NORTH		1.77 [0.46][***]	
	SOUTH		-0.64 [0.48]	
Rate of growth of final consumption	NORTH		-0.31 [0.21]	
	SOUTH		-0.04 [0.07]	
Rate of growth of intermediate demand	NORTH		-0.89 [0.31][***]	
	SOUTH		-0.30 [0.35]	
Share of Product Innovators	**NORTH**			.002 [.0005][***]
	SOUTH			-0.0004 [0.0006]
New machinery per employee	NORTH		0.50 [0.86]	0.017 [0.007] [***]
	SOUTH		-1.90 [1.56]	-0.03 [0.01]
Rate of Growth of Unit Labour Cost	NORTH			-0.008 [0.001][***]
	SOUTH			-0.001 [0.002]
Domestic Intermediate Input (low-tech)	NORTH			-0.0008 [-0.006]
	SOUTH			-0.007 [-0.006]
Domestic Interm. Input (high-tech)	NORTH			-0.012 [0.003] [***]
	SOUTH			0.004 [0.005]
Imported Interm. Input (low-tech)	NORTH			0.001 [0.004]
	SOUTH			0.008 [0.005]
Imported Interm. Input (high-tech)	NORTH			0.008 [0.004] [**]
	SOUTH			0.003 [0.005]
Country dummies		Yes[**]	Yes[**]	Yes[**]
Pavitt dummies		Yes[**]	Yes[**]	Yes[**]
Obs		172	172	172
RMSE		2.40	13.14	0.09
Chi-2		870.78	1741.75	1594.93
(p-value)		(0.00)	(0.00)	(0.00)

In order to achieve our objective we used the interaction terms technique. We are able to estimate the different coefficients for the groupings of Northern and Southern European countries. The interaction model allows different intercepts and slopes for all the variables considered in the model.

The North-South divide clearly emerges from the results of our 3SLS system estimation in Table 8. In the R&D equation (column 1) the *technology push* effect is important and significant in both areas, but in the North its value is more than twice the one in the South. Given the size of the standard error, it is clear that

this difference is significant at the 5% significance level. On the contrary, the *demand pull* effect identified by the New Market Objective variable remains significant for the South only. The common relevance of industry characteristics means that size has an equal significance in both areas, with a higher coefficient in the South where R&D is more likely to be concentrated in few large firms. The internal financing of R&D through past profits is significant in the South alone, as external sources of R&D funds may be more accessible in Northern countries. Export market shares affect R&D efforts with positive and significant coefficients; their value, however, is greater in the North where the feedback loop between international market power and technological efforts appears to be stronger. Nevertheless, we cannot distinguish them at a statistically significant level.

In the new product equation (column 2) the path dependency of R&D appears to be strong both in Northern countries and in the South – both coefficients are positive and significant, the Northern is larger but not statistically different from the latter. The impact on new processes loses its significance in both areas – but in Southern countries it shows a negative coefficient, stressing the substitution between new products and processes. Coming to demand variables, the 'pull effect' of export growth on new products is positive and significant for Northern countries only; a key link in the innovation-performance relationship appear to be missing in Southern countries. No other element of demand is significant in either area, with the exception of the domestic demand for intermediate production in the North, showing a negative sign and confirming the hypothesis discussed above on the lower innovative dynamism of such demand component.

The export market share equation (column 3) is the one where the patterns for Northern and Southern countries are most contrasting. The key determinants of competitiveness are found to operate in the former and appear to be missing in the latter. This applies to the impact of the share of product innovators on export market share; to the significance of the contribution of new machinery to competitiveness; and even to the support that lower unit labour costs provide for cost competitiveness. The coefficients of the variables capturing the average growth in the usage of imported high tech intermediate inputs again is significant for the North only, and maintains the same order of magnitude and sign as in the previous models. While the North confirms the characteristics of the 'virtuous circle' between innovation inputs and outputs and competitiveness, in the South such links appear to be largely missing. Competitiveness and export success for the industries of Southern countries are not supported by innovative performances and the other expected determinants, but rather by non-technological sources that are not captured by the present model.

6. Conclusions

The results of our model – focusing on the industry level - are capable to account for important dimensions of the interconnected engines of economic change in a Schumpeterian perspective. The results derived from the system of three equations support empirically some of the main tenets of the evolutionary literature. The following figure depicts the circular and cumulative relationships we have identified.

First, R&D intensity in industries is the result of industries' technological opportunities – summed up by the cumulative nature of research and knowledge, the demand pull effect of the potential for new products, and firm size –, of their market power – reflected in export shares - and of the resources available for financing R&D from lagged profits. Second, the determinants of product innovation show that, on the supply side, the cumulative nature of R&D is important, while new processes may reveal a complementary or a substitutive role; demand factors either stimulate the introduction of new products, in the case of strong export growth, or may delay it when consumption and intermediate demand characterize industries' markets. Third, in the export market share equation we find that both technological and cost competitiveness matter. The direct effect of product innovation reflects a strategy of technological competitiveness in line with the literature which previously investigated the connection between technology and exports. The introduction of new machinery may improve technological capabilities and reduce costs at the same time. Lower unit labour

costs contribute to higher cost competitiveness. Imported intermediate inputs originating from high technology industries also contribute to higher export market shares.

Figure 1. The system of relations with feedbacks and loops
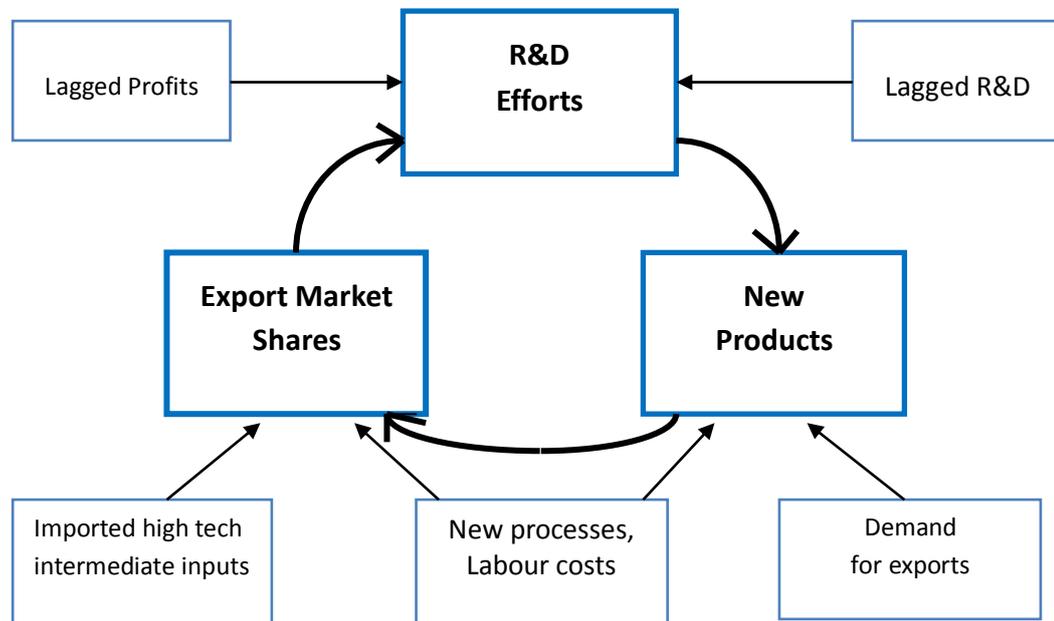
Four improvements on the existing literature emerge from our model and findings. First we strengthen the evidence on the innovation-performance links provided by Bogliacino and Pianta (2013a, 2013b), through an enlargement of the time span (the previous analysis was limited to 2005) and using data form different sources. In this way we are able to show that the recursive set of relationships depicted in Figure 1 persists over a longer time span.

Second, the role of exports is fully addressed, pointing out the fundamental role of competitive success in 'closing' the 'virtuous circle' between innovation and performance. Its determinants in technological factors – such as new products and processes – are, for the first time to our knowledge, combined with the importance of the intermediate input mix. Export success is shown to depend from high technology imported inputs, which are playing an increasing role in the current process of fragmentation of international production.

Third, we enrich the evolutionary literature that has traditionally focused on supply and technology factors, with a full consideration of demand, broken down in its major components. Our results lend support to the 'learning by exporting' thesis showing that exports represent the most dynamic component of demand capable to 'pull' the emergence of new products. Conversely, domestic demand, particularly for intermediate products is much less dynamic and unable to stimulate innovation. These results echo the Schumpeterian distinction between novel productions based on major innovations on the one hand, and standard activities in the 'circular flow' of the economy (Schumpeter, 1942).

Fourth, we show - on empirical grounds – that this set of relationships not necessarily holds for all countries (and, possibly, for all times, as shown for the innovation-employment nexus by Lucchese and Pianta, 2012). Northern European countries do provide evidence of a 'virtuous circle' between innovation and international competitiveness that however is largely missing in Southern ones. This result shows the relevance of national differences and may help explain the observed divergent dynamics in international competitiveness between

different areas of the European Union. It also has important policy implications on the need for addressing the gaps in technological efforts and capabilities in Southern economies, and on the policy proposals that may support better and more converging performances in Europe.

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8. Appendix

8.1 The Pavitt taxonomy of industry groups

In order to control for sectoral technological specificities we use Pavitt dummy variables relying on the revised Pavitt taxonomy proposed by Bogliacino and Pianta (2010). The Pavitt taxonomy (Pavitt, 1984) considered the nature, sources and patterns of innovation as well as firm size and market structure and identified four industry groups: Science Based industries (SB), Specialized Supplier industries (SS), Scale Intensive industries (SI) and Supplier Dominated industries (SD). The revised Pavitt taxonomy allows to extend the classification considering both manufacturing and services as well as ICT activities. Table A1 presents the taxonomy for the 38 industrial sectors analysed in our paper. Using Pavitt dummies in the econometric analysis allowed us to account for common characteristics and diversity in technological patterns detectable at the industry level for both manufacturing and services.

Table A1. The Revised Pavitt taxonomy for Manufacturing and Service

SCIENCE-BASED	NACE Rev. 1 codes
Chemicals	24
Office machinery	30
Manufacture of radio, television and communication equipment and apparatus	32
Manufacture of medical, precision and optical instruments, watches and clocks	33
Communications	64
Computer and related activities	72
Research and development	73
SPECIALISED SUPPLIERS	
Mechanical engineering	29
Manufacture of electrical machinery and apparatus n.e.c.	31
Manufacture of other transport equipment	35
Real estate activities	70
Renting of machinery and equipment	71
Other business activities	74
SCALE INTENSIVE	
Pulp, paper & paper products	21
Printing & publishing	22
Mineral oil refining, coke & nuclear fuel	23
Rubber & plastics	25
Non-metallic mineral products	26
Basic metals	27
Motor vehicles	34
Financial intermediation, except insurance and pension funding	65
Insurance and pension funding, except compulsory social security	66
Activities auxiliary to financial intermediation	67

SUPPLIER DOMINATED	
Food, drink & tobacco	15-16
Textiles	17
Clothing	18
Leather and footwear	19
Wood & products of wood and cork	20
Fabricated metal products	28
Furniture, miscellaneous manufacturing; recycling	36-37
Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel	50
Wholesale trade and commission trade, except of motor vehicles and motorcycles	51
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods	52
Hotels & catering	55
Inland transport	60
Water transport	61
Air transport	62
Supporting and auxiliary transport activities; activities of travel agencies	63

8.2 Descriptive statistics

8.2.1 Export Market Shares

The six countries contained in our sample account for 95% of the EU-15 and for the 70% of the EU-28 exports (the percentages are obtained dividing the sum of the exports of the considered countries by the total EU exports. Data are synthetized in Table A2). Moreover, export performances of the countries in our sample (measured by the export market shares) remain stable when different data sources are considered (calculations based on our SID database are compared with Eurostat data) and when exports are distinguished by destination. These elements bring us to consider the export market share variable used in the third equation of the system as a reliable proxy for industries performances in terms of international competitiveness.

Table A2. Export Market Shares of the 6 major European countries
Ger, Nl, Uk, Fr, Sp, It, EU15, EU28. Averages over the sampled period 1995-2010

Country	Export Mkt Sh. in the 6 major EU countries	Export Mkt Sh. in the EU 15	Export Mkt Sh. in the EU 28
Germany	0.29	0.26	0.22
Netherlands	0.12	0.10	0.08
UK	0.23	0.14	0.11
North	0.64	0.50	0.41
Spain	0.08	0.06	0.05
France	0.14	0.12	0.10
Italy	0.14	0.10	0.09
South	0.36	0.28	0.24

Sources: SID database (first column) and Eurostat
Notes: All values are in real terms deflated with OECD-STAN and Eurostat deflators (base year 2000) and corrected for PPP.

8.2.2 Innovation vs Performance variables

The following scatter plots relate product innovation with export and value added as proxies for economic performance; they identify countries' heterogeneity and sectoral regularities, using Pavitt classes. Figure A1 shows a clear correlation between R&D efforts and innovation performances; Science Based and Supplier Specialized industries - those sectors for which innovation is most important – are located at the top right of

the graph, as expected. Within technological intensive sectors, the best performers are from Northern countries and France. Figure A2 relates product innovation and exports and also in this case the correlation between the two variables is detected. As in Figure A1, sectors with a higher technological intensity (SB and SS) are positioned in the top right of the graph and the North-South divide is again clear in the distribution. Figure A3 provides a cross country comparison plotting product innovation versus the rate of change of value added over the sampled period. In this graph the North-South divide is again clear, as well as the role of Germany as an outlier. The descriptive evidence provided is the background to the results of the econometric model developed in section 5

Figure A1. Product Innovation vs R&D expenditure by country and Pavitt Categories
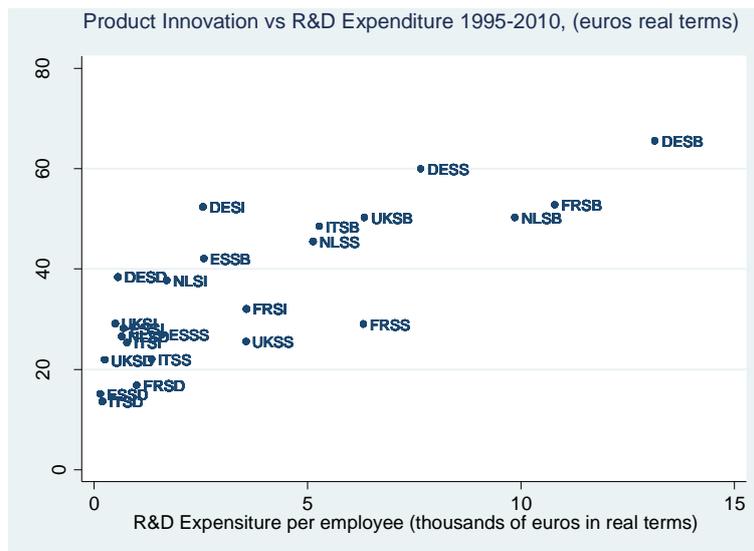

Figure A2. Product Innovation vs Exports by country and Pavitt Categories
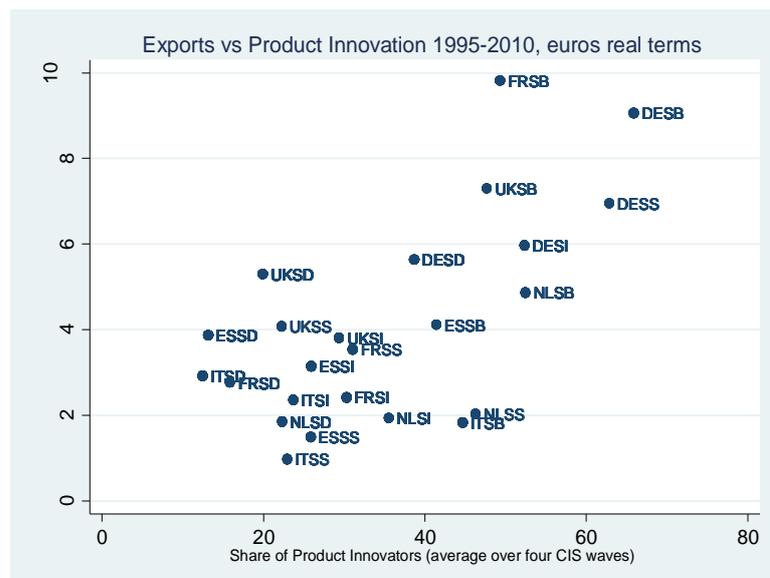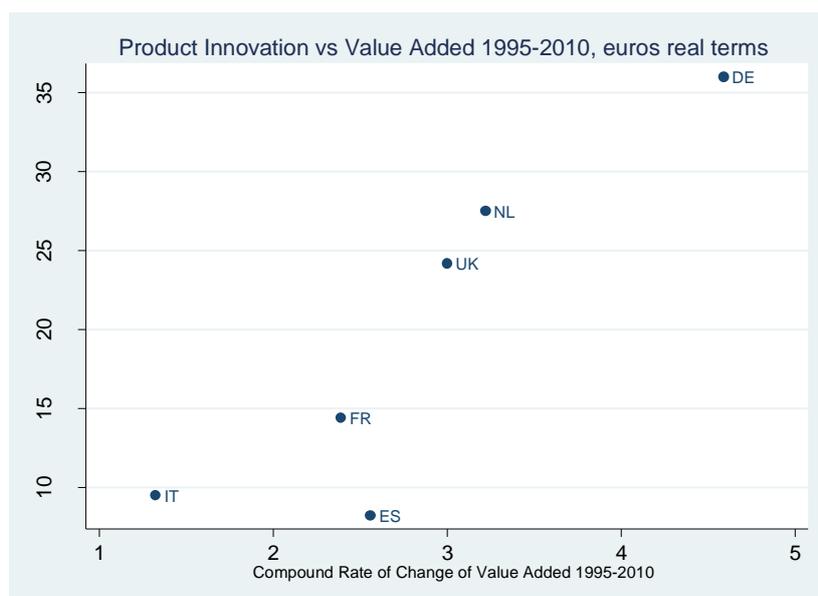

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Figure A3. Product Innovation vs Value Added by country

8.2.3 Intermediate Inputs

The final step of this data inspection regards the role played by intermediate inputs, distinguishing them in terms of technological content and source. Table A3 reports the share of each intermediate input over total industry production of countries. The numbers in Table A3 depict a situation where there is little variability across countries; even the high tech imported inputs have a highly stable relevance across countries. Conversely, domestic low tech intermediate inputs play a major role in Southern countries and Italy in particular, where their share over total production is 32%, ten point higher than the Northern average.

Table A3. Intensity in the use of domestic and imported inputs by country (1995-2010).
Expenditures for the acquisition of input as a share of total production, average values.

Country	Domestic Low tech	Domestic High tech	Foreign Low tech	Foreign High tech
Germany	.20	.17	.07	.05
Netherlands	.19	.19	.11	.10
UK	.23	.14	.06	.05
North	.21	.17	.08	.05
Spain	.26	.15	.06	.05
France	.24	.18	.06	.05
Italy	.32	.17	.06	.04
South	.27	.17	.06	.05

Notes: High Tech intermediate inputs are those originating sectors belonging to SB and SS Pavitt categories while Low Tech ones are those coming from SI and SD sectors.

The final Table A4 reports the intensity in the use of domestic and imported inputs by Pavitt Categories for the period 1995-2010. As expected, the variability across Pavitt Categories is higher than the one observed among countries. Sectors belonging to Science Based and Supplier Specialized categories rely mostly on high tech intermediate inputs and their openness to the foreign market is also remarkable. Conversely, Scale Intensive and Supplier Dominated sectors are characterized by an intensive use of low tech inputs originating

principally from the domestic market. A substantial divergence in terms of economic and innovative performances across our sample's countries emerges from this first data inspection. Moreover, technological factors turn out as a crucial element in the explanation of competitiveness for the EU countries we have considered.

Table A4. Intensity in the use of domestic and imported inputs by revised Pavitt Category (1995-2010).
Expenditures for the acquisition of input as a share of total production, average values.

Pavitt Category	Domestic Low tech	Domestic High tec	Foreign Low tech	Foreign High tec
Science Based	.19	.20	.04	.10
Supplier Dom.	.27	.14	.07	.03
Scale Intensive	.26	.17	.11	.05
Supplier Spec.	.18	.19	.03	.08

Notes: High Tech intermediate inputs are those originating from sectors belonging to SB and SS Pavitt categories while Low Tech ones are those coming from SI and SD sectors.

8.3 Model diagnostics

The standard diagnostic tests are examined here equation by equation. We try to detect the presence of heteroscedasticity and/or multicollinearity. To check for them we respectively use a Breusch-Pagan test and a Variance Inflation Factor (VIF, calculated on the baseline WLS regression). In order to address the endogeneity issue we regress the explanatory variables over a set of instruments , compute the residuals and re-run a robust standard errors-WLS of the equation, with the residuals included as explanatory variable. The T-test for the coefficient of the residuals included becomes a test of endogeneity, see Wooldridge (2002, p. 118).

Table A5. R&D equation

Breusch-Pagan Test	
Chi2(1)	107.30
p-value	0.0009
Multicollinearity	
Average Variance Inflation Factor	1.32
Endogenity	
SIZE (p-value)	0.21
t-stat	-1.27
R&D(p-value)	0.35
t-stat	-0.93

Table A6. Innovation equation

Breusch-Pagan Test	
Chi2(1)	46.76
p-value	0.0000
Multicollinearity	
Average Variance Inflation Factor	1.26
Endogenity	
EXP (p-value)	0.12
t-stat	-1.54
EXMACHE (p-value)	0.19
t-stat	-1.31

Table A7. Innovation equation

Breusch-Pagan Test	
Chi2(1)	35.92
p-value	0.0000
Multicollinearity	
Average Variance Inflation Factor	2.55
Endogenity	
INT_IMP_HT (p-value)	0.13
t-stat	-1.52

The results are the following ones: we have to estimate robust standard errors since the Breusch-Pagan rejected the null hypothesis of homoscedasticity, explanatory variables are orthogonal to the error term, and multicollinearity is not an issue; usually VIF is considered worrisome if it is higher than four (or higher than ten, according to different sources), and these thresholds are four to ten times higher than the value of our sample statistics. We cannot reject our formulation of WLS with robust standard errors. Regarding endogeneity (we developed standard endogenity tests on SIZE, EXPGR, MACH and INT_IMP_HT), our diagnostic rejects the hypothesis of endogeneity for the tested variables.

To go a step further in the endogeneity test we report the results of the 2SLS estimation of each of our baseline equations (as already illustrated above we instrumented our regressors suspected of being endogenous with their lag, the rate of change of value added, country dummies, time dummies and Pavitt dummies).

The basic formulation of the R&D (1) and New products (2) equations is not rejected by the results and the overidentification test supports the validity of the selected instruments. As a final step we report the results of the 2SLS estimation for the third equation of the system.

Table A8. The R&D equation

Dependent Variable: *R&D expenditure per employee.*

2SLS for panel data with robust standard errors and weighted data (weights are the numbers of employee).
Included Endogenous: Size Excluded Instruments: rate of change of value added, country dummies, Pavitt dummies, time dummies.
z-stat in brackets.
* significant at 10%, ** significant at 5%, *** significant at 1%.

	(1) Baseline Model
Lagged R&D expenditure	0.70
	$[7.97]^{***}$
Firm Size	1.73
	$[1.69]^{*}$
New Markets Obj.	0.03
	[1.64]
Profits (first lag)	0.013
	$[2.16]^{**}$
Export Market Share (first lag)	3.27
	$[1.71]^{*}$
Constant	-1.01
	[-0.94]
N.observations	256
Uncentered R2	0.71
Overidentification Test (Hansen J tests)	18.36
p-value	0.04

Table A9. The Innovation equation

Dependent Variable: *Share of product innovators*

2SLS for panel data with robust standard errors and weighted data (weights are the numbers of employee).
Included Endogenous: Compound rate of growth of exports. Instruments:, lagged exports, rate of change of value added, country dummies, time dummies and Pavitt dummies) z-stat in brackets.
* significant at 10%, ** significant at 5%, *** significant at 1%.

	(1) Baseline Model
Lagged R&D expenditure	2.32
	[8.40]***
Expenditure for new Machineries	1.67
	[2.22]*
Final Demand	-0.65
	[-0.71]
Intermediate Demand	-0.58
	[-2.41]**
Compound rate of growth of exports	0.20
	[1.95]**
Constant	-1.01
	[-0.94]
N.observations	256
Uncentered R2	0.73
Overidentification Test (Hansen J tests)	7.31
p-value	0.12

Table A10. The Export Market Share Equation

Dependent Variable: Export Market Share.

2SLS with robust standard errors and weighted data (weights are the numbers of employee).
Included Endogenous: Expenditure for new machineries for employee and Imported intermediate inputs – high tech. Instruments: lagged expenditure for new machineries, lagged mported intermediate inputs, rate of change of value added country dummies, time dummies and Pavitt dummies) z-stat in brackets.
* significant at 10%, ** significant at 5%, *** significant at 1%.

	(1) Baseline Model
Lagged Product Innovation	0.0015
	[2.88]***
Expenditure for Mach. & Equipments	0.014
	[2.41]***
Unit Labour Cost (Rate of Growth)	-0.005
	[-3.39]***
Domestic Interm. Inputs, low tech (Rate of Growth)	-0.012
	[-3.51]***
Domestic Interm. Inputs, high tech (Rate of Growth)	-0.004
	[-1.43]
Imported Interm. Inputs, low tech (Rate of Growth)	0.002
	[1.02]
Imported Interm. Inputs, high tech (Rate of Growth)	0.015
	[5.31]***
N.observations	300
Uncentered R2	0.56
Overidentification Test (Hansen J tests)	16.78
p-value	0.02

Also in this case our formulation is consistent with the data and the instruments are properly selected.