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Innovation and Productivity in European Industries

by

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Abstract

The labour productivity impact of innovation is investigated in this paper combining neo-Schumpeterian insights on the variety of innovation, with the importance of industrial structures and firm size; two models are proposed for explaining productivity and export success in European manufacturing industries and firm size classes. The empirical estimates are based on data from the European innovation survey (CIS 2), covering Austria, France, Italy, the Netherlands and the UK, broken down by 22 sectors and for large, medium and small firms. The econometric results, obtained adopting cross-sectional estimation methodologies able to account for unobserved industrial characteristics, show that productivity in Europe relies on product and process innovation, with the support of the efficiency gains provided by a grouped business structures. Conversely, in Italy the introduction of new machinery linked to innovation appears as the key mechanism supporting domestic productivity. When export success is considered, all countries have to rely on an innovation-based model of competitiveness.

1. INNOVATION AND PERFORMANCE[1]

Innovation has long been considered a key source for labour productivity growth in all economic theories and approaches. However, when it comes to conceptualising and modelling both innovation and productivity, major differences in theories and empirical methods emerge. In this paper we combine neo-Schumpeterian insights on the variety of innovation, with a perspective considering the importance of structural change and industrial dynamics in productivity performances. The analysis will integrate industry level and firm size perspectives; we will investigate differences in the levels of turnover per employee in Europe and Italy, and in the share of exports in turnover, considering the role of different innovation indicators and of industry and business structures.

Our starting point is an emphasis on the *differences* in the types of innovation, on their systemic and localised nature, and on the variety of efforts required to carry them out in firms and industries. Innovations are affected by the technological regime that in each industry shapes the opportunities for change and by the specific strategy characterising industries and firms[2]. Two basic mechanisms have

[2] Works in the tradition of Schumpeter (1934) include Freeman and Louça (2001), Antonelli (2003); on sectoral systems see Breschi, Malerba, Orsenigo (2000); Malerba (2002,2004).

been identified on the ways different innovative activities lead to diverging economic effects: the model of *active price competitiveness* and the one of *technological competitiveness* (Pianta, 2001). The former, largely relying on process innovations, increases efficiency mainly through a reduction of labour inputs; the latter, rooted in product innovations, raises productivity mainly through an expansion of output. These two parallel, and sometimes alternative, paths to productivity growth will be investigated in this paper with an effort to empirically test the relevance of each factor in Europe and Italy in the mid-late 1990s.

While this paper focuses on the innovation dynamics, we should acknowledge that is not the sole determinant of economic performance. Structural and demand factors play an equally important role, including the business and market structure, the growth of demand and the cost and wage dynamics, and are investigated in parallel studies (Mastrostefano and Pianta, 2004; Crespi and Pianta, 2005). Such an approach allows to conceptualise innovation as a deliberate process of *endogenous* change, highly specific to firms and industries, shaping their productivity growth.[3]

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[3] This contrasts with the traditional view of *exogenous* technological change in neoclassical growth models, with the view of technology as information and the reliance on knowledge spillovers. New growth theories have made efforts to endogenise innovation considering R&D activities, learning or human capital as factors contributing to growth, while differentiating between innovating and non innovating firms. Such approaches tend to view innovation as the emergence of a new production technology changing capital/labour ratios and productivity, concentrating therefore on process innovations, while the introduction of product innovations is rarely addressed in these models.

The paper is organized as follows: in the next section previous works are discussed; in Section 3 the data source is presented; in Section 4 two testable models are provided; in Section 5 econometric results are discussed, while conclusive remarks are listed in the final Section 6.

2. STUDIES ON INNOVATION AND PRODUCTIVITY

Since the mid-1990s, the rapid growth of the US economy (associated to the booming stock exchange), the large scale introduction of ICTs and a series of other developments have renewed the interest on the dynamics and sources of productivity growth. The debate has been particularly intense in the United States, where it followed a previous discussion on the causes of the "productivity slowdown" since the 1970s and on the "Solow paradox".[4] The outstanding performance of the US economy in terms of growth and productivity in the second half of the nineties was explained by Gordon (1998) with the deceleration of inflation associated to the strength of the dollar, a decline in real oil prices, an accelerated fall in computer prices, a reduced relative inflation in medical care and in a series of improvement in inflation measurement; such a slow down in inflation was not reversed by the continuing fall in the unemployment rate. On the other hand, Jorgenson and Stiroh (2000) argued that the US performance was not due to temporary shocks, but to a long-term rise in the total factor productivity especially

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[4] In 1987 Solow argued that "You can see the computer age everywhere but in the productivity statistics".

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in IT sectors[5]. Nordhaus (2002) found that the productivity rise was not concentrated in the "new economy" sectors alone. Finally, Gordon (2003) stressed that after the collapse of the New Economy, labour productivity growth not only did not slow down, but accelerated.

An important part of the debate focuses on the role of ICTs and innovation in supporting productivity growth at the micro and macro level, considering both total factor productivity and labour productivity. Several firm level studies found strong evidence of productivity gains resulting from the introduction of ICTs (and an association with organisational innovations and increasing skills of the workforce), but the macroeconomic picture has remained far from clear due to problems in definition, measurement and performance. This had led to a renewed "productivity puzzle", with positive effects at the firm level and a lack of impact at the macroeconomic level (Greenan, L'Horty and Mairesse, 2002). The key measurement problem concerns the methods of accounting for the quality improvements in output and price changes resulting from ICT based innovation and the expansion of related services; the estimates of production and productivity heavily depends on the method used, that in the US included the use of hedonic prices in order to reflect improved quality (Triplett, 2002).

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[5] On the other hand, Carlaw and Kosempel (2004) found renewed evidence of a slowdown in total factor productivity for Canada up to 1996, in spite of increasing investment-specific technology. A sectoral study on Canada again by Gu and Tang (2004) found that a composite measure of innovation had a positive impact on labour productivity over the 1980-1997 period.

Further work with a macro approach has been carried out by the OECD in its "growth project"; productivity growth has been considered as the result of ICT production and use, R&D efforts, higher skills, structural change, and product market competition, while paying attention to the institutional factors that help explain the differences in the US and European performance (OECD 2003).

Within this context, a number of studies have addressed the impact of ICTs and technological change on producivity at the firm and industry level.

At the firm level, using panels of firms, mainly in the US, it has been shown that various measures of ICT investment, use, computerisation of production processes, and IT related labour generally have important effects on productivity. Moreover, a strong complementarity exists between technological and organisational innovation and their productivity effect reflects such pattern. However, in empirical studies the processes, complexity and costs of organisational innovation are usually disregarded, relying on ICT investment alone as the key input investigated (Hitt and Brynjolfsson, 2002; Black and Lynch, 2001).

A more solid approach, in Europe, has carried out firm level studies using innovation surveys (European Commission-Eurostat 2001,2004), investigating the relationships between inputs and outputs in the innovation process and the productivity effects of innovation, concentrating on the case of European manufacturing industry. The results have shown the importance of innovation in sustaining productivity, alongside the role played by structural factors, with strong cross country differences.[6]

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[6] See Crépon, Duguet and Mairesse (1998), Mairesse and Mohnen (2001, 2002), Mohnen, Mairesse and Dagenais (2004), Van Leeuwen (2002), Hinloopen (2003).

A frequent problem, however, is found with firm level studies. They are generally unable to identify whether the gains of innovating firms are made at the expense of competitors (the so-called "business stealing effect"), or whether there is a net effect on aggregate industry.[7] Firm level studies may show that innovative firms are winners, and non-innovators tend to be losers, but they may provide limited information on the overall outcome and the labour productivity effects in an industry. In this paper the analysis will be carried out at the industry level, as this makes it possible to identify such overall effects of technological change within sectors.[8]

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[7] Such a contrast between firm level and industry (or macro) level results is often found also in studies on the employment impact of innovation. In the study on France by Greenan and Guellec (2000), the positive relationship between both product and process innovation and employment at the firm level disappeared when the analysis was carried out on the same data at the industry level, where product innovation alone was associated to job creation. A second problem of the literature on firms is that, with the exception of works based on innovation surveys, most studies use surveys of firms in panels that usually are *not representative* of the whole manufacturing industry. The sample selection bias may lead to panels where the presence of innovators is distorted, and this makes comparisons of different studies difficult, and prevents us from drawing conclusions on what may happen to industry as a whole. Their results, in other words, cannot be easily generalised. See also Pianta (2005).

[8] The indirect effects that operate within an industry include business stealing effects, product substitution or differentiation, price-elastic market expansion, change in market shares, entry and exit of firms, competition patterns, vertical integration/disintegration, etc.

Studies on industries have suggested that structural change (Pasinetti 1981) is the driving force behind the impact that the evolution of technology has on output and jobs, accounting also for the evolution of demand. The literature on sectoral systems of innovation (Malerba 2004) has shown that the sources and opportunities for progress are specific in individual manufacturing (and service) industries. Moreover, an industry perspective makes it possible to consider a variety of other structural and country factors that constrain or support the operation of firms.

Among them, firm size plays an important role in bridging the micro and macro performances. While the traditional "Schumpeterian hypothesis" holds that small firms are at a disadvantage in introducing innovations and increasing productivity, much recent research has found that small firms do not have a worse innovative performance. They spend less on R&D than large firms, but they outperform large firms when considering innovation counts[9]. Such a perspective has highlighted the importance of market structure for the performance of large and small firms; with different datasets and different model specifications several studies found mixed results regarding the effect of market concentration on the innovation performance of small and large firms. The presence of skilled labour favours small firms more than large ones, while the contrary holds for capital intensity.[10]

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[9] The relationship between firm size, innovation and performance has been investigated by the studies of Rothwell (1989), Kleinknecht (1989), Santarelli and Sterlacchini (1990), Link and Bozeman (1994), Hansen (1992), Acs and Audretsch (1988, 1990), Brouwer (1998).

[10] Van Dijk et al. (1997), considering as dependent variable not innovation counts but the expenditure in R&D, found the same results for market concentration and capital intensity using a dataset of Dutch firms. They did not find any different

The literature on firm size, innovation and productivity has shown that no general pattern exists, due to the variety of sources of productivity growth that can be accessed by firms of different size, including those internal and external to the firm, associated to the presence of spillovers or localised externalities, the organisation of small firms in groups, etc. All these factors require consideration in an analysis of the innovation-productivity link.

Therefore, in this paper we will combine industry level and firm size perspectives, using data from innovation surveys that cover the whole of manufacturing industry in Europe. This appears as the most appropriate and viable approach to a study of the productivity impact of innovation. In this paper we focus on the effects of different patterns of technological innovation on performance, and we are less concerned with differences in capital intensities and on their impact on growth. Therefore, our primary interest is in the analysis of how labour productivity reflects innovative efforts. Moreover, data on capital intensity of industries broken down by firm size classes (that would be required in a study of TFP) are not available. As will be discussed later in the presentation of the model, sectoral differences in capital intensities will be treated as unobserved industry characteristics.

Alongside the analysis of Europe as a whole, a parallel investigation will be carried out for Italy, the country that has the most distinct profile in terms of industrial structure, (with an over-representation of traditional industries), firm

effect of skilled labour on the innovative performance of small and large firms, though they did find that market growth has a greater effect on large firms than on small firms.

size distribution (with the dominance of small firms) and innovative efforts (with lower than average R&D), in order to test the stability of the innovation-productivity link in different national contexts.

3. DATA

The innovation-productivity relationship is investigated in this section at the industry level with a breakdown by firms size classes, as the sources and the patterns of innovation tend to be highly sector-specific and the industrial composition of national economies has a key role in explaining differences in performances. The empirical analysis uses the SIEPI-CIS2 database developed by a group of European universities coordinated by the University of Urbino. In order to overcome privacy restrictions, CIS 2 data (referring to 1994-1996) at the industry level for 22 manufacturing sectors, broken down in three firm size classes (20-49; 50-249; above 250 employees), have been obtained by each team at its national statistical office; micro data, on the other hand, were not available. In the context of innovation studies, our dataset is highly original and makes it possible to analyse innovation patterns across a great number of industries in different European countries[11]. As the breakdown for firm-size classes is available only for Austria, France, Italy, the Netherlands and the UK, the analysis will consider these five EU countries.

The innovation survey data provide information on quantitative and qualitative aspects of firms' performances and innovative activities, including information on turnover, employment, exports, product and process innovations, on innovative expenditures and

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[11] Acs and Audretsch (1988), for instance, exploited a similar dataset for the US.

on several other aspects of innovative strategies (European Commission-Eurostat 2001,2004). In order to use data broken down by firm size, we are constrained to consider the performance variables available in the CIS survey only, that is turnover, export and employment in 1996, as no matching with data based on national accounts or industrial statistics (such as value added, investment, capital stock, etc.) is possible.[12].

Therefore the performance indicators that will be considered include the turnover per employee, a standard measure of labour productivity levels, and the share of exports in total turnover, a more focused indicator of success in international competitiveness for each unit of observation. Two models will be developed for investigating their determinants, in section 5.

The list of the variables considered in this analysis is the following:

- *the turnover-employment ratio*, used as an indicator of labour productivity *;*

- *the export-turnover ratio*, used as an indicator of success in export orientation of the sector;

- *the percentage of innovating firms* (i.e. firms that have introduced either a product or a process innovation over 1994-1996), used as an indicator of the overall diffusion of innovation in European industries;

- *the expenditure per employee due to acquisition of machinery and equipment linked to innovations*, used as an indicator of innovative efforts relying on the introduction of new machinery linked to innovation and process innovation;

- *the percentage patent applicants,* calculated as the share of firms that have applied for a patent in 1994-1996, an indicator of the inventive success of an industry, and a proxy for product innovation;

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[12] As highlighted also by Pianta and Vaona (2005).

- *the percentage of firms that are part of a group* on the whole number of firms belonging to a given sector, providing evidence of the business structure prevailing in the industry and firm size group.

Some descriptive evidence can help setting the analysis in the context of European (and Italian) trends in the late 1990s. Figure 1 shows that, taking industry averages and comparing the whole of four EU countries considered (Austria, France, the Netherlands and the UK) and Italy, we find that the EU average is generally higher than the values for Italy, with the exception of a small lead in turnover per employee and of a larger advantage in machinery expenditure per employee. Italian industry is moderately behind the EU average in export-turnover ratio, and in terms of the percentage of innovative firms, but the lag becomes larger when we consider the percentage of patent applicants and the share of firms belonging to a group. While this evidence confirms much of the well known characteristics of Italian and European industry, it provides a useful context for the econometric analyses in the next sections.

As far as firm size is concerned, Figure 2 shows a very stable distribution for most variables in all countries, with large firms having the highest value, followed by medium and small firms. The distance between large and small firms is particularly important in the percentage of patent applicants and in the share of firms belonging to a group. The only exception is the expenditure for new machinery per employee; for European countries small firms have the highest average value, followed by medium sized ones and then by large firms, whereas in Italy medium firms lead, followed by small firms and by large firms. The importance of this source of innovation for the small and medium sized firms clearly emerges from these data.

When we compare the Italian case to the average of other EU countries, we find that innovation takes the form of new technologies embodied in machinery more than that of new patents and actual innovations. Such a model appears to be effective in generating a higher value of turnover per employee, but much less so in increasing the share of exports in turnover (in spite of the large devaluation of late 1992 whose effect was probably felt also in 1996). This suggests that the reasons of concern for Italy are not mainly in the domestic performance of individual sectors, but in the industrial mix that characterise its economic structure and that explains the lower export-turnover ratio in Italy with respect to Europe.

Going back to the discussion in section 2, the variety of innovative efforts documented by the variables shown here suggests that, on the one hand, Europe may reveal a strategy based on innovation success, relying on several sources of improved performance. Italy, on the other hand, reflects a strategy based on the intensive use of innovative machinery, leading to a model of cost based competitiveness, associated to labour saving and productivity increasing investment. This is the combined result of deliberate strategies by firms and of the constraints set by Italy's industrial structure. A broader analysis of the heterogeneity of innovation patterns in different sectors in Europe has shown that industries differ in their innovative behaviour, strategies and performances, and this has a specific impact on their growth and productivity performances.[13] Our

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[13] Such distinct patterns of innovation show a strong stability over time. The distributions of the percentage of innovative firms in 1994-1996 (CIS 2 survey) and in 1998-2000 (CIS 3 survey) show a close association (Mastrostefano and Pianta, 2004). An empirical study of the nature and sources of variety of innovation in industry across Europe has been carried out by Evangelista and Mastrostefano (2004), using the SIEPI

indicators therefore capture persistent patterns across sectors, firm size groups and countries in the diffusion and impact of innovations.

4. THE MODELS

4.1 Explaining productivity and export success

In this section two models are proposed aiming to test the impact of innovation on performance measures. Considering the cross-sectional nature of the data, these models aim to identify key associations between variables, more than actual causation. The first relationship to be tested is the influence on labour productivity levels of the diffusion of innovations in firms, of the introduction of innovation-related machinery (a major source of improvements in production processes), and of the relevance of business groups within the industries and firm size classes considered, that affect the overall efficiency of organisations and business structures.

The specification of the first model is the following:

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database drawn by the second Community Innovation Survey for 10 countries, 22 manufacturing sectors and three firm size classes. The analysis has shown that the type of activity undertaken by firms to innovate is largely sector specific. This result confirms the existence of sector specific technological regimes (Malerba 2002,2004) that hold across countries and are only marginally affected by the size of firms. In particular, the analysis has shown that the greatest influence of sectors is found for indicators such as the percentage of turnover due to new products, the percentage of personnel involved in R&D activities, the importance of either R&D or new investment in total innovation expenditures.

$$Y_{isj} = k + aI_{isj} + bM_{isj} + cG_{isj} + e_{isj} \qquad [1]$$

where, for sector i, size class s and country j:

Y is the ratio between turnover and employment,

k is a constant,

I is the general indicator of the diffusion of innovation in firms (measured by the share of innovative firms, either in products or in processes in the period 1994-1996),

M is the expenditure per employee on machinery and equipment associated to the introduction of innovations in 1996, suggesting an orientation towards process innovations,

G is the share of firms belonging to a group,

e is the error term.

We expect all variables to have a positive impact on labour productivity, although different mechanisms may be relevant for different countries. Labour productivity is expressed by turnover over employment, a measure used also by Tsai and Wang (2004) or Wakelin (1997). This model specification, however, partially departs from a production function specification (used by the above cited contributions and by Siegel and Lichtenberg, 2001). We do not include capital intensity as a regressor because such data are not produced with a firm-size breakdown, and it would be questionable to use the same capital intensity for different firm size classes. Moreover, endogenous growth theory has shifted the attention from production functions that include capital, to alternative ones that include R&D effort, innovation and intermediate inputs (Barro and Xala-i-Martin, 1995). By estimating model [1] and treating capital intensity as an unobserved characteristic, we would like to highlight stylized facts that can be useful to

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theoretical models interested more on the effect of innovation on productivity than those just relying on capital deepening.

A second model is developed in order to move from labour productivity levels to an indicator of competitiveness such as the share of turnover devoted to exports (in 1996), and to test the specific impact of different types of innovative activities, with a contrast between product and process orientations.

$$E_{isj} = k + aI_{isj} + bP_{isj} + cM_{isj} + e_{isj} \qquad [2]$$

E is the ratio between export and turnover,

k is a constant,

I is the general indicator of the diffusion of innovation in firms (measured by the share of innovative firms, either in products or in processes in the period 1994-1996),

P is the share of firms that have applied for a patent in 1994-1996, an indicator of the inventions made by firms and a proxy for their orientation toward product innovation,

M is the expenditure per employee on machinery and equipment associated to the introduction of innovations in 1996, suggesting an orientation towards process innovations,

e is the error term.

Tables 1 and 2 show the results of the empirical tests of the model. The Appendix provides further information on the variables and data used.

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4.2 Methodology

The dataset used in this paper collects observations that can be grouped along three categories: countries, sectors and class sizes. It is well known in the literature that the presence of unobserved variables for each of the groups of a dataset can lead either to correlation between the regressors and the errors, or to correlation between the errors. In both the cases, OLS is highly misleading: it provides biased estimates in the first case and biased standard errors, and therefore unreliable significance test statistics, in the second case.

The econometric tool developed to cope with these problems is the error components model (ECM). First the one- and two-way ECM for balanced datasets have been developed[14], distinguishing between the fixed effects (FE) and the random effects (RE) models. The first is generally recommended when regressors are correlated with the errors due to group unobserved variables, the latter when unobserved variables induce correlations between the errors but not between the regressors and the errors. In order to check which model best fits the data, Hausman (1971) suggested to compare the two estimators above, on the ground that in the first case they are "distant", because the random effect estimator is biased, and in the second case they are close, as under this hypothesis they are both consistent.

One of the shortcomings of the literature above is that practitioners very often have to deal with datasets with missing values and with more than two groups. As far as

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[14] See Balestra and Nerlove (1973), Wallace and Hussain (1969), Amemya (1971), Nerlove (1971a, b), Mazodier (1972) and Fuller and Batese (1974).

the first aspect is concerned, Baltagi (1985) and Wansbeek and Kapetyn (1989) developed respectively the one- and the two-way ECM for unbalanced data. Finally, Davis (2002), that is the main methodological reference for this paper, showed that the one- and the two-way ECM for unbalanced data are only special cases of a multi-way ECM and provided the WITHIN, the RE and the maximum likelihood (MLE) estimators for unbalanced datasets[15]. In essence the model we are going to estimate is the following:

$$y_{dij} = \alpha + \beta x_{dij} + \gamma_d + \lambda_i + \mu_j + \nu_{dij} \qquad [3]$$

where y is the dependent variable, α is the constant, x is the vector of regressors, γ is the class size effect, λ is the sector effect and μ is the country effect.

A further point to remember is that the RE estimator is just a GLS estimator, correcting the variance covariance matrix of the residuals by allowing for within group correlation. Like all the GLS estimators, what is actually possible to compute is their Feasible GLS (FGLS) counterpart and many possible routes have been proposed. Baltagi (2003) provides a good survey of the different approaches. Here, a minimum norm quadratic unbiased estimator (MINQUE[16]) was computed, discarding the WITHIN estimator on the ground of the Hausman test.

It is worth recalling that Davis (2002) performed Montecarlo Simulations and concluded that the maximum likelihood estimator (MLE) is computationally more

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[15] It is also worth recalling that Davis (2003) provided a multiway system ECM estimators for unbalanced datasets.

[16] In its MV_3 variant, as labelled by Davis (2002).

[18] After Moulton and Randolph (1989)

intensive, has a higher mean squared error than RE estimators when the group variances are different from zero, but offers huge advantages when some of the group variances are equal to zero. The WITHIN estimator displayed a much worse performance than all alternatives. Therefore, in order to exploit the computational advantages of the RE estimators without incurring into model misspecification, we supported our estimates with an SLM test[18] for each of the components of the error in order to check whether group variances were significantly different than zero. According to the results of these tests we imposed the appropriate group variances to be zero.

Finally, in order to account for the industrial mix, we weighted the observations with the share of each observation (sector and firm size class) in the total turnover of its country, in order to give more weight to sectors were most of the production is concentrated. The weighted regression allows to take into account not only the effect of the regressors on the dependent variable, but also the effect of the industrial mix of a country, whereby large sectors have a greater impact on the national economy than smaller ones.

5. RESULTS

Table 1 presents the results of the first model, calculated for the whole of the five European countries and for Italy alone, in order to test the specificity of the country that has the most distinct pattern of innovation and industrial structure.[19]

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[19] Both the present and the next models were tested also excluding Italy from the group of European countries. The results are largely the same presented in Tables 1 and 2; the sign and the significance of the coefficients were never affected; the values of the

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The method used is a weighted regression (with the share of country turnover for each unit of observation), applying the three and two way unbalanced error component model with random effects described above.

Two remarkably different mechanisms for productivity growth emerge from the results. On the one hand, Europe as a whole relies on a positive and significant role of innovation (in both products and processes) and on a business structure where the presence of groups of firms has a positive and significant role. The introduction of new machinery linked to innovation, on the other hand, is not significant for European industries.

On the other hand, labour productivity in Italian industries is higher where the share of innovating firms is lower, and a much greater importance emerges for both the group structure (positive, significant and with a higher coefficient than in Europe as a whole) and investment per employee in new machinery (with very high, positive and significant coefficients).

The importance of industry differences (including their different capital intensities) can be tested by the use of sectoral dummies in a fixed effect model. This test has been carried out, obtaining very similar results for the variables' coefficients, and the results for the dummies are shown in Table 2, where we find that only two sectors (Food and Machinery), for Europe only, emerge with significant coefficients. However, the Hausman test shown in Table 1 suggests that the random effect estimator (used in Table 1) is preferable to the fixed effect model; this means that the standard errors of the fixed effect model are biased, resulting in misleading statistical inference and unreliable t-statistics (Baltagi,

coefficients would slightly increase if the Italian coefficient is lower than the European one, and decrease if the Italian coefficient is higher.

2003). Every inference that might be drawn from the sign of the dummies is very likely to be highly misleading, given that due to biased standard errors, we do not actually know what is statistically different from zero or not. Given the evidence provided by the Hausman test, the results provided in Table 1 are the relevant ones.

Concerning the differences among firm size classes, the value of σ_γ for Europe is significantly different from zero, suggesting that heterogeneity exists between large, medium and small firms; a reasonable hypothesis may be that larger firms may have an actual labour productivity higher than the one predicted by the model, associated to the Schumpeterian aspects of increasing returns to innovative efforts and scale effects. In Italy, on the other hand, the value of σ_γ is zero, suggesting that all firm sizes are equally accounted for in the model. This may imply that Italian small firms are not different from larger ones in the way innovation is related to productivity.[21]

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[21] The Standardized Lagrange Multiplier test finds no error correlation for firm-size classes in Italy alone. An unweighted OLS version of the above model has also been carried out, finding basically the same results for Italy (the negative impact of the share of innovative firms loses its significance), while for Europe the latter again is not significant, and expenditure for new machinery per employee becomes positively significant.

The basic picture that emerges in Europe is an *innovation-based* model of productivity growth, relying on both product and process innovation, supported by the efficiency gains provided by a grouped business structures. Conversely, in Italy *innovation through the introduction of new machinery* appears as the key mechanism supporting domestic productivity, relying on large scale investment (with obvious negative consequences on employment, as shown in Pianta 2000, Antonucci and Pianta 2002, Mastrostefano and Pianta, 2004), with an above-average effect of group links, considering the below-average size of Italian firms. Remarkably, the introduction of innovations is higher in industries where turnover per employee is lower; Italy thus appears largely unable to harness the powerful engine of productivity growth associated to innovative strategies.

The second model investigates the relative success of European and Italian industries in the competition for export markets, identifying more closely the role of innovation diffusion, new machinery and invention as sources of productivity and competitiveness. Table 3 shows the results of the regressions for Europe and Italy, using the same method presented above. Again, the Hausman test shows that the fixed effect estimator has resulted inferior to the random effect model, and industry dummies are therefore unreliable.

When the export performance is considered, the European and the Italian models appear much more similar. Competitiveness in different industries emerges as both *innovation based* and *invention based,* with significantly positive roles of the share of innovating and patenting firms; the introduction of new machinery linked to innovation, on the other hand, emerges with a significantly negative correlation with export performance for both Europe and Italy. A difference is found, however, in the values of coefficients, with Italy showing a lower importance of

patenting. Looking at the differences among firm size classes, we find the same results as in Table 1. The value of σ_γ for Europe is significantly different from zero, while for Italy it is equal to zero. In Europe larger firms may have a higher than expected export orientation and competitiveness. In Italy firms of all sizes appear to behave in the way described by the model.[22]

When the competitive test of export markets is considered, in contrast to the determinants of labour productivity levels, we find that industries with a good export performance have to rely in all countries on improvements in both products and processes. Sectors with a relevant effort of *capital deepening* may be successful in achieving higher productivity levels (mainly through a lowering of labour inputs, rather than with an expansion of output), but the resulting cost-based competitiveness is unable to lead to high export shares. Advanced economies such as the European ones can expand their foreign markets only through a strategy of technological competitiveness, where innovation plays a key role.

6. CONCLUSIONS

This econometric investigation has explored the innovation-productivity link in European manufacturing industries, highlighting the contrast between the European and Italian models of labour productivity growth. Compared to studies

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[22] The Standardized Lagrange Multiplier test detects absence of error correlation for firm size classes in the European model and for sectors in the Italian model. A systematic analysis of differences in innovative performances among firm size classes in European industries is developed in Pianta and Vaona (2005).

using R&D expenditure (an input indicator) or patent data (an indicator of inventive output), the use of innovation survey data in this analysis makes it possible to consider the effective introduction of innovations in firms and the efforts associated to innovative investments; the measurement and assessment of innovation is therefore more accurate. Moreover, data used in this work refer to *total* innovative and economic activities in the industries concerned, and the results we have found report the patterns of the whole manufacturing industry. This is a major advantage compared to panel studies on samples of firms that are not representative of the universe, and whose results cannot be generalised.

The use of more specific innovation indicators allows to identify the different mechanisms that support labour productivity growth: innovation based, invention based and capital deepening. We have shown that European industries rely on the former two processes of technological change, while in Italy productivity growth is rooted in the introduction of new machinery linked to innovation alone, a model that has had major negative effects on employment in the 1990s. When export success is considered, all countries have to rely on innovation in products and processes. The lesson for future research is that generic indicators of both productivity and innovation are less and less adequate to capture the specific innovative strategies pursued by firms and industries. Therefore, while the dataset concerns only one period of time and coefficients may not be considered as detecting causal effects, however they do detect different sectoral patterns between Italy and Europe, highlighting important features of the way high productivity or successful export performance are achieved.

In addition to innovation diversity, structural factors may deserve more attention. Parallel studies on innovation and employment dynamics in Europe and Italy (Mastrostefano and Pianta, 2004; Crespi and Pianta, 2005) show that demand

patterns play a role in stimulating innovative performances and that long term employment growth needs both demand and a concentration on product innovations with a strong market impact. Such conditions are more likely to be found in high innovation industries characterised by rapid technological change and high growth of final demand. The industrial structure of several European countries, and even more so the Italian one, shows a limited presence of such industries, and a troubling presence of strategies aiming at cost competitiveness, through the introduction of new machinery linked to innovation, *labour saving* process innovations and wage containment. Such structural factors and current strategies, combined with the continuing restraint on demand due to fiscal and monetary policies, suggest that Europe's industrial and employment base are in danger of further erosion, if no active macroeconomic, industrial and innovation policies are introduced.

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Table 1 - The determinants of productivity in European and Italian industries
Dependent variable: turnover-employment ratio.
Method: weighted three and two way unbalanced error component model (MINQUE Random Effect). The weight used is the share of turnover in each unit of observation
*: significant at the 95% level
Countries in the European regression: AT, FR, IT, NL, UK.
Number of observations: 263 for Europe and 65 for Italy.

	Europe	Italy
Percentage of firms introducing a process and/or a product innovation	0.20*	-0.34*
t-stat	(4.12)	(-4.66)
Percentage of firms part of an enterprise group	0.19*	0.43*
t-stat	(3.9)	(6.80)
Expenditure per employee due to acquisition of machinery and equipment linked to innovations	1.43	101.45*
t-stat	(0.36)	(11.17)
σ_μ	4.5×10^{-7}	-
σ_λ	2.9×10^{-6}	0.0060
σ_γ	1.1×10^{-6}	0
σ_v	1.6×10^{-5}	0.0089
Hausman	3.00	3.00
p-value	(0.39)	(0.39)
$\mathbf{SLM_\mu}$	2.15	-
p-value	(0.03)	-
$\mathbf{SLM_\lambda}$	5.78	-0.01
p-value	(0.00)	(1.00)
$\mathbf{SLM_\gamma}$	4.57	-0.38
p-value	(0.00)	(1.00)

Table 2 – Sectoral Dummies for the fixed effect estimator of the productivity model (NACE 10 sector classification).

Sector	Europe		Italy	
	Coeff.	t-stat	Coeff.	t-stat
Food and beverages	$0.39 \cdot (10^{-2})$	(2.68)	$-0.20 \cdot (10^{-2})$	(-0.95)
Textile, Wearing and Leather	$-0.05 \cdot (10^{-2})$	(-0.53)	$0.05 \cdot (10^{-2})$	(0.65)
Wood, Pulp and Printing	$-0.09 \cdot (10^{-2})$	(-0.93)	$-0.09 \cdot (10^{-2})$	(-1.15)
Coke and Chemicals	$0.22 \cdot (10^{-2})$	(1.91)	$0.11 \cdot (10^{-2})$	(0.94)
Rubber and other non metallic products	$-0.14 \cdot (10^{-2})$	(-1.36)	$-0.10 \cdot (10^{-2})$	(-1.03)
Basic and fabricated metal products	$-0.16 \cdot (10^{-2})$	(-1.57)	$-0.14 \cdot (10^{-2})$	(-1.29)
Machinery and Equipment	$-0.36 \cdot (10^{-2})$	(-2.74)	$0.05 \cdot (10^{-2})$	(0.23)
Office, electrical equipment and radio	$-0.15 \cdot (10^{-2})$	(-1.64)	$-0.08 \cdot (10^{-2})$	(-1.10)
Transport equipment	$-0.18 \cdot (10^{-2})$	(-1.62)	$-0.03 \cdot (10^{-2})$	(-0.24)
Recycling and Manufacturing NEC	$-0.11 \cdot (10^{-2})$	(-0.83)	$0.1 \cdot (10^{-2})$	(0.09)

Table 3 - The determinants of the export share of turnover in European and Italian industries
Dependent variable: export-turnover ratio.
Method: weighted three and two way unbalanced error component model (MINQUE Random Effect)
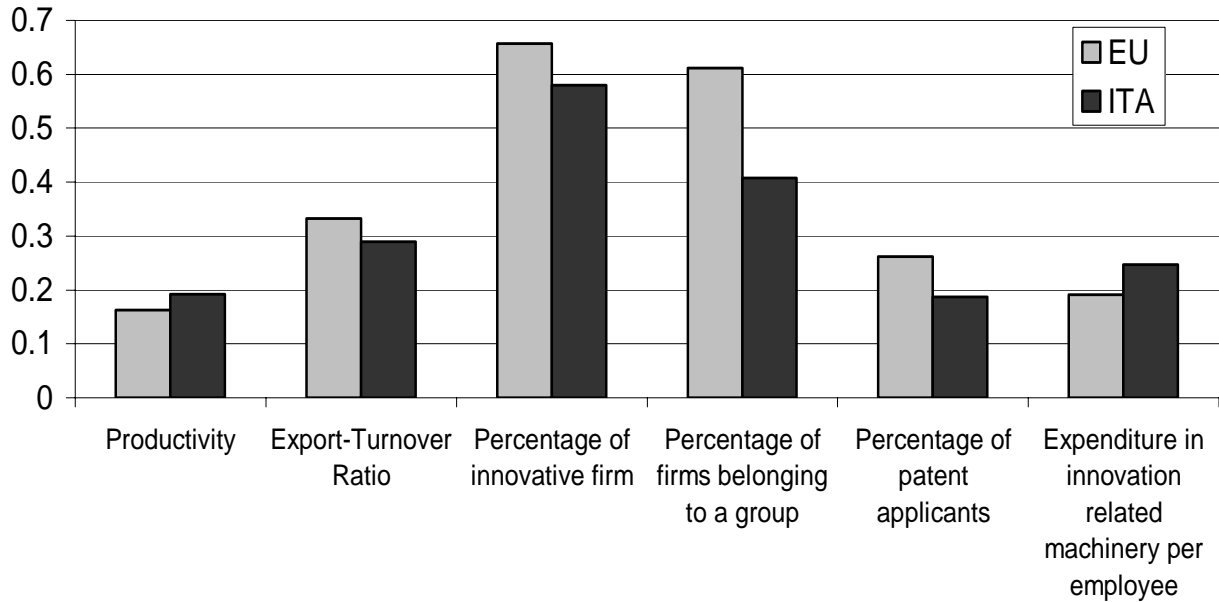*: significant at the 95% level
Countries in the European regression: AT, FR, IT, NL, UK.
Number of observations: 230 for Europe and 65 for Italy.

	Europe	Italy
Constant	0.01	0.01*
t-stat	(0.35)	(2.25)
Percentage of innovating firms	0.32*	0.29*
t-stat	(9.20)	(4.49)
Percentage of patent applicants	0.54*	0.36*
t-stat	(8.54)	(3.63)
Expenditure per employee of firms acquiring machinery and equipment linked to innovations	-23.21*	-25.67*
t-stat	(-3.78)	(-2.60)
σ_μ	1.8×10^{-6}	-
σ_λ	0	6.5×10^{-6}
σ_γ	1.1×10^{-6}	0
σ_ν	1.7×10^{-5}	3.8×10^{-6}
Hausman	3.01	2.97
p-value	(0.39)	(0.40)
SLM_μ	5.77	-
p-value	(0.00)	-
SLM_λ	1.46	4.67
p-value	(0.14)	(0.00)
SLM_γ	3.37	1.64
p-value	(0.00)	(0.10)

Fig. 1 – Innovation and performance in manufacturing industry
Average Productivity, Export-Turnover Ratio, Percentage of Innovative Firms, Expenditure in Innovation Related Machinery per Employee, Percentage of Patent Applicants per head and Percentage of firms in a group in four EU countries and in Italy in 1996
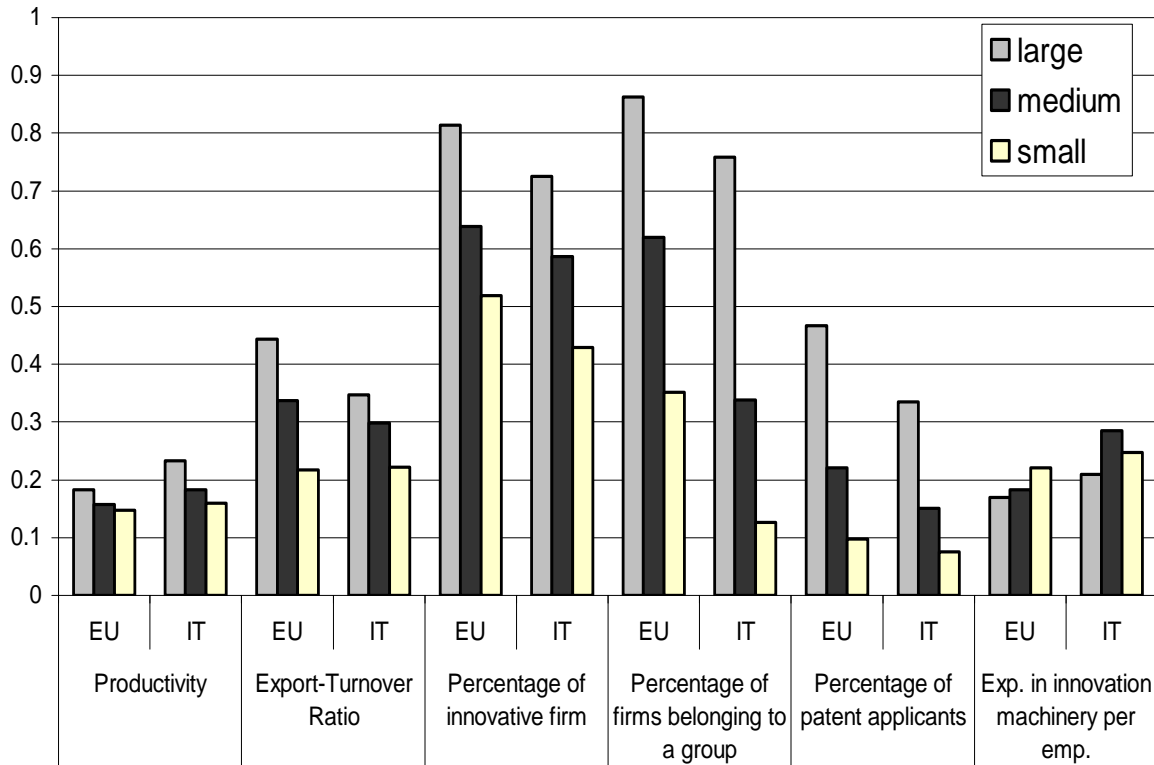

Source: SIEPI database, University of Urbino.
Note: Productivity is defined as turnover per employee. The expenditure in innovation related machinery is measured in hundreds of millions of euros per employee, whereas Productivity in millions of euros per head. By "Europe" we define here the four countries included in the study besides Italy, that is Austria, the Netherlands, France, the UK.

Fig. 2 – Innovation and performance by firm size classes
Average Productivity, Export-Turnover Ratio, Percentage of Innovative Firms, Expenditure in Innovation Related Machinery per Employee, Percentage of Patent Applicants per head and Percentage of firms in a group in four EU countries and in Italy in 1996, by firm size classes

Source: SIEPI database, University of Urbino.
Note: Productivity is defined as turnover per employee. The expenditure in innovation related machinery is measured in hundreds of millions of euros per employee, whereas Productivity in millions of euros per head. By "Europe" we define here the four countries included in the study besides Italy, that is Austria, the Netherlands, France, the UK.