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Business Cycles, Technology and Exports

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Business Cycles, Technology and Exports

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Abstract

This article shows – on both conceptual and empirical grounds - the importance of business cycles in affecting key relationships between innovation and international performance. While periods of upswing are characterised by a well documented 'virtuous circle' between innovation inputs, new products and export success, during downswings most of the positive relationships and feedbacks tend to break down. The findings of Guarascio et al. (2014) on the long-term relationships between R&D, new products and exports are confirmed and qualified with major novelties. But when the period of analysis is split between periods of upswing and downswing - following Lucchese and Pianta (2012) – significantly different relationships emerge. These results are obtained through an approach that combines several complementary perspectives. A Schumpeterian view on the diversity of technological change allows to disentangle the specificities and effects of innovation inputs and outputs, and of new products and new processes. A structural change perspective on the role of demand as a driver of innovation and on the importance of open economies allows to link industries' dynamics with international competitiveness. A business cycle perspective crossing the two previous appraoches sheds new light on the fragility of key economic relationships and on the long term damage that recessions may cause to the 'virtuous circle' of innovation and performance.
The model we propose links exports, R&D and innovation success in a system of three simultaneous equations allowing for the presence of feedbacks loops among key variables. The empirical test is carried out for the period 1995-2010 at the industry level, on 21 manufacturing and 17 service sectors; country coverage includes Germany, France, Italy, Spain, the Netherlands and the United Kingdom, representing a very large part of the European economy.

Keywords
Business cycles, Innovation, Export, Three Stage Least Squares

JEL codes
F41, F43, O31, O33, C3

1. Introduction

The Great Recession started after the US financial crisis of 2007 has posed new challenges for economic research. First, the importance of business cycles has to be brought back; the study of long run growth cannot ignore the sequence of upswings and downswings that characterise economic development. Technological change, structural change and demand dynamics are well known factors that may lead to phases of acceleration and slowdown of growth. Conversely, the different phases of business cycles have asymmetric effects on the economy; the relationships between innovation and economic performance may deeply differ during upswings and downswings.

Second, the constraints that international openness puts on national economies – especially on European ones – have to be given greater consideration. In the context of free international capital movements and rapid financial expansion it has long been assumed that capital markets could be efficient in allocating resources and assessing risks, and that capital flows could easily compensate structural imbalances in trade flows. The 2007 crisis has shown how unrealistic such assumptions were and how important – especially in Europe – international competitiveness is in supporting growth. Moreover, in the context of the European stagnation and widespread austerity policies, exports have become the only source of demand that could pull European countries out of the recession.

The challenge we want to address in this article is to reassess the relationships between technological change, demand and economic performance in open economies, allowing for heterogeneous relationship across the business cycle. We develop a model and test it at the industry level – on 38 manufacturing and service sectors - on six major European countries. We start from the well known proposition that technological change is a key engine of growth and we focus on the 'virtuous circle' that has been identified between innovation and exports. We consider the diversity of technological change – in particular the strategy of technological competitiveness relying on new products and the search for cost competitiveness based on new processes – and we separate innovative efforts (supported by R&D expenditure) from the actual market success of new products. We explore the impact that such innovative dynamics has on export performances and the feedback effect that may emerge on innovative efforts. However, we argue that such set of relationships cannot be expected to be a permanent engine of long term growth; we set them in the context of business cycles and explore how they change in periods of upswing and downswing.

We build on two main blocs. First, the links between innovation and performance are explored by adopting the framework proposed by Bogliacino & Pianta (2013a, 2013b) and extended by Guarascio et al. (2014). The model links exports, R&D and innovation success in a system of three simultaneous equations allowing for the presence of feedbacks loops among key variables. The complexity of such links is accounted for by the consideration of novel dimensions. Innovative efforts – measured by R&D expenditure – require the support coming from export success. The diversity of technological efforts contribute to innovative outputs – measured by the importance of new products. Supply and demand factors are both considered, highlighting the interplay between the two and their joint impact on innovation. Innovation success is considered as a key source of international competitiveness – measured by export market share – but it requires the distinction between technological and cost competitiveness (Pianta, 2001). In this perspective, we introduce different qualities of labour, exploring the impact on competitiveness of wage growth for different skill groups. Finally, the new complex patterns of international trade with a growing fragmentation of production are considered by introducing offshoring strategies through the importance of intermediate input flows, distinguished according to their technological content.

As a second building block, we introduce in such a model the impact of business cycles following the approach of Lucchese and Pianta (2012), who show how the phases of business cycles change the relationship between innovation and employment, carrying out separate estimations for upswings and downswings. In this article we explore whether the links between industries' export success, R&D efforts and new products are affected by business cycles.

This approach accounts for the complexity of the innovation-competitiveness link and allows to identify the occurrence of a structural impact of business cycles, interpreted as the qualitative change of the relationship in the economy. While business cycles studies have generally focused on aggregate dynamics, our sectoral analysis allows to identify the different pace of technological and structural change in upswings and downswings. In this perspective, it has important implications for identifying policies targeted towards innovation and competitiveness in the context of the current stagnation in Europe.

In this article the unit of analysis of this work is the industry, the area of reference is Europe and the period under analysis is 1995-2010, distinguishing phases of upswings and downswings. Data for the empirical analysis come from the Sectoral Innovation Database (SID) developed at the University of Urbino. Data are available at the two-digit NACE classification for 21 manufacturing and 17 service sectors. The country coverage includes Germany, France, Italy, Spain, the Netherlands and the United Kingdom, representing a very large part of the European economy.

In our econometric strategy, the identification is based on instrumental variable techniques for system of equations, due to the presence of feedback loops. We implement Three Stages Least Squares and, as in Lucchese and Pianta (2012) and Bugamelli et al. (2014), we allow for the heterogeneity of model's slopes and intercepts according to specific clustering of the sample. We replicate our baseline structural 3SLS estimation by grouping industries according to periods of upswings and downswing of business cycles through the introduction of interaction terms. We perform a systematic assessment of potential model issues, most of which is discussed in the Appendix.

The organization of the article is the following. Section 2 presents the theoretical context and the relationships with the previous literature. Section 3 introduces the model describing in detail each equation. Section 4 describes the data and the main relationships during the upswings and downswings of business cycles. Section 5 presents the econometric strategy and the results for both the baseline model and the interaction terms estimation. In Section 6 a discussion of the results and some general conclusions are offered. Robustness check and some further evidence are provided in the Appendix.

2. The theoretical framework

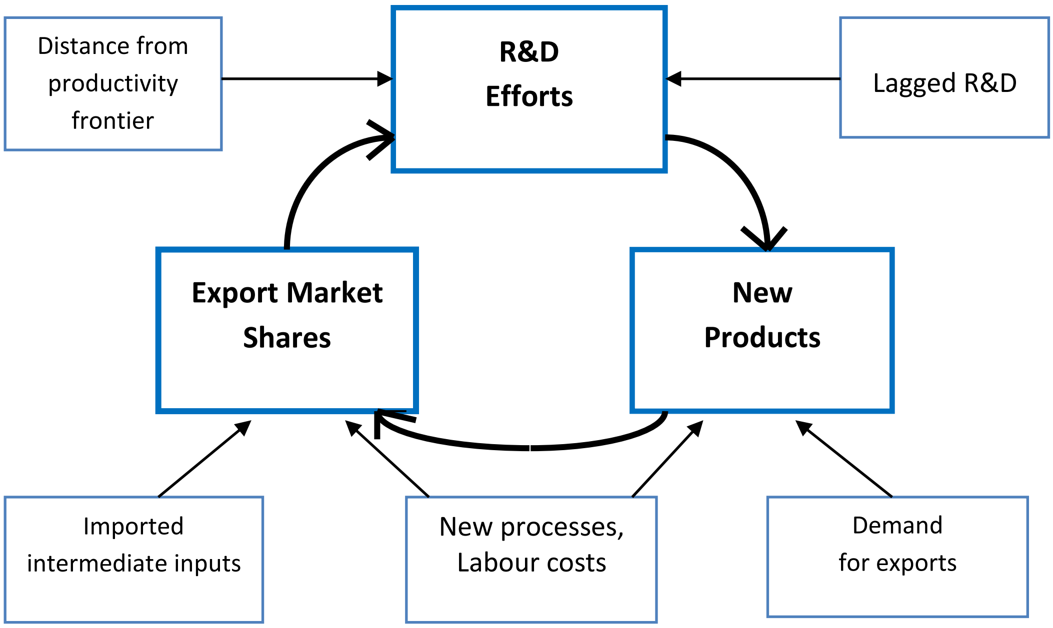
2.1 R&D, innovation and international performance

Mainstream theories based on equilibrium are unsuitable for modelling innovation. As suggested by Arthur (2013) equilibrium imposes a "strong filter" over the lens with which we look at the economy, because by transforming the complex and sequential nature of economic processes into a simultaneous balanced relationship, it removes adjustment – i.e. adaptation, innovation, learning – from view. It also eliminates feedbacks and path-dependence, two key aspects of technology; innovation can hardly be conceptualised as an occasional exogenous shock, but rather is a continuous process of endogenous change.

In our approach the complex, continuous and endogenous flow of changes and interactions between economic and technological forces takes the form of a circular loop of self-reinforcing relations between R&D efforts, new products and export performance. In other words, our model allows for a 'virtuous circle' between technology and economic performance operating in an interconnected and internationally fragmented production system.

The model we use is characterized by the following dynamics. R&D investments lead – with a time lag - to successful innovations; new products drive the acquisition of export market shares; higher export market shares enhance R&D efforts aimed to preserve and expand international competitiveness (Bogliacino and Pianta, 2013a, 2013b; Guarascio et al., 2014). Figure 1 provides a graphical representation of such 'virtuous circle'. It highlights the key endogenous variables – the engines of the 'circle', feeding its recursive mechanism – as well as the exogenous drivers of the system.

Figure 1. The recursive system of relations between innovation and international performance



Source: Adapted from Guarascio et al. (2014)

Our framework is a structural model. Technology is analyzed separately in its input and output, following the classic literature over the role of uncertainty and diversity (Stiglitz and Weiss, 1981; Nelson and Winter, 1982; Dosi, 1982 and Arthur, 2013). Demand pull and technology push factors are identified as factors shaping the innovation process (Schmookler, 1966; Scherer, 1982; Pasinetti, 1981; Dosi et al. 1990, 2014). We focus on the relation between product and process innovation and export success (Fagerberg, 1988; Amendola et al., 1993, Carlin et al., 2001; Dosi et al. 2014; Guarascio et al. 2014). Moreover, we include production offshoring, identified by intermediate inputs flows (Hummels, 2001; Timmer at al., 2013 and Colantone and Crinò, 2014) and the heterogeneity in industries' wage patterns across educational levels, exploring their impact on technological and cost competitiveness (Bartel and Lichtenberg, 1987; Munch and Skaksen, 2008). We refer to Bogliacino and Pianta (2013a, 2013b) and Guarascio et al. (2014) for a detailed review of the literature on innovation and performance and for the conceptual framework of our model; in the next section we focus on the impact business cycles have on such links.

2.2 The importance of business cycles

The determinants of economic fluctuations were investigated since the Classics. While many authors considered cycles to be nothing more than transitory fluctuations, Marx (1863) emphasised the cyclical nature of capitalist accumulation, opening up a stream of research on the "long waves" of growth. Building on such views, Schumpeter (1942) showed that economic cycles have roots in the dynamics of technological development. The investment associated to the introduction of radical innovations - promising high monopoly profits – and to the subsequent swarming of imitations are, in Schumpeter's theory, at the root of upswings; only when this period of "creative destruction" ends, the economy can return to a state of equilibrium. Keynes focused on short-term business cycles arguing that – in favourable monetary conditions - upswings are the result of investments motivated by high expected profits; the expansion of production may meet at some point inadequate demand, resulting in a downswing with falling investment, output and employment (Keynes, 1936).

The modern neoclassical explanation of business by Lucas (1975) goes back to Say's Law. Business cycles are defined as the transitory dynamics of macroeconomic variables around their trend; the equilibrium view of economic processes is at the centre of this approach and of the following literature. Within such perspective, Real Business Cycle and Endogenous Growth theories have proposed different explanations of business cycles (Gali, 1999; Gaggl and Steil, 2007). The former describes the dynamics of business cycles as exogenously driven by "technology" shocks resulting in higher Total Factor Productivity (TFP) (King et al., 1988). Conversely, endogenous growth models assume that a group of firms is able to introduce product and process innovation, increasing productivity and aggregate growth in upswings. Even downswings can lead to productivity improvements if they are characterized by a restructuring process whereby inefficient firms are pushed out of the market (Caballero and Hammour, 1991; Aghion and Saint-Paul, 1998).

Looking at the pro-cyclical nature of technological change, upswings could strengthen economic growth due to the increased amount of capital devoted to learning and training (Blackburn and Pelloni, 2004). Stiglitz (1993) emphasized the role of financial constraints, highlighting the relevance of firms' internal resources to finance innovative activities. During upswings, a rise in sales and profits could reduce the need to borrow resource to innovate; in this way, the financial constraint affecting firms' R&D activities is considerably softened allowing for an increase in such activities financed through profits and internal resources.

Alternative approaches have produced a strong literature on business cycles. Marx's interpretation was translated into a dynamic mathematical model by Goodwin (1972). In his model, the conflict between capital and labour operates as the key engine of economic change, leading to a sequence of expansionary phases, with growing employment and labour shares of national income, and recessions, with increasing unemployment and capital shares.

The Schumpeterian legacy has been developed by evolutionary approaches. Following Schumpeter (1942), innovation is interpreted as an uncertain and discontinuous process, leading to uneven and unbalanced growth. The importance of technological change in shaping the long waves of growth has been studied by Mensch (1979), who argued that inventions cluster during depressions; during upswings incentives to innovate are relatively lower due to the opportunity of extracting rents from a higher demand of existing products; during downswings, profits expectation are lower and inventions – measured by patents - are an effective strategy to recover such rents. Conversely, Freeman (1974, 1982; Freeman and Louça, 2001) underlines the uncertain nature of technological change and the difficulty of successfully introducing innovations during downswings; it is during recoveries, when strong demand and expanding markets create high profit expectations that major product innovations are introduced in the economy. During downswings – he argues – firms give priority to new processes associated to the restructuring and scaling down of production.

Freeman also introduced the concept of techno-economic paradigms - clusters of radical innovations that drive technological change with rapidly falling costs and pervasive applications throughout the economy - that create the conditions for the long waves of growth (Freeman and Louca, 2001; Dosi, 1982, 1998). In order to emerge, techno-economic paradigms must be embedded in favorable social and institutional conditions, with the presence of appropriate knowledge, skilled labour, social relations, infrastructures and public policies (Perez, 1983, 2002). The concept of techno-economic paradigms is very important for understanding the long term dynamics of growth; in his work in the 1970s Freeman has already identified the emergence of Information and Communication Technologies (ICTs) as the emerging paradigm of our time. He argued that the opportunities offered by scientific discoveries were able to expand knowledge, investment and production in unprecedented directions, resulting in the diffusion of new technologies, products and services that could change economic structures and meet new demand. Building on such framework, Lucchese and Pianta (2012) have explored the effect on employment of technological change in different phases of business cycles.

Several studies have explored the relations between business cycles and international openness. During downswings exports play a key role as a source of demand in order to exit from recessions, as they may not be affected by the domestic downswing – unless there is a full synchronization of business cycles across countries. A more recent literature has shown that the international fragmentation of production is closely related with business cycle dynamics, although the direction of causation is not clear (Easterly at al. 2000; Burstein et al. 2008; Feenstra, 2010). The impact of offshoring on the volatility of business cycles has been investigated at the macroeconomic level by Easterly et al. (2000) and at the sectoral level by Di Giovanni and Levchenko (2009). They found that openness has two offsetting effects: on the one hand, sectors more open to trade of both intermediaries and final goods are relatively more volatile; on the other hand, the same sectors are less dependent on the dynamics of the domestic economy. Conversely, at the firm level Buch et al. (2007) found that export oriented firms - more integrated in global value chains – appear to be relatively less volatile with respect to other firms. Bergin et al. (2007) argued that demand shocks affect in a different way the country that originates offshoring and the one where offshoring takes place, stressing that in this way the home country exports its own business cycle, amplifying the volatility abroad. Finally, the model by Feenstra (2010) shows that demand shocks are the most relevant feature in business cycles and in their transmission in a world where offshoring of production takes place. When demand sharply increases in the home country, relative wages increase, inducing the offshoring of activities; this in turn reduces domestic output, softening the impact of the original demand expansion.

In the model we develop in this article we try to combine these streams of research. Our hypothesis is that the 'virtuous circle' described in Figure 1 between innovation inputs, success of new products and exports operates mainly during upswings and is disrupted during recessions. During downswings, the lack of demand, the fall of R&D, investment, output and profits break down the chain of positive feedbacks that fuel the 'virtuous circle'. Expanding on Freeman (1982) and Lucchese and Pianta (2012) we expect that product innovation supports exports during upswings, while process innovation – linked to firms' restructuring– contributes to export success during downswings. In turn, export success cannot be adequate to support R&D efforts during recessions. Concerning imitation and knowledge diffusion, we assume that these processes are stronger during upswings when demand is strong – negatively affecting the need to carry out original R&D. Therefore we expect that both the 'supply push' and 'demand pull' effects of technology operate better during expansions. Finally, we explore the impact on industries' competitiveness of two additional factors over the business cycle; first, the importance of offshoring, distinguishing between the acquisition of high and low tech foreign inputs; second, the role of wage growth – distinguishing between high, medium and low skilled workers – as a factor that may be associated to a lower cost competitiveness, or to a greater technological edge of industries. The following section illustrates the model as a whole and each component of the 'virtuous circle' we want to investigate.

3. The model

3.1 Modelling innovation and performance

A first attempt towards a more integrated accounting of innovation has been carried out with the model proposed by Crépon, Duguet and Mairesse (1998) and its extensions in Mairesse and Mohnen (2010). The authors present a framework characterized by a clear distinction between input and output of innovation.

In their model – tested empirically at the micro level[1] – firms' R&D efforts lead to innovation – the latter is proxied by patent or turnover due to new products - that subsequently fosters productivity (or sales growth). In a similar vein but without recurring to innovation survey, Parisi et al. (2006) broke down the relationship

[1] A discussion of advantages and drawbacks in using firm versus industry-level data in this kind of analysis is provided by Bogliacino and Pianta (2013a)

between innovation and performance into three equations. In their application for Italy, they claim a complementarity between process and product innovation in shaping companies productivity.

Bogliacino and Pianta (2013a and 2013b) expanded - theoretically and empirically - the sequence of relationships from innovation inputs to performance and profits, moving from a linear to a circular dynamics, as in the 'virtuous circle' depicted in Figure 1. The novelties they introduce include the following. First, there is a fundamental distinction between the strategy of technological competitiveness – relying on R&D and new products -, and the search for cost competitiveness through new processes and labour saving innovations. Second, in presence of financing constraints, internal sources generated through retained profits may finance further innovative effort. Third, the 'engines of growth' of industries include both supply and demand side determinants; the 'technology push' effect comes from the technological opportunities opened up by R&D and innovation; the demand pull effect depends on the growth rate of industry's final and intermediate demand (Schmookler, 1966; Scherer, 1982; Pasinetti, 1981; Crespi and Pianta, 2007). Fourth, the alternative options of catching up through the imitation of leaders and the search for advancing at the R&D frontier are introduced through the average distance from industries' productivity frontier.

Guarascio et al. (2014) provide an extension of the model to the open economy, introducing the export market shares equation; the findings show that export success is fundamentally driven by technological competitiveness and by the importance of product innovation. The model is tested on the same six countries we investigate here, but a breakdown is explored between Northern and Southern Europe. The findings show that the North – Germany, the Netherlands and United Kingdom - carries out a strategy based on technological competitiveness and new products, while the South – Italy, Spain and France – search for competitiveness mainly through process innovation and labour cost reduction. Moreover, the 'demand pull' effect is split between domestic and foreign demand components, finding that exports are the only dynamic element of demand capable to pull innovative activities.

In the following subsections, we present the model focusing separately on each equation, highlighting the novelties introduced compared to the work by Guarascio et al. (2014). Finally, we introduce the system of structural relationships emphasizing the linkages with business cycle dynamics.

3.2 Explaining R&D efforts

In evolutionary approaches, the localized nature of search in the fundamentally uncertain domain of technology constrains the direction of technological change (Nelson and Winter, 1982; Dosi, 1982). In the R&D equation of our model, we account for this path dependency by including lagged R&D among the explanatory variables.[2] The influence of industrial structure on R&D effort is captured through average firm size (Piva and Vivarelli, 2007). The successful economic performance – expressed in our model by exports market shares – represents a crucial source of resources for sustaining industries' R&D activities.[3] This is in line with the large literature on the role of financing constrains on R&D activities (Hall, 2002; Griliches, 1995; Cincera and Ravet, 2010; Bogliacino and Gomez, 2014). Such constraints are mainly due the intangible nature of R&D, which is difficult to collateralize, also due to informational problems (Stiglitz and Weiss, 1981). Another important determinant in our model is the distance from the technological leader expressed in productivity terms (Bogliacino and Gómez, 2014). The opportunity to imitate and to benefit from external knowledge spillovers could reduce the incentives to carry out new R&D efforts.

[2] The path dependent nature of R&D efforts has been widely proven as in Cohen and Levinthal (1994), Antonelli et al. (2013) and Bogliacino and Pianta (2013a and 2013b)

[3] According to our conceptualization export success, acting as the more dynamic and 'innovation related' component of economic performance, plays a substantial role in providing the resources required for R&D. A similar line of reasoning emerged in many previous contribution considering export success as an element leading to new demands for knowledge and competences traditionally required for international competition (Amendola et al., 1993; Carlin, 2001; Laursen and Meliciani, 2010; Dosi et al., 1990, 2014 and Guarascio et al. 2014).

Finally, a significant novelty is the inclusion of the growth of high skilled workers' wages as one of the determinants of R&D intensity. There are two reasons for considering workers with tertiary (university) education as an important factor. First, their knowledge is a complementary factor to R&D efforts; industries where wages for such top skills increase more can be expected to expand faster than others their R&D intensity – in fact a large part of R&D expenditure is made of wages for research personnel. Second, high wage growth could be an incentive for greater R&D targeted to innovations that may save labour (Kennedy, 1962). In either case, a positive association is expected.
The first equation of our model is specified as follows:

$$\log(Z_{ijt}) = \beta_1 \log(Z_{ijt-1}) + \beta_2 Size_{ijt} + \beta_3 Fr_{ijt} + \beta_4 \log(Wages\_hs_{ijt}) + \beta_5 \log(Expsh_{ijt}) + v_{ij} + \varepsilon_{ijt} \quad (1)$$

Sectoral R&D efforts – Z in our theoretical specification - are expressed as a function of their lag, taking into account the path dependency of R&D (Z_{t-1}); of average firms size (Size), which proxies a 'Schumpeterian' market structure effect; of the distance from the technological frontier (Fr) linked to imitation and technological spillovers; of the 'induced technical change' component, identified by high skilled workers' wages; and, finally, of industries' export market shares (Expsh).
The distance from the frontier variable identifies the push towards new R&D efforts, which is expected to be stronger when the opportunities for technological imitation are lower. The latter is computed as the percentage distance of sectoral labour productivity (Lp) from the highest value for the same industry in the sample (i.e. among the six major European countries considered in our database). The formal specification (2) is as follows:

$$\mathrm{FR_{ijt}} = \frac{\left|\mathrm{Lp_{ijt}} - \mathrm{Lp_{i,jMax,t}}\right|}{\mathrm{Lp_{ijt}}} 100 \quad (2)$$

$$\mathrm{i} \in \mathrm{NACE}, \qquad \mathrm{j} \in \{\mathrm{DE, ES, FR, IT, UK}\}$$

The rationale is that a lower distance from the frontier (Fr) will bring in higher R&D efforts due to lower opportunities of imitation and technological acquisition from the leaders. The opposite occurs when the distance from the frontier is higher (Bogliacino and Gomez, 2014).
Taking first differences of (1) in order to eliminate time invariant effects, we obtain:

$$\Delta\log(Z_{ijt}) = \beta_1 \Delta\log(Z_{ijt-1}) + \beta_2 \Delta\log(Size_{ijt}) + \beta_3 \Delta\log(Fr_{ijt}) + \beta_4 \Delta\log(Wages\_hs_{ijt}) + \beta_5 \Delta\log(Expsh_{ijt}) + \varepsilon_{ijt} \quad (3)$$

From (3) we have the empirical specification of the R&D equation:

$$R\&D_{ijt} = \beta_1 * R\&D_{ijt-1} + \beta_2 * Size_{ijt} + \beta_3 Fr_{ijt} + \beta_4 * Wages\_hs_{ijt} + \beta_5 * Expsh_{ijt} + \varepsilon_{ijt} \quad (4)$$

where i stands for sector at two digits level (NACE Rev. 1), j for country and t for time. The R&D variable is expenditure for research and development per employee (in thousands of euros). We expect that a greater Size – average number of employees in industries' firms – would go along with higher R&D efforts. Fr is the distance from the technological frontier described above. Expsh is the lagged export market share of industries, calculated 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 (Carlin et al., 2001; Dosi et al. 2014 and Guarascio et al. 2014). Wages_hs is the compound average growth rate of wages per worked hour paid to the group of high skilled workers employed in the sector. We expect that sectors where a sustained growth of high skilled workers' wages is observable are also characterized by a higher R&D investment.[4]

3.3 Explaining innovative performance

The second equation of our model is the one referred to new products. In line with the previous literature, we hypotheses a Cobb-Douglas specification of technological capabilities. Considering this framework, technological capabilities are expressed as a function of the knowledge or R&D stock – the variable estimated in (4) -, of a variable that proxies process innovation – supposed to have a complementary effect with the search for new products -, and industry level demand – proxied by value added growth.
The new products equation expressed in logarithms is the following:

$$log(N\_Prod_{ijt}) = \beta_1 log(Z_{ijt-1}) + \beta_2\, log(K_{ijt}) + \beta_3\, log(Size_{ijt}) + \beta_4\, log(Demand_{ijt}) + \vartheta_{ij} + e_{ijt} \quad (5)$$

As in the case of the R&D equation, we get rid of the time invariant effects differentiating (5):

$$\Delta log(N\_Prod_{ijt}) = \beta_1 \Delta log(Z_{ijt}) + \beta_2 \Delta log(K_{ijt}) + \beta_3\, \Delta log(Size_{ijt}) + \beta_4\, \Delta log(Demand_{ijt}) + e_{ijt} \quad (6)$$

From equation (6) we obtain our final empirical specification:

$$NEWPROD_{ijt} = \beta_1 * R\&D_{ijt-1} + \beta_2 MACH_{ijt} + \beta_3 * SIZE_{ijt} + \beta_4 * DEMGR_{ijt} + e_{ijt} \quad (7)$$

where NEWPROD stands for the share of firms that are product innovators in the sector – an indicator from innovation surveys of the relative success in introducing new products in markets. Its first determinant is the lagged R&D, the technology-push factor; the ability of new R&D expenditure to lead to successful innovations takes time and for this reason the variable capturing R&D efforts is inserted with one period lag. In terms of innovation dynamics, we consider the possible complementarity with innovation in processes identified by the expenditure for machinery and equipment, in thousands of euros per employee (MACH). As in the R&D equation, SIZE is our variable relating product innovation with average firms' size and, thus, to market structure. The success in the introduction of new products is also affected by demand factors[5] – proxied, in our analysis, by the average growth of sectoral value added (DEMGR); e is the usual error term.

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[4] As argued above, our R&D equation specification is partly built on the Schumpeter Mark II hypothesis. The latter is identifiable with the presence of average firm on the right end side of the R&D equation. Such hypothesis regards the possibility to find an effect of firm size on further R&D efforts (Cohen and Levin, 1989; Cohen, 2010). Nevertheless, this line of reasoning has been subjected to criticism of different kind. A first one regarded the unclearness on whether it is innovation input or output that is affected by size. A second criticism, emphasized the risk of endogeneity connected to the fact that both market structure and innovation are codetermined by industries' fundamental features (appropriability, cumulativeness and the knowledge base, as explained by Breschi et al. 2000).
However, the use of industry level data allows to overcome the controversial evidence emerging from firm level studies about the association of past economic performances and R&D efforts (Greeve, 2003). Beside this, 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 elements allow us to, on the one hand, emphasize the role of the incumbent position in export markets as a key element in determining R&D efforts in European countries; on the other, to include size as a control variable without incurring into the risk of endogeneity via omitted variable.

[5] In previous contributions, Bogliacino and Pianta (2013a and b) and Guarascio et al. (2014) found a differentiation in the impact that demand components have on product innovation. Exports resulted as the most dynamic component having always a positive and strongly significant impact on product innovation (similar arguments are put forth by Crespi et al. 2008). Conversely, the growth of domestic demand – without distinction between consumption and demand for capital goods - has been found to have a non-significant and – in some cases - negative impact. The role of demand in fostering innovation diffusion has been discussed theoretically by Pasinetti (1981).

We expect that product innovation be fostered by a combination of 'technology push' and 'demand pull' elements. Moreover, similarly to what happens in the R&D equation, average size of firms is expected to have a positive impact – as assumed by the Schumpeter Mark II hypothesis - on the dynamics of new products. Finally, we hypotheses a complementarity between product and process innovation holding at the sectoral level as found by Parisi et al. (2006) at company level.

3.4 Explaining export success

For the third equation of our model, we followed the work of Carlin et al. (2001) and Guarascio et al. (2014). In a general model of imperfect competition – sketched as a simple Cournot model of competition in open economy in which firms compete for international market shares – export market shares are explained by both domestic relative cost – namely, sectoral unit labour costs – and technological factors related to products quality and technological capabilities of countries and sectors. As a further refinement of Carlin et al. (2001), we distinguish among technological strategies considering both process and product innovation. Moreover, we move beyond Guarascio et al. (2014) by breaking down workers by three educational levels and exploring the impacts that wage growth for each group may have on the export success. Wage growth is at the same time a cost that may reduce industries' cost competitiveness, and a proxy of the improved qualifications of workers, that may reflect higher competences and a greater contribution to technological competitiveness. The effect of wage growth on export success may therefore be either positive or negative depending on which influence prevails.[6]

An additional novelty of our approach is that we connect this framework to the literature concerning fragmentation and international organization of production (Grossman and Rossi-Hansberg, 2008; Feenstra, 2010; Montresor et al. 2009; Timmer et al. 2013). Production linkages and participation in Global Value Chains have strongly affected competitiveness and trade flows of advanced countries. We assess the hypothesis put forth by Timmer at al. (2013) that international fragmentation of production can increase competitiveness by affecting the organization of production through the technological content of intermediate inputs. In particular, import of high tech intermediate inputs could lead to improvements in technological competitiveness due to the higher overall technological content of output; import of low tech intermediate inputs – connected to the offshoring of the more labor intensive part of the production process – could lead to improvements on the cost competitiveness side. We model offshoring through a modified version – computed through the WIOD Input-Output database - of the Feenstra and Hanson (1996) broad offshoring indicator. We accounted for the technological intensity of industries which source intermediate inputs so to differentiate between high and low tech offshoring.

Our industry level offshoring index is specified as follows:

$$OFFSH_{ijt} = \frac{Int\_Inputs_{ijt}^{k}}{Tot\_Output_{ijt}} \quad (8)$$

$$k \in \{HT\ Foreign\ industries, LT\ foreign\ industries\}$$

Where, i stands for the industry, j for country and t for time as before while HT identifies "high" and LT "low tech" industries. In order to distinguish between high and low tech industries we relied on the Pavitt's taxonomy of industries (1984) as revised by Bogliacino and Pianta (2015). We distinguish intermediate

[6] We relied on the definition of skill types used in the WIOD database (Timmer et al. 2015) on the basis of the level of educational attainment of the worker. Educational systems and attainment levels are not always comparable across countries in a straightforward manner. We use the 1997 International Standard Classification of Education (ISCED) classification to define low, medium and high skilled labour.

inputs in production on the basis of both their origin (domestic or imported) and their technological content.[7] The 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):

$$EXPSH = \frac{EXP_{ijt}}{\sum_{j}^{j\in\{1,..,6\}} EXP_{ijt}} \quad (9)$$

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

The export market shares as computed in (9) represent a reliable measure of relative competitiveness of the industries in our sample since the ranking is rather stable.[8] The major source of cost competitiveness is related to labour costs, and is proxied by the compound average annual rate of change of labor costs per worked hour.

The formal definition of the indicator is the following:

$$WAGES\_PH_{i,j,s} = \frac{WAGES\_PH_{\,i,j,s}}{W\_HOURS_{\,i,j,s}} \quad (10)$$

$$i \in \{NACE\}, \qquad j \in \{Ger, Sp, Fr, It, Uk\}, \qquad s \in \{High\ skill, Medium\ skill, Low\ skill\}$$

Finally, the logarithmic form of the third equation of our system is:

$$log(ExpSucc_{ijt}) = \beta_1 log(N\_Prod_{ijt}) + \beta_2\, log(Proc\_Inn_{ijt}) + \beta_3\, log(Wages\_Ph_{ijst}) + \beta_4\, log(Offsh_{ijt}) + \delta_{ij} + n_{ijt} \quad (11)$$

As in the previous cases, we get rid of the time invariant effects differentiating (11). Then, we have:

$$\Delta log(ExpSucc_{ijt}) = \beta_1 \Delta log(N\_Prod_{ijt}) + \beta_2\, \Delta log(Proc\_Inn_{ijt}) + \beta_3\, \Delta log(Wages\_Ph_{ijst}) + \beta_4\, \Delta log(Offsh_{ijt}) + n_{ijt} \quad (12)$$

Finally, the empirical specification of our third equation is:

$$EXPSH_{ijt} = \beta_0 + \beta_1 NEWPROD_{ijt} + \beta_2 PROC\_INN_{ijt1} + \beta_3 WAGES\_PH_{ijst} + \beta_4 OFFSH_{ijt} + n_{ijt} \quad (13)$$

Export 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 are proxied by PROC_INN – the share of firms innovating with the aim of reducing labor costs. The impact of labour cost is identified by three variables reporting, respectively, the compound average annual rate of high, medium and low skilled workers' wages (WAGES_PH). The effects of offshoring – represented in terms of intermediate inputs flows – are captured by the share of high and low tech intermediate inputs (OFFSH).

As argued, we expect industries' international performance to be driven by both technological and cost competitiveness, with a stronger importance of product innovation. Regarding the role of labour cost, we expect a heterogeneous effect across skill groups. In particular, we argue that industries characterized by a relatively stronger growth of high skilled workers' wages could have better international performances.

[7] Our criterion is the following: within foreign intermediate inputs, HT are the intermediate inputs provided by Science Based and Specialized Supplier, and LT are those provided by Scale Intensive and Supplier Dominated sectors. A detailed description of the revised Pavitt taxonomy is in Bogliacino and Pianta (2015).

[8] An extensive analysis of the reliability of this variable as a proxy for export performances is provided in Guarascio et al. (2014).

Finally, offshoring variables are expected to be positively associated with international competitiveness. However, we expect that a higher share of high tech intermediate inputs could have a stronger impact on export success than low tech ones.
As in Bogliacino and Pianta (2013b) and Guarascio et al. (2014) we put together the three equations in a simultaneous system. We expect to identify in this way a 'virtuous circle' between innovation and competitiveness at the industry level. We will then explore to what extent such relationships are affected by the different phases of business cycles. Our full system of equations reads:

$$\begin{cases} R\&D_{ijt} = \beta_0 + \beta_1 * R\&D_{ijt-1} + \beta_2 * SIZE_{ijt} + \beta_3 * FR + \beta_4 * EXPSH_{tij-1} + \beta_5 * WAGES\_HS_{tij} + \varepsilon_{ijt} \\ NEWPROD_{ijt} = \beta_0 + \beta_1 * R\&D_{ijt-1} + \beta_2 MACH_{ijt} + \beta_3 * SIZE_{ijt} + \beta_4 * DEMGR_{ijt} + e_{ijt} \\ EXPSH_{ijt} = \beta_0 + \beta_1 NEWPROD_{ijt} + \beta_2 PROC\_INN_{ijt} + \beta_3 WAGES\_PH_{ijt} + \beta_4 OFFSH_{ijt} + n_{ijt} \end{cases} \quad (14)$$

The system (14) is the analytical representation of the interdependencies among our variables. As claimed before, R&D efforts, innovative performances – proxied by new products – and export success are the key drivers of the 'circle'. Business cycles are expected to affect the set of relationships of our 'virtuous circle'. On the supply side, evolutionary insights suggest that the pace and direction of technological change can be affected by the upswings and downswings of the economy. On the demand side, structural change perspectives suggest that industries' performance can be deeply affected by the dynamics of demand components. In particular, we expect that during downswings the positive impact of new products on export success may disappear and, in turn, international competitiveness could not expand R&D efforts – due to falling returns and to the lack of confidence characterizing recessions. The bias of R&D activities towards larger firms is assumed to be indifferent to business cycles' movements. Concerning the role of process innovations, their contribution to the introduction of new products and to better export performances could hold during both up and downswings; in bad times new processes are developed as part of restructuring aimed to reduce labour costs, sustain cost competitiveness and protect profit margins.

4. Data and descriptive evidence

4.1 The database

The database used in this paper is the Sectoral Innovation Database (SID) developed at the University of Urbino[9] 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 (Pianta and Lucchese 2011). For innovation variables data are from four European Community Innovation Surveys – CIS 2 (1996-1998), CIS 3 (1998-2000), CIS 4 (2002-2004) and CIS 6 (2006-2008). The R&D investments variables are drawn from the ANBERD-OECD database with the same periodization of the CIS waves plus the initial period 1992-1996 (The Pearson correlation coefficient computed to check the compatibility of CIS and the OECD ANBERD R&D variable is significant and equal to 0.91). The availability of this additional lag for the R&D variable allowed us to exploit the whole time dimension of the data avoiding any loss of observations.
Economic variables are obtained from the OECD-STAN database; demand, trade, labour cost – broken down by workers' skills - and intermediate inputs variables are drawn from the World Input Output Database (WIOD) (Timmer et al., 2015). As in the case of the R&D variable, an additional lag – referred to the period 1992-1996 - has been computed for the sectoral value added[10]. This is motivated by our identification strategy and will be discussed in details below,

[9] The stability and the consistency of the database is assessed in Bogliacino and Pianta (2009).
[10] The variable reporting the sectoral value added has been drawn from the EU-KLEMS database which is completely compatible with the information contained in the WIOD (on this point see Timmer et al., 2015).

The country coverage of the database includes six major European countries – Germany, France, Italy, Netherlands, Spain, and United Kingdom - that represent a very 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 expressed as average rate of change over the periods 1996-2000, 2000-2003, 2003-2007 and 2007-2010. Innovation variables refer to 1996-1998 (linked to the first period of economic variables); 1998-2000 (linked to the second period of economic variables); 2002-2004 (linked to the third period of economic variables) and 2006-2008 (linked to the fourth period of economic variables)[11]. The R&D investment variable calculated for the period 1992-1996 is imputed as lag for the R&D in the first time period of the model.

All economic variables are deflated using the sectoral Value Added deflator from WIOD (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.

Table 1. List of variables

Variable	Unit	Source
In-house R&D expenditure per employee	Thousands euros/empl	OECD-ANBERD
New machinery expenditure per employee	Thousands euros/empl	CIS
Share of firms innovating with the aim *of reducing labor cost*	Percentages	CIS
Share of product innovators	Percentages	CIS
Average firm size	Number empl. per firm	CIS
Rate of growth of exports	Annual rate of growth	WIOD I-O Tab.
Export market shares	Percentages	WIOD I-O Tab.
Rate of growth of value added	Annual rate of growth	WIOD I-O Tab.
Share of imported intermediate inputs (high and low-tech)	Percentages	WIOD I-O Tab.
Rate of growth of wages (high, medium and low skill)	Annual rate of growth	WIOD SEA Tab.

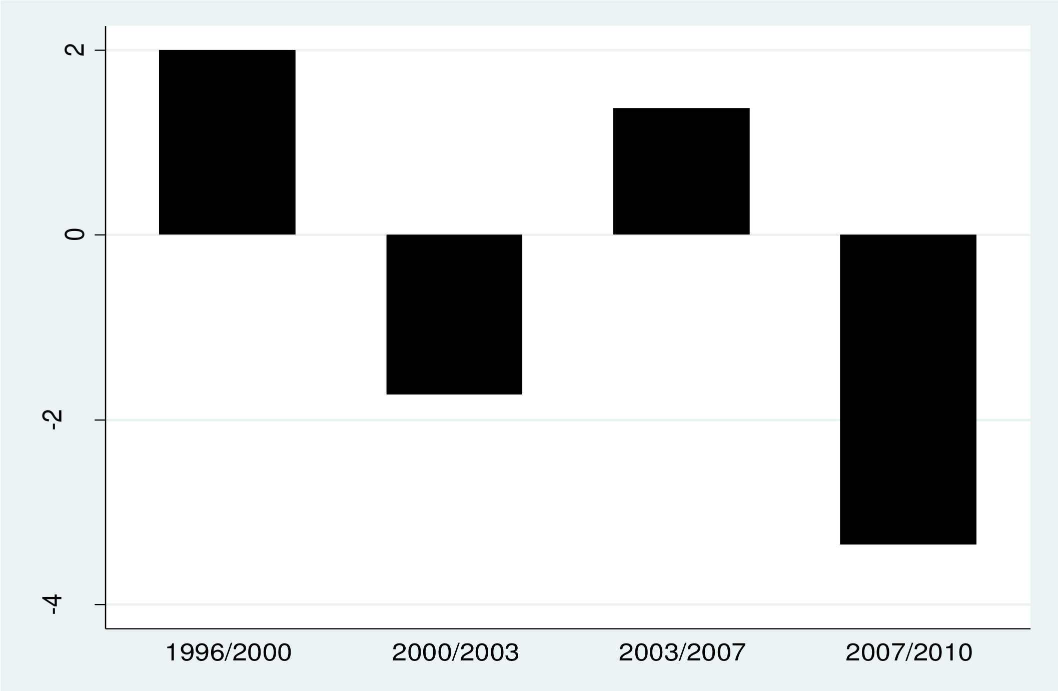
Source: Sectoral Innovation Database, University of Urbino

4.2 Descriptive evidence

This section provides some evidence on the dynamics of our key variables over the selected time span. First, it is important to show the increasing importance of business cycles in the period we investigate. Figure 2 shows the average annual rate of change of value added in total manufacturing industry for the aggregate of the six countries considered. The first cycle has an upswing phase between 1996 and 2000 – with a 2% average growth -, followed by the downswing from 2000 to 2003. The second cycle has an upswing from 2003 to 2007 – with more modest growth -, and a recession from 2007 to 2010, with value added falling by 3.5% per year on average. We consider manufacturing industry here because both innovation and exports are much more important in manufacturing than in services, and manufacturing is characterised by deeper business cycles than the rest of the economy. Our econometric analysis, however, will be carried out on all manufacturing and service industries.

[11] Adopting the same strategy of Bogliacino and Pianta (2013a), we use as reference year for our estimations the last year of the CIS wave (1998, 2000, 2004, 2008). We, thus, consider four years lags backward from the last CIS year for innovation variables associating them respectively to each period of the economic variables (1996-2000; 2000-2003; 2003-2007; 2007-2010)

Fig. 2. Business cycles in Europe, 1995-2010
Total manufacturing industries of GER, SP, FR, IT, NL, UK
Compound rate of change of value added at constant prices



Source: authors elaboration on WIOD data.

In Table 2 we report the average annual rate of variation of our key variables – aggregated for the whole sample of countries and industries – over the four periods identified above. Upswings feature a sustained growth and high levels of all variables. Downswings – and in particular the recession after 2007 – are marked by a fall of economic indicators. Innovation variables appear to be more stable across time compared to the economic ones; both R&D expenditure per employee and the share of firms introducing product innovation are slightly higher during upswings. Remarkably, process innovation efforts - industries' expenditure for new machinery per employee - have an opposite behavior, with higher values during downswings, highlighting the expected importance of restructuring and labour saving innovations during recessions.

Table 2. Economic and innovation dynamics during upswings and downswings

Variable		**Upswing (1996-2000)**	**Downswing (2000-2003)**	**Upswing (2003-2007)**	**Downswing (2007-2010)**
Rate of growth of value added	Mean (whole sample)	3.94	0.56	3.07	-2.04
Rate of growth of profits	Mean (whole sample)	6.06	0.38	2.86	-14.93
Rate of growth of exports	Mean (whole sample)	10.33	0.77	7.85	-3.90
In-house R&D exp. per employee	Mean (whole sample)	2.90	2.45	2.67	2.57
New Machinery exp. per employee	Mean (whole sample)	1.50	2.46	1.51	1.43
Share of product innovators	Mean (whole sample)	48.66	32.88	30.78	30.93

Source: Sectoral Innovation Database (Pianta and Lucchese, 2011) Note: data are expressed in compound annual rate of variations. Calculations are made for the whole selected countries (Ger,Sp,Fr,It,Nl,UK)

5. Econometric strategy and results

5.1 Identification Strategy

Our identification strategy relies on explicit modeling of the interdependencies of the main variables in a system of equations and on the use of the instruments for endogenous regressors. We instrumented the following variables: expenditure for new machineries per employee and the rate of change of value added; the rate of change of high skilled wages; the rate of change of medium and low skilled wages and the share of firms innovating with the aim of reducing labor cost. The adopted instruments: variable lags; lagged rate of change of value added; country, time and Pavitt dummies. We use the 3SLS estimator, which 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.[12]

The average growth rates are equivalent to the long (log) differences, which further address the problem of endogeneity by removing individual time invariant effect (Caroli and Van Reenen, 2001; Piva et al. 2005 and Bogliacino and Pianta, 2013a). In addition, we used country, time and sectoral specific fixed effects in order to control for other potential sources of endogeneity.[13]

Furthermore, the variables that are not expressed as rates of growth are scaled by the number of employees or firms (the ones expressed as shares), so we are correcting for the potential bias deriving from using groups of unequal size.

In the second part of the analysis, we estimated different coefficients for the upswings and downswings, showing that there are major differences in the shaping of the 'virtuous circle' looking at different phases of the business cycle. The adopted technique – based on the inclusion of an up-downswing dummy variable interacting with each covariate in all the equations – allows both the intercepts and the slopes of each equation to vary according to the selected clusters – in our case up and downswings of business cycle (Lucchese and Pianta, 2012).

Robustness of the specification is assessed through the implementation of an OLS and WLS estimations equation-by-equation, with related diagnostic tests (reported in the Appendix). The industry data we use are grouped data of unequal size, so we cannot expect all industries to provide the same contribution in terms of information; as a result, the consistency of the estimation is affected. A way to guarantee consistency is the use of weighted least squares (WLS) that allows taking the relevance of industries into account (see the discussion in Wooldridge, 2002, Ch. 17). The use of a correct weight becomes crucial and the choice is usually limited to value added and number of employee. 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 (Bogliacino and Pianta, 2013a).

5.2 Main results and robustness checks

Table 3 reports the results of the baseline model. Results are in line with expected effects and confirm the findings obtained in Guarascio et al. (2014).

[12] The 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).

[13] We used as additional instrument in the first-step estimations of the rate of growth of wages the lagged shares of employees identified according to their educational level.

In the R&D equation (first column) past R&D efforts and export market shares – with strongly significant coefficients - support R&D investments, that – in this specification - are not 'pushed' by the importance of firm size. In line with Bogliacino and Pianta (2013a), R&D expenditures are also driven by the presence of high technological opportunities identified by the 'distance from the frontier' variable. Industries where a relatively higher growth of high skilled workers' wages is detected, are also characterized by a higher intensity of R&D investments.
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 – proxied by the variable capturing expenditure for new machinery per employee - plays a complementary role to new products, with a positive and significant coefficient. Supporting the structural change view - according to which a growth in sectoral demand would have a positive effect on the diffusion of new products – the demand component has a positive and significant impact on product innovation. Differently to what detected in the R&D equation, average firm size – our Schumpeter Mark II variable – turns out to be positive and strongly significant.
Export market shares (column 3) appear to be mostly driven by technological competitiveness. The variable associated to product innovation is positive and strongly significant, while process innovation is not significant. These results confirm a wide empirical evidence concerning the major role played by technological competitiveness in explaining European industries' export performances (see European Commission, 2013; Tiffin, 2014; Cirillo and Guarascio, 2015).
The impact of labor cost components varies considerably when differences in skills are accounted for. The growth of high skilled workers' wages is positively associated with export market shares; this represents further evidence of the importance of highly qualified workers for supporting industries' technological competitiveness. Medium skilled wages have a negative and significant impact on the dependent variable, while the growth of low skilled workers' wages has no significant role in explaining export market shares. Finally, both offshoring variables are positive in sign, but only the low tech offshoring proxy is statistically significant. Industries' cost competitiveness, in other words, is supported essentially by offshoring the more labour intensive parts of production in low wage countries – and this can partly explain the lack of significance of low skilled wages. Taken together, the three equations of Table 3 confirm the presence of 'virtuous circle' between technology and exports at the industry level in the main European countries.

Table 3. The virtuous circle between 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%.
Included endogeneous: R&D per employee, Export market shares, Rate of growth of demand, Expenditure for new machineries, Rate of growth of wages; *Excluded instruments*: Rate of growth of value added (first lag), country, time and Pavitt dummies; Share of workers with primary, secondary and tertiary education.

	Equation 1 **R&D per employee**	**Equation 2** **Share of Product Innovators**	**Equation 3** **Export Market Share**
R&D per employee (First lag)	0.70 [0.03]***	**0.77** **[0.36]****	
Size	0.71 [0.01]	20.62 [6.07]***	
Distance from the frontier	-0.04 [0.01]***		
Export market share	**0.02** **[0.00]*****		
Rate of growth of demand		1.10 [0.46]***	
New machinery per employee		13.83 [0.93]***	
Share of Product Innovators			**0.38** **[0.04]*****
Share of innovations aiming to reduce labour cost			0.08 [0.06]
Rate of Growth of hourly wages (high skill)	0.24 [0.79]***		1.00 [0.46]**

Rate of Growth of hourly wages (medium skill)			-1.42
			[0.47]**
Rate of Growth of hourly wages (low skill)			0.00
			[0.26]
Rate of growth of Imported Interm. Input (low-tech)			1.99
			[0.05]***
Rate of growth of Imported Interm. Input (high-tech)			1.00
			[0.70]
Obs	492	492	492
RMSE	3.19	37.91	16.01
Chi-2	962.07	524.08	826.43
(p-value)	(0.00)	(0.00)	(0.00)

Table 4 reports the estimations of the same model in which we allow for heterogeneous coefficients across the business cycle. As expected, during downswings most of the key relationships shaping the 'virtuous circle' break down.

In the first equation, R&D efforts appear to be path dependent – the coefficient of lagged R&D expenditure is positive and significant - during both up and downswings. During downswings, however, R&D is no longer driven by export market shares and imitation – proxied by the distance from the frontier variable. Also the relevance of high skill work is lost during downswings. Recessions, in other words, offer little scope for R&D efforts, which become more concentrated in large firms – as shown by the size variable than now turns positive and significant; larger firms have greater internal resources that may help them support R&D in downturns, while smaller innovators may be forced to cut R&D – or exit the market - by the recession.

In the second equation, the impact of business cycles on the share of new product innovators is less dramatic. The technology push effect – captured by the lag of R&D expenditures – as well as the complementarity between product and process innovation hold during both up and downswings. The positive effect of demand turns negative during recessions; the industries where demand growth remains higher during downswings are those where the share of new products is lower; in other words, the recession hits most the industries that are more technologically dynamic (a result that is consistent with the findings of Lucchese and Pianta, 2012).

In the third equation, export market shares are deeply affected the business cycle. In line with our expectations, technological competitiveness strategies have a positive and significant effect only during upswings. The opposite happens for cost competitiveness strategies – proxied by the share of firms innovating with the aim of reducing labor costs – that have a positive and significant effect during downswings only. The role of wages and offshoring differs deeply across phases of the business cycle. Labour cost variables are significant during downswings only. Again, the growth of high skilled wages positively affects export market shares, while low skilled wages have a negative and significant impact; this confirms the opposite effects of high qualifications that contribute to preserve technological advantages and exports – even in bad times -, and of low skills that worsen business costs in periods of low demand and increased international competition. Low tech offshoring continues to drive export success during upswings, but loses its relevance in recessions, when offshoring is cut faster than domestic output. Conversely, importing a relatively higher share of high tech intermediate inputs contributes to export success during downswings; this result could be linked to a higher participation of industries in Global Value Chains which may be less affected by the recession hitting national economies.

Table 4. The impact of the business cycle on the 'virtuous circle'

Three Stage Least Squares. Standard Errors in brackets, * significant at 10%, ** significant at 5%, *** significant at 1%.
UPSWING (1996-2000; 2003-2007), DOWNSWING (2000-2003; 2007-2010)
Included endogeneous: R&D per employee, Export market shares, Rate of growth of demand, Expenditure for new machineries, Rate of growth of wages. *Excluded instruments*: Rate of growth of value added (first lag), country, time and Pavitt dummies; Share of workers with primary, secondary and tertiary education.

	Equation 1 R&D per employee (UPSWING)	**Equation 1 R&D per employee (DOWNSWING)**	**Equation 2 Share of Pr. Innovators (UPSWING)**	**Equation 2 Share of Pr. Innovators (DOWNSWING)**	**Equation 3 Export Market Share (UPSWING)**	**Equation 3 Export Market Share (DOWNSWING)**
R&D per employee (First lag)	0.77	0.77	**2.00**	**3.03**		
	[0.04]***	[0.04]***	**[0.37]***	**[0.34]***		
Size	0.35	2.02	58.42	39.02		
	[0.94]	[0.63]***	[7.63]***	[5.24]***		
Distance from the frontier	-0.07	-0.00				
	[0.01] **	[0.02]				
Export market share	**0.03**	**-0.00**				
	[0.01]*	**[0.00]**				
Rate of growth of demand			0.76	-0.95		
			[0.21] ***	[0.25]***		
New machinery per employee			5.47	2.95		
			[0.72]***	[0.54]***		
Share of Product Innovators					**0.33**	**0.03**
					[0.05]*	**[0.04]**
Share of innovations aiming to reduce labour cost					0.04	0.93
					[0.05]	[0.09]***
Rate of gr. of hourly wages (high skill)	0.18	0.05			0.12	0.53
	[0.04] ***	[0.03]			[0.31]	[0.24]*
Rate of gr. of hourly wages (medium skill)					0.11	0.60
					[0.36]	[0.35]
Rate of gr. of hourly wages (low skill)					0.06	-0.90
					[0.14]	[0.20]**
Rate of gr. of Imported Interm. Input (low-tech)					2.28	-0.74
					[0.59]***	[0.98]
Rate of gr. of Imported Interm. Input (high-tech)					-0.74	2.28
					[0.98]	[0.59]***
Obs	492	492	492	492	492	492
RMSE	3.09	3.09	26.84	26.84	13.87	13.87
Chi-2	1067.72	1067.72	826.43	826.43	524.08	524.08
(p-value)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

6. Conclusions

This article shows – on both conceptual and empirical grounds - the importance of business cycles in affecting key relationships between innovation and international performance. While periods of upswing are characterised by a well documented 'virtuous circle' between innovation inputs, new products and export success, during downswings most of the positive relationships and feedbacks tend to break down. The findings of Guarascio et al. (2014) on the long-term relationships between R&D, new products and exports are confirmed and qualified with major novelties. But when the period of analysis is split between periods of upswing and downswing - following Lucchese and Pianta (2012) – significantly different relationships emerge.

These results are obtained through an approach that combines several complementary perspectives. A Schumpeterian view on the diversity of technological change allows to disentangle the specificities and effects of innovation inputs and outputs, and of new products and new processes. A structural change perspective on the role of demand as a driver of innovation and on the importance of open economies allows to link industries' dynamics with international competitiveness. A business cycle perspective crossing the two previous approaches sheds new light on the fragility of key economic relationships and on the long term damage that recessions may cause to the 'virtuous circle' of innovation and performance.

A relevant set of novelties have emerged from our findings. First, the results of the baseline estimations confirm how the proposed structural model effectively accounts for the dynamics of R&D efforts, innovation and export success of European industries.

Second, the relevance of the distinction between technological and cost competitiveness (Pianta, 2001) is strongly confirmed. This concerns in particular the role of labour costs – traditionally taken as a parameter affecting competitiveness only in a negative way . Once we distinguish labor cost according to workers' skills, growing wages of the high skilled emerge as an important factor contributing to expand industries' export market shares. On one side, higher wages – and, in particular those of high skilled workers - could have a positive impact on competitiveness according to an 'efficiency wage' mechanism which fosters industries' productivity (Akerlof and Yellen, 1990). On the other, a relatively stronger growth rate of high skilled wages could signal a tendency towards industries' technological and quality upgrading. Moreover, due to a potential 'induced bias' effect, an increase in high skilled wages could even spur new R&D investment aiming at reducing labour inputs.

Third, downswings emerge as periods of major disruption of the 'virtuous circle' between technology and export. A similar break down regards imitation and knowledge spillovers, the benefits of which seem to spread only during upswings.

Fourth, as in Lucchese and Pianta (2012), the success of technological competitiveness as a determinant of exports is found in expansionary phases alone. Conversely, downswings are associated with the relative importance of cost competitiveness efforts linked with restructuring and cost-cutting in firms and industries.

Fifth, the relationship between offshoring and industries' international performances is also affected by business cycles. Results show the use of low tech foreign intermediate inputs during periods of high demand and the importance of participating in Global Value Chains with high tech intermediate flows in periods of recession.

Finally, important consequences emerge from our findings for business cycle studies. Far from being transitory deviations from stable, linear, equilibrium relationships, business cycles appear able to disrupt in deep ways the 'engines of growth' of capitalism, affecting the nature and direction of technological change, the pace of structural change and the forms of integration in the world economy. This has major policy implications, especially in the context of the long European recession. As argued by a growing international debate (Cirillo and Guarascio, 2015; Landesmann, 2015; Mazzucato, 2015; Pianta, 2015), in order to protect the innovative capacity and the production systems of European countries a new industrial policy is needed, focusing on the search for technological competitiveness.

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8. Appendix

8.1 Robustness check

In order to check the robustness of the results we use the following strategy. First, we provide some diagnostic tests. Table A1 present the results of the diagnostic tests equation by equation. We report the outcome of the Variance Inflation Factor (VIF) and the Breusch-pagan tests performed on the WLS specification of each equation of the model. Multicollinearity (which may induce noise in the estimation) is never an issue: VIF critical threshold, as a standard rule of thumb, is four, i.e. higher than the value of our sample statistics. Moreover, the outcome of the Breusch-Pagan test signals the presence of heteroscedasticity in all the equations. The last result gives support to the adopted choice of robust standard errors.

Table A1. Robustness tests

R&D equation	
Breusch-Pagan Test	
Chi2(1)	5142.30
p-value	0.0000
Multicollinearity	
Average Variance Inflation Factor	1.25
Innovation equation	
Breusch-Pagan Test	
Chi2(1)	112.31

p-value	0.0000
Multicollinearity	
Average Variance Inflation Factor	1.12
Export market shares equation	
Breusch-Pagan Test	
Chi2(1)	133.30
p-value	0.0000
Multicollinearity	
Average Variance Inflation Factor	3.40

Secondly, we estimate the model equation by equation on all manufacturing and service industries with two different specifications: 1) A baseline OLS model; 2) a WLS model with robust standard errors – weighting observations with the number of employees in each industry so as to account for the uneven distribution of information provided by statistical units included in industry-level datasets – using time, country and Pavitt dummies to account for fixed effects. Results are shown in Tables A2, A3, A4.

As can be seen, the results are robust across specification. The only minor differences are the following ones. In the R&D equation the distance from the frontier loses some significance. In the equation for export market share, the rate of growth of wages – irrespectively to the education level of workers – is no longer statistically significant. The offshoring variables are both positive and significant.

Table A2. The R&D equation

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

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

	(1) **OLS baseline estimation**	(2) **WLS with dummies**
Lagged R&D expenditure	0.29 [0.02]***	0.36 [0.18] **
Firm Size	-0.03 [0.10]	-0.02 [0.10]
Distance from the frontier	0.03 [1.64]	0.00 [0.01]
Rate of growth of wages (high education)	0.15 [0.00] ***	0.13 [0.04]***
Export Market Share	0.03 [0.01]***	0.04 [0.01]**
Constant	1.06 [0.25]***	
Country and time dummies		Yes***
Pavitt dummies-industry groups		Yes***
Time dummies		Yes***
N.observations	669	669
R2 (Adj)	0.26	0.48

Table A3. The New Product Equation

Dependent Variable: Share of firms carrying out product innovation.

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

	(1) **OLS baseline estimation**	(2) **WLS with dummies**

Lagged R&D expenditure	0.70 [0.10]***	1.16 [0.69]***
Expenditure for Mach. & Equipments	1.42 [0.31] ***	4.12 [0.82]**
Average firms size	3.44 [1.92] *	9.70 [7.06]
Domestic Demand (Rate of Growth)	0.11 [0.09]	0.28 [0.12]**
Constant	1.06 [0.25]***	
Time dummies		Yes
Country dummies		Yes
Pavitt dummies-industry groups		Yes
N.observations	616	616
R2 (Adj)	0.10	0.64

Table A4. The Export Market Share Equation

Dependent Variable: Export market share.

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

	(1) **OLS baseline estimation**	(2) **WLS with dummies**
Product innovation	0.09 [0.04]**	0.09 [0.03]**
Process innovation	0.23 [0.05] ***	0.23 [0.04] ***
Rate of growth of wages (high education)	0.57 [0.01] ***	0.62 [0.14] ***
Rate of growth of wages (medium education)	-0.54 [-0.17]***	-0.60 [0.18]**
Rate of growth of wages (low education)	0.01 [0.09]	0.02 [0.09]
Imported intermediate inputs (low tech)	1.44 [0.43] ***	1.45 [0.47] ***
Imported intermediate inputs (high tech)	1.79 [0.44] ***	2.01 [0.52] ***
Time dummies		Yes
Country dummies		Yes
Pavitt dummies-industry groups		Yes
N.observations	704	704
R2 (Adj)	0.50	0.56

Third, we replicate the 3SLS estimation using as regressors the first lag of our key variables (the lagged variables are export market shares, product and process innovation; results are reported in table A5). Using this procedure, we control for all the potential biases due to reverse causality among the relationships. Even controlling for a potential reverse causality bias involving the dependent variables and the key regressors of the model (export market share, product and process innovation variables), the system of relations appears robust and stable. Beside this, all the other detected relationships – with the exception of the distance from the frontier in the first equation and the rate of growth of demand in the second one – are confirmed by the test. The statistical significance of the offshoring variables in the third equation is inverted in favor of the high tech offshoring variable.

Table A5. The system of three equations with lagged regressors

Three Stage Least Squares. Standard Errors in brackets, * significant at 10%, ** significant at 5%, *** significant at 1%.

Included endogeneous: R&D per employee (first lag), Export market shares (first lag), Rate of growth of demand, Expenditure for new machineries, Rate of growth of wages; *Excluded instruments*: Rate of growth of value added (first lag), country, time and Pavitt dummies; Share of workers with primary, secondary and tertiary education.

	Equation 1 **R&D per employee**	**Equation 2** **Share of Product Innovators**	**Equation 3** **Export Market Share**
R&D per employee (First lag)	0.63 [0.04]***	**2.18** **[0.34]****	
Size	0.62 [0.80]	23.40 [5.97]***	
Distance from the frontier	-0.03 [0.02]		
Export market share (First lag)	**0.05** **[0.01]*****		
Rate of growth of demand		-0.03 [0.27]	
New machinery per employee		8.43 [0.77]***	
Share of Product Innovators (First lag)			**0.40** **[0.05]*****
Share of innov. aiming to reduce labor cost (First lag)			0.08 [0.07]
Rate of Growth of hourly wages (high skill)	0.22 [0.08]***		1.53 [0.39]**
Rate of Growth of hourly wages (medium skill)			-1.02 [0.44]**
Rate of Growth of hourly wages (low skill)			0.77 [0.33]**
Rate of growth of Imported Interm. Input (low-tech)			-0.50 [0.80]
Rate of growth of Imported Interm. Input (high-tech)			2.16 [1.05]**
Obs	313	313	313
RMSE	3.76	28.37	17.48
Chi-2	482.00	453.00	415.03
(p-value)	(0.00)	(0.00)	(0.00)

Finally, we estimate the 3SLS using a different measure of export success - the compound average annual growth rate of exports - as a dependent variable in the third equation of the system and as a regressor in the first equation. The results, shown in Table A6, highlight the stability of the system of relationships when a different indicator of international performances is adopted, confirming the results in Guarascio et al. (2014). With this specification, the growth of wages loses significance in the third equation. Finally, the coefficients associated to the offshoring variables are coherent in sign and significance with the baseline 3SLS estimation.

Table A6. The system of three equations with the rate of growth of exports

Three Stage Least Squares. Standard Errors in brackets, * significant at 10%, ** significant at 5%, *** significant at 1%.
Included endogeneous: R&D per employee, Rate of growth of exports, Rate of growth of demand, Expenditure for new machineries, Rate of growth of wages; *Excluded instruments*: Rate of growth of value added (first lag), country, time and Pavitt dummies; Share of workers with primary, secondary and tertiary education.

	Equation 1 **R&D per employee**	**Equation 2** **Share of Product Innovators**	**Equation 3** **Rate of growth of exports**
R&D per employee (First lag)	0.71 [0.04]***	**1.36** **[0.34]****	
Size	1.10 [0.53]**	26.48 [5.81]***	
Distance from the frontier	-0.05 [0.01]***		
Rate of growth of exports	**0.08** **[0.01]*****		
Rate of growth of demand		0.44 [0.22]*	
New machinery per employee		12.87 [0.87]***	
Share of Product Innovators			**0.10**

			[0.02] ***
Share of innovations aiming to reduce labor cost			0.02
			[0.04]
Rate of Growth of hourly wages (high skill)	0.18		-0.21
	[0.04] ***		[0.15]
Rate of Growth of hourly wages (medium skill)			0.22
			[0.18]
Rate of Growth of hourly wages (low skill)			0.09
			[0.09]
Rate of growth of Imported Interm. Input (low-tech)			2.38
			[0.40] ***
Rate of growth of Imported Interm. Input (high-tech)			0.61
			[0.48]
Obs	488	488	488
RMSE	3.27	34.55	11.64
Chi-2	978.83	542.87	152.00
(p-value)	(0.00)	(0.00)	(0.00)