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The role of human capital in identifying the drivers of product and process innovation: empirical investigation from Italy

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Abstract

Economists recognize that the local availability of higher human capital represents significant knowledge spillovers, especially for innovation process. This research question is tested on a sample of Italian manufacturing companies, originally edited by Mediocredito Centrale and currently carried out by the Capitalia Banking Group's Research Department over two waves: 2001–2003 and 2004–2007. The aim of our work is to investigate the role of human capital (measured as educational level) for innovation process in particular contexts, where the highest educated people and the highest innovation levels are differently located. To this end, we select the Italy country, characterized by a relevant North-South economic divide. Our analysis suggests that the positive spillovers can arise because the firms generate more technology innovation than those located in areas with higher educational attainment workforce. The more efficient macro regions who produce highly skilled graduates have, in a sense, saturated their contribution on firms' innovation (i.e. that have already reached their steady state). The role of some factors (size, technological and territorial) to the probability of firm's innovation has also been investigated.

Keywords Product innovation · Process innovation · Human capital

JEL classification D22 · O3 · R1

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1 Introduction

The local availability of higher educational level represents a significant positive spillover for the firms in the same area in terms of workforce (Marshall 1890; Ciccone and Peri 2006; Sena and Higon 2014). The quality of the pool of employees from where a firm can obtain its workers may affect its innovation process through different channels. First, firms located in areas with more qualified workforce, can select employees able to exploit the tangible inputs in the most opportune way. Moreover, high educated workers could improve the productivity of their co-workers through the complementarity process (Battu et al. 2003). Second, the proximity to higher educational attainment plays a relevant role. Indeed, the interactions between co-located employees with the same human capital may lead to important flow of knowledge information (Jaffe 1989; Audretsch and Feldman 1996). The availability of more graduates in an area can determine positive externalities from the local universities. Moreover, another important channel of creation and diffusion of knowledge flows derives from mobility of more qualified employees (Moen 2005; Crespi et al. 2007).

In this paper, the aim of our work is to investigate the role of human capital, measured in terms of high educated workers, in identifying the drivers of product and process innovation in particular contexts, where the highest educated people and the highest innovation levels are differently located. To this end, we select the Italy country, characterized by a relevant North-South economic divide (Daniele 2015). Our main aim is to investigate the role of human capital. Our contribution consists both theoretical and empirical framework. On the hand, a simple theoretical model a la Acemoglu (1996) is employed for better investigate human capital investments' effects generated during an innovation process. On the other hand, in order to give more support to the theoretical framework, the empirical analysis is conducted on a sample of Italian manufacturing firms, sourced by the Capitalia Banking Group's Research Department over two waves: 2001–2003 and 2004–2007. In particular, we implement a bivariate probit regression, in which the dependent variables are product and process innovation decisions. As said before, the main contribution to the relative literature is to explore the effect of human capital on firms' innovation by taking into account *simultaneously* different economic aspects in the firm life, such as the 'size class' effect, based on the number of employees, the 'technological' effect, based on the PAVITT classes (Pavitt 1984) and the 'territorial' effect, based on the geographical distribution of the firms.

The paper is structured as follows. In Sect. 2, we present a literature review about knowledge spillovers and human capital. A Theoretical model is showed in Sect. 3. Our empirical strategy to test for the theoretical hypothesis is explained in Sect. 4, along with the data and the details on variables construction. The empirical findings are discussed in Sect. 5. Section 6 performs opportune robustness checks for our empirical results. Specifically, we try to check how some factors (size, technological and territorial) can explain the differences in innovation between firms situated in different environmental context. Finally, Sect. 7 concludes, giving some insights for policy implications.

2 Literature review: the role of human capital

The objective of measuring human capital is always an interesting topic in the literature (Soboleva 2010; McGuirk et al. 2015; Alpaslan and Ali 2018; Bogers, Foss and Lyngsie 2018; Botric and Bozic 2018; Wixe 2018). In particular, the main problem in human capital measurement is represented by the difference between human capital observed as physical asset and human capital identified as intangible asset (Soboleva 2010; McGuirk et al. 2015). According to Becker (1993), we can distinguish general and specific human capital. General human capital represents the skills that are transferable between the firms, while specific human capital identify the skills less transferable and more related to an activity in terms of applicability.

The investments in education and training lead to intangible asset rather than financial or physical asset (Becker 1993). In order to asses the skill levels of a workforce, Hofheinz (2009) identifies educational attainment as an efficient methodology: higher skills are represented by tertiary attainment or equivalent and medium skills are determined by secondary or equivalent education.

We can expect a positive impact of higher educational level on firms' innovation. Indeed, from one hand, higher education affects innovation, because graduates may introduce new technological ideas; from one another hand, higher education affects innovation, because graduates may exploit in more a opportune way the technological processes (Lundvall and Johnson 1994).

Ganotakis (2012) measures specific human capital as specific educational attainment and finds that qualified human capital produces positive effects on firms' performance. Also Criaco et al. (2013) find positive relations between entrepreneurial education and university start-up.

Heirman and Clarysse (2004) observe a higher educational level of entrepreneurs engaged in high technology sectors. Roberts (1991) detect that high technology entrepreneurs have at least a Master's degree and have similar family features.

Finally, in order to compare human capital quality and quantity across different countries, Ederer (2006) introduces the European Human Capital index. The shortcoming of this measure is that it does not consider the potential impact of human capital on firms' innovation (McGuirk et al. 2015).

In this paper, our main contribution is to explore the potential effects of the quality aspect of worforce observed as intangible asset on firms' probability to generate product and process innovations. To this aim, we proxy the educational level of workforce through the number of graduates at the provincial level, in line with the relative core literature on human capital theory. Specifically, we follow the same approach suggested by Agasisti et al. (2017) and Barra and Zotti (2017), i.e. using the number of Italian graduates and universities' efficiency scores as (institution-level) indicators of human capital in order to evaluate it influences upon firms' innovation.

3 Theoretical underpinning and hypothesis development

This section, in order to give a basic background and more support to the next empirical exploration, will focus on a simple theoretical model a la Acemoglu (1996) for better investigate human capital investments' effects generated during an innovation process. We consider a simple Non-overlapping Generation Model (NOGM) in which each generation is assumed to consist of a continuum of worker, entrepreneurs and inventors each of them normalized to one. All agents, assumed to be risk neutral, and with an inter-temporal preference rate equal to zero, live for two periods. In the first workers choose their human (*educational*) level, entrepreneurs opt for their optimal knowledge capital, and inventors decide how much invest in Knowledge (*R&D*) capital; in the second period production occurs in the form of a partnership of one entrepreneur, one inventor and one worker. Consumption takes place at the end of the second period and then agents die. Workers, entrepreneurs and inventors consume all their assets leaving no bequests.

The production function is assumed to be constant return to scale and takes the following form:

$$Y_{i,j,z,t} = Ah_i^{\alpha} k_j^{\beta} c_z^{(1-\alpha-\beta)}, \tag{1}$$

where $0 < \alpha, \beta < 1$, A stands for a positive technology parameter, while h_i, k_j and c_z measure respectively the human, physical and knowledge capital of the ith worker, the jth entrepreneur and the zth-inventor.

In line with Acemoglu (1996) we will focus on the case of a physical capital market framework characterized by the presence of a costly search activity and a matching technology function that is assumed to be random and constant returns to scale in its arguments:job vacancies and unemployed workers. The randomness of the matching technology function will entail that all workers have the same probability of meeting each entrepreneur and each inventor, and once the partnership has been formed it is too costly to break it up in order to find new partners for each agent. Following the standard literature on search models it is reasonable to assume a bargaining process and the consequent income distribution rule according to which total output (the surplus from a match) has to be shared between workers, entrepreneurs and inventors in constant proportion a, b and $(1-a-b)$[1] measuring respectively the bargaining power of agents. Further the randomness of the matching technology function will imply anonymity of contracts, in the sense that each worker, at the time of investment in human capital, does not know who their partners will be, and consequently her/his expected return depends on the whole of physical and knowledge capital respectively across all the entrepreneurs and inventors. Similar reasoning will occur for all of other agents. Hence the expected wage bill of the ith worker W_i, and the expected returns of the jth entrepreneur R_j and the zth-inventor P_z are given by the following:

$$W_i = ah_i^{\alpha} \int_0^1 k_j^{\beta} d_j \int_0^1 c_z^{(1-\alpha-\beta)} d_z \tag{2}$$

$$R_j = bk_j^{\beta} \int_0^1 h_i^{\alpha} d_i \int_0^1 c_z^{(1-\alpha-\beta)} d_z \tag{3}$$

$$P_z = (1-a-b) c_z^{(1-\alpha-\beta)} \int_0^1 k_j^{\beta} d_j \int_0^1 h_i^{\alpha} d_i. \tag{4}$$

The utility functions of the the three types of agents will be given by:

$$U_i = C_i - \frac{\lambda_i \left(h_i\right)^{(1+\gamma)}}{(1+\gamma)} \tag{5}$$

[1] Where $0 < a, b < 1$.

$$U_j = C_j - \frac{\theta_j\left(k_j\right)^{(1+\gamma)}}{(1+\gamma)} \tag{6}$$

$$U_z = C_z - \frac{\sigma_z\left(c_z\right)^{(1+\gamma)}}{(1+\gamma)} \tag{7}$$

where λ_i, θ_j and σ_z capture disutility from investments in human, physical and knowledge capital, C_i, C_j and C_z the consumption levels equal to the different agents' expected, γ a taste positive parameter.

The *f.o.c.* of the maximization processes give:

$$h_i = \left\{ \frac{a\alpha \int_0^1 k_j^{\beta} d_j \int_0^1 c_z^{(1-\alpha-\beta)} d_z}{\lambda_i} \right\}^{\frac{1}{1+\gamma-\alpha}} \tag{8}$$

$$k_j = \left\{ \frac{b\beta \int_0^1 h_i^{\alpha} d_i \int_0^1 c_z^{(1-\alpha-\beta)} d_z}{\theta_j} \right\}^{\frac{1}{1+\gamma-\beta}} \tag{9}$$

$$c_z = \left\{ \frac{(1-a-b)(1-\alpha-\beta) \int_0^1 k_j^{\beta} d_j \int_0^1 h_i^{\alpha} d_i}{\sigma_z} \right\}^{\frac{1}{\beta+\alpha+\gamma}}, \tag{10}$$

from which, assuming $\lambda_i = \lambda, \theta_j = \theta$ and $\sigma_z = \sigma$ we may easily derive the equilibrium values of $h_{i,}, k_j$ and c_z and state what follows:

H: There exist positive externalities between human, physical, knowledge capital and R&D. When a group of workers increase their investment in human capital, other agents, will respond, and the equilibrium rate of return of all subjects will improve.

4 The empirical framework

4.1 The econometric approach

In order to test the hypothesis above described, giving credit to our theoretical specification, and then focus our attention to the role of human capital on firms' innovation, we assess an econometric model consisting of two simultaneous equations related to the following dependent variables: process and product innovation. These variables are also interrelated due to both observed and unobserved variables. In fact, the two innovation equations are structural or outcome equations with human capital (but also other production factors, such as physical capital and knowledge capital) and R&D decisions variables as explanatory factors.

The two indicators are binary variables and are jointly described by a multivariate probit (or bivariate) model. The model follows a two-equation structure:

$$\begin{cases} y^*_{1i} = h'_{1j}\boldsymbol{\alpha}_1 + x'_{1i}\boldsymbol{\beta}_1 + \epsilon_{1i} \\ y^*_{2i} = h'_{1j}\boldsymbol{\alpha}_2 + x'_{2i}\boldsymbol{\beta}_2 + \epsilon_{2i} \\ \qquad\qquad . \end{cases} \tag{11}$$

The two latent variables are defined as follows: y_1* are product innovations and y_2* are process innovations; h_{kj} represents the human capital (proxied using graduates weighted by marks) distributed in the territory j, which influence those probabilities for firm i; x_{ki} are vectors of exogenous variables (see Table 1 for more details about these variables), which influence those probabilities for firm i; $\boldsymbol{\alpha}_k$ and $\boldsymbol{\beta}_k$ are parameter vectors; and ε_{ki} are error terms, which are assumed to be jointly normal with the unknown correlation coefficient, ρ_{kl}. The latter measures how far the unobserved factors influence y_k and y_l, if ρ_{lk}=0 cannot be rejected, this implies that the equations need not to be estimated as a system and can be estimated separately.

The latent variables y_{ki}* are not observed; however, the binary variables, y_{ki}, are observed, and these are linked to the former according to the following rule:

$$\begin{cases} y_{ki} = 1, \text{ if } y^*_{ki} > 0; \\ y_{ki} = 0 \quad \text{otherwise; } k = 1, 2 \end{cases} \tag{12}$$

The common latent factor structure of the multivariate probit framework makes it possible both to correct the potential sample selection and to control for the potential endogeneity of the R&D investment decision (Monfardini and Radice 2008). The resulting biprobit model can be described as an instrumental variable framework for categorical variables and can be estimated using the simulated maximum likelihood method.

This method uses the Geweke–Hajivassiliour–Keane smooth recursive conditioning simulator to evaluate the multivariate normal distribution; the simulated probabilities are unbiased and bound within the (0, 1) interval (Cappellari and Jenkins 2003). All the equations in (1) can be estimated separately as single probit models but the estimated coefficients are inefficient because the correlation between the error terms is neglected and the simultaneity is not taken into account. Only in the case of independent error terms ε_{ki} it is possible to deal with the above model as independent equations (Maddala 1983).

The estimation of a multivariate probit model (in our case bivariate probit because we only have two dependent variables) with endogenous binary regressors requires some consideration for the identification of the model parameters. Maddala (1983) proposes that the exogenous covariates in the reduced form equations should contain at least one regressor not included in the structural equations but Wilde (2000) shows that no exclusion restrictions on the exogenous variables are required for parameter identification, when there is sufficient variation in the data. This last condition is ensured by the assumption that each equation contains at least one varying exogenous regressor, an assumption which is rather weak in economic applications. Given the assumption of joint normality, the multivariate probit model is identified by functional form. Wilde's contribution makes it clear that theoretical identification does not require availability

Table 1 Variables and descriptive statistics

Variables	Description of the variables	Mean	SD	Min	Max
Innovation					
Product innovation	Dummy variable taking the value of one in case the firm carried out any product innovation	0.4559	0.4981	0	1
Process innovation	Dummy variable taking the value of one in case the firm carried out any process innovation	0.4230	0.4940	0	1
Production factors					
Physical capital	Number of employees in the firms	110.513	354.2616	0.33	11959
Knowledge capital (mil. €)	Amount of R&D expenditure of firms	111,720.3	1,702,357	0	1.28e+08
Human capital	Number of graduates weighted by graduation degree in the area in which firm is located	2929.325	3476.565	0	15,754.59
Firm characteristics					
R&D collaboration with other firms/cons	Dummy variable taking the value of one in case the firm undertaken any R&D activities with other firms	0.06079	0.2389	0	1
R&D collaboration with univ/res labs	Dummy variable taking the value of one in case the firm undertaken any R&D activities with universities/research labs	0.0593	0.2362	0	1
R&D intensity (%)	Percentage of the total turnover that the firm has invested in R&D	1.2552	5.4434	0	100
Subsidy dummy	Dummy variable taking the value of one in case the firm received financial incentives provided by the public sector	0.3233	0.4678	0	1
Skilled employees (%)	Percentage of graduates in firm workforce	5.1661	18.9520	0	100
Firm age	Firm age in the year in which the firm has been surveyed	27.7864	22.4629	1	256
Very small firm size	Dummy variable taking the value of one in case the firm has between 10 and 19 employees	0.2120	0.4087	0	1
Small firm size	Dummy variable taking the value of one in case the firm has between 20 and 49 employees	0.3175	0.4655	0	1
Medium firm size	Dummy variable taking the value of one in case the firm has between 50 and 99 employees	0.1838	0.3873	0	1
Large firm size	Dummy variable taking the value of one in case the firm has between 100 and 249 employees	0.1191	0.3239	0	1
Very large firm size (Reference group)	Dummy variable taking the value of one in case the firm has more than 249 employees	0.1088	0.3114	0	1

Table 1 (continued)

Variables	Description of the variables	Mean	SD	Min	Max
No cooperative dummy	Dummy variable taking the value of 1 in case the firm is a: public company (société anonyme), a limited liability partnership (société a responsabilité limitée), a limited liability sole proprietorship (entreprise unipersonnelle à responsabilité limitée), a public limited company (société par actions simplifiée), other forms of firms	0.9803	0.1390	0	1
Cooperative dummy (Reference group)	Dummy variable taking the value of 1 in case the firm is a cooperative	0.0197	0.1390	0	1
Technological characteristics					
Supplier-dominated	Dummy variable taking the value of one in case the firm belongs to the Supplier-dominated Pavitt macro-sector	0.1825	0.3862	0	1
Scale-intensive	Dummy variable taking the value of one in case the firm belongs to the Scale-intensive Pavitt macro-sector	0.5015	0.5000	0	1
Specialised-suppliers	Dummy variable taking the value of one in case the firm belongs to the Specialised-suppliers Pavitt macro-sector	0.2681	0.4430	0	1
Science-based	Dummy variable taking the value of one in case the firm belongs to the Science-based Pavitt macro-sector	0.0429	0.2028	0	1
Territorial characteristics					
North-West	Dummy variable taking the value of one in case the firm is located in the North-West region	0.3961	0.4891	0	1
North-East	Dummy variable taking the value of one in case the firm is located in the North-East region	0.2965	0.4568	0	1
Centre	Dummy variable taking the value of one in case the firm is located in the Centre region	0.1683	0.3742	0	1
South	Dummy variable taking the value of one in case the firm is located in the South region	0.1389	0.3458	0	1

Own elaboration

of any additional instruments for the endogenous variables. However, the presence of equation-specific regressors in formally identified models may improve convergence and make the estimation results more robust to distributional misspecifications (Monfardini and Radice 2008).

4.2 Extending the model: the role of physical and knowledge capital to firms' innovation

In order to give more support to our theoretical model (see Eq. 1), we extend the econometric specification, adding two other important production factors, being relevant drivers in the process of innovation: physical and knowledge capital. Formally, using the same terminology of theoretical framework, the econometric model, as described in Eq. 12, becomes:

$$\begin{cases} y^*_{1i} = h'_{1j}\boldsymbol{\alpha}_1 + k'_{1i}\boldsymbol{\alpha}_2 + c'_{1i}\boldsymbol{\alpha}_3 + x'_{1i}\boldsymbol{\beta}_1 + \epsilon_{1i} \\ y^*_{2i} = h'_{1j}\boldsymbol{\alpha}_1 + k'_{1i}\boldsymbol{\alpha}_2 + c'_{1i}\boldsymbol{\alpha}_3 + x'_{2i}\boldsymbol{\beta}_2 + \epsilon_{2i} \\ . \end{cases} \tag{13}$$

where *h*, *k* and *c* measure respectively the human (number of graduates weighted by graduation degree in the area in which firms is located), physical (number of employees in the firms) and knowledge capital (R&D expenditure of firms) while the other variables are the same as described in Eq. (11).

4.2.1 The data and the descriptive statistics of the variables

The survey used in order to explore firms' innovation is based on Italian manufacturing companies, originally edited by Mediocredito Centrale, is currently carried out by the Capitalia Banking Group's Research Department. The survey is a fundamental point of reference for politicians, scholars and operators that are interested in the structural and evolutionary characteristics of Italian industrial system. A key feature of the Observatory database on small and medium-sized enterprises is the wealth of qualitative information gathered through the administration of a questionnaire divided into six sections (for more details see the questionnaire distributed by Mediocredito Centrale). The survey is of a sample type and concerns qualitative data of about 4.000 companies for each wave. Qualitative information and balance sheet ratios are classified by employee classes (with more than 10 employees), by sectors of technological activity (see PAVITT classification in footnote 5) and by geographical area (Noth-West. North-East, Centre and South).. In terms of representiveness of the sample comparatively to the business enterprises of the different Italian geographical areas, we can observe that the selected firms account for more than 9% of the main variables. This satisfying result is in line with other studies based on the same data source (Hall et al. 2013).

In particular, the sampling design has been structured following a two dimension stratification: industry or class of activity (11 NACE-CLIO codes), region (NUTS 1 level) and size class (10–19; 20–49; 50–99; 100–249 and more than 250 employees). The data cover the waves 2001–2003 and 2004–2007 and contains quantitative and qualitative information on R&D and innovation. More specifically, firms are asked whether product and/or process innovation[2] had been introduced during the previous 3 years (2001–2003 and 2004–2007). The questionnaire also collects information regarding whether the R&D was acquired from external sources such as universities/research labs and other firms/consultants. Other information used here includes the amount of R&D expenditure (our proxy of knowledge capital) and whether the firm benefits from tax allowances and financial incentives for R&D investment or other activities. Size classes have been used with respect to the number of employees, along with other firm characteristics, such as the presence of skilled employees (that is graduated), age of the firm and its current legal form (cooperatives ns no cooperatives).

Moreover, unlike to other works, we are interested to analyse the contribution of human capital to firms' innovation. Then, we add to this dataset a variable concerning the human capital indicator (as recently suggested in the empirical literature—see for instance Agasisti et al. (2017) and Barra and Zotti (2017), proxied using graduates weighted by marks and covering the 50% of Italian provinces, has been collected from the National Committee for the Evaluation of the University System (CNVSU) website (http://www.cnvsu.it); specifically, data have been collected by the Italian Ministry of Education, Universities and Research Statistical Office. We use NUTS-3 code (provincial level) in order to combine this necessary information with Mediocredio Centrale database.

Table 1 below describes the variables used for modelling the role of production factors (in particular human capital) and R&D collaboration of the probability to innovate, and provides their descriptive statistics, while Table 2 reports the correlations between variables. Finally, Table 3 describes the distribution of firms' innovation and production factors (physical, knowledge and human capital) for macro regions. In estimating the biprovit model we rely on STATA 13.

Specifically, in order to take into account the importance of capturing the contribution of production factors and R&D collaborations to the product and process innovation, we rely upon highly territorially disaggregated data such as Italian provinces—a deeper territorial disaggregation than NUTS 2 level subdivisions—being sub-regional geographical areas where the bulk of the labour force lives and works and where establishments can find the largest amount of the labour force necessary to occupy the offered jobs and where, according to the Italian Statistical Office (ISTAT), their economic and social relationships take place.

4.2.2 The empirical specification

The empirical specification of the two equations, described in Eq. (13), is as follows:

Innovation $j = f_j$ (number of graduates weighted by graduation degree in the area in which firms are located (human capital), number of employees in the firms (physical capital), R&D expenditure of firms (knowledge capital), R&D collaboration with universities/ research labs, R&D collaboration with private firms/consultants, R&D intensity, public

[2] Product innovation is defined as the "introduction of a good which is either new or significantly improved with respect to its fundamental characteristics. The innovation should be new to the firm, but not necessarily to the market". Process innovation is defined as the "adoption of a production technology which is either new or significantly improved. The innovation should be new to the firm, but the firm has not necessarily to be the first to introduce the new process".

Table 2 Correlations between variables of the analysis

	Product innovation	Process innovation	Physical capital	Knowledge capital	Human capital	R&D collaboration with univ/res labs	R&D collaboration with other firms/cons	R&D intensity (%)	Subsidy dummy	Skilled employees (%)	Firm age	Very small firm size	Small firm size	Medium firm size	Large firm size	Very large firm size	No cooperative dummy
Product innovation	1.000																
Process innovation	0.3861	1.000															
	0.0000																
Physical capital	0.0447	0.0654	1.000														
	0.0000	0.0000															
Knowledge capital	0.0451	0.0409	0.3775	1.000													
	0.0000	0.0001	0.0000														
Human capital	0.0110	−0.0001	0.0311	0.0303	1.000												
	0.2838	0.9911	0.0030	0.0033													
R&D collaboration with univ/res labs	0.1325	0.1138	0.0980	0.0700	0.0131	1.000											
	0.0000	0.0000	0.0000	0.0000	0.2035												
R&D collaboration with other firms/cons	0.1579	0.0923	0.0616	0.1029	0.0107	0.2087	1.000										
	0.0000	0.0000	0.0000	0.0000	0.3007	0.0000											

Table 2 (continued)

	Product innovation	Process innovation	Physical capital	Knowledge capital	Human capital	R&D collaboration with univ/res labs	R&D collaboration with other firms/cons	R&D intensity (%)	Subsidy dummy	Skilled employees (%)	Firm age	Very small firm size	Small firm size	Medium firm size	Large firm size	Very large firm size	No cooperative dummy
R&D intensity (%)	0.1184	0.0698	0.0109	0.0413	0.0250	0.0809	0.0527	1.000									
	0.0000	0.0000	0.2953	0.0001	0.0151	0.0000	0.0000										
Subsidy dummy	0.1060	0.1379	0.1073	0.0575	−0.0172	0.1126	0.1624	0.0147	1.000								
	0.0000	0.0000	0.0000	0.0000	0.0953	0.0000	0.0000	0.1526									
Skilled employees (%)	0.0654	0.0613	0.2844	0.3287	0.0471	0.1252	0.0851	0.0448	0.0520	1.000							
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000								
Firm age	0.0556	0.0659	0.1200	0.0132	0.0381	0.0448	0.0279	−0.0156	0.0352	0.0315	1.000						
	0.0000	0.0000	0.0000	0.2087	0.0003	0.0000	0.0076	0.1355	0.0008	0.0026							
Very small firm size	−0.0924	−0.1057	−0.1431	−0.0326	0.0212	−0.0885	−0.0720	−0.0183	−0.1245	−0.0857	−0.0957	1.000					
	0.0000	0.0000	0.0000	0.0015	0.0398	0.0000	0.0000	0.0753	0.0000	0.0000	0.0000						
Small firm size	−0.0142	−0.0277	−0.1551	−0.0380	−0.0185	−0.0457	−0.0449	−0.0173	−0.0298	−0.0851	−0.0579	−0.3538	1.000				
	0.1679	0.0072	0.0000	0.0002	0.0724	0.0000	0.0000	0.0934	0.0038	0.0000	0.0000	0.0000					
Medium firm size	0.0388	0.0449	−0.0553	−0.0172	−0.0081	0.0248	0.0443	−0.0037	0.0816	−0.0110	0.0592	−0.2462	−0.3237	1.000			
	0.0002	0.0000	0.0000	0.0955	0.4311	0.0160	0.0000	0.7176	0.0000	0.2851	0.0000	0.0000	0.0000				
Large firm size	0.0518	0.0908	0.0421	0.0230	−0.0062	0.0997	0.0921	0.0141	0.0936	0.0655	0.0977	−0.1907	−0.2509	−0.1746	1.000		
	0.0000	0.0000	0.0001	0.0258	0.5445	0.0000	0.0000	0.1700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000			

Table 2 (continued)

	Product innovation	Process innovation	Physical capital	Knowledge capital	Human capital	R&D collaboration with univ/res labs	R&D collaboration with other firms/cons	R&D intensity (%)	Subsidy dummy	Skilled employees (%)	Firm age	Very small firm size	Small firm size	Medium firm size	Large firm size	Very large firm size	No cooperative dummy
Very large firm size	0.0472	0.0593	0.5713	0.1090	0.0207	0.0836	0.0363	0.0256	0.0722	0.1919	0.1011	−0.1813	−0.2384	−0.1659	−0.1285	1.000	
	0.0000	0.0000	0.0000	0.0000	0.0443	0.0000	0.0004	0.0128	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		
No cooperative dummy	0.0472	0.0118	−0.0005	0.0080	0.0123	0.0169	0.0130	−0.0052	−0.0160	0.0182	−0.0631	−0.0141	0.0050	0.0142	−0.0067	0.0006	1.000
	0.0000	0.2500	0.9590	0.4374	0.2331	0.1000	0.2064	0.6138	0.1195	0.0774	0.0000	0.1700	0.6265	0.1689	0.5162	0.9534	

Own elaboration

Table 3 The distribution of firms' innovation and production factors for macro regions

Variable	Mean	SD	Min	Max
North-West				
Product innovation	0.4675	0.4990	0.00	1
Process innovation	0.4284	0.4949	0.00	1
Physical capital	121	389	0.33	11959
Knowledge capital	153547.8	2512684	0.00	1.28e+08
Human capital	2904	2517	0.00	7.428
South				
Product innovation	0.3743	0.4841	0.00	1
Process innovation	0.4018	0.4904	0.00	1
Physical capital	89	274.2838	2	6.337
Knowledge capital	68442.47	1225870	0.00	3.90e+07
Human capital	2300	2053	0.00	7.184
North-East				
Product innovation	0.4779	0.4996	0.00	1
Process innovation	0.4193	0.4935	0.00	1
Physical capital	115	363	1	9.097
Knowledge capital	101442.8	727519.6	0.00	1.94e+07
Human capital	3294	5014.032	0.00	15754.59
Centre				
Product innovation	0.4580	0.4983	0.00	1
Process innovation	0.43415	0.4958	0.00	1
Physical capital	97	309	2	5.501
Knowledge capital	67384.29	432777.8	0.00	1.05e+07
Human capital	2874	2928.678	0.00	8.158

Own elaboration

subsidies, skilled employees, firm age, firm size dummies, firm legal form dummies, industrial sector dummies, macro area dummies), where j = product or process.

As Table 1 shows, almost 6% of our firms have R&D collaborations with a university or research lab, while 5% have R&D collaborations with other firms or consultants. Among all firms in the sample, 45% have introduced product innovation, and 42% have introduced process innovation. R&D intensity, measured as the percentage of the total turnover that the firm has invested in R&D on average in the two waves (2001–2003 and 2004–2007) is around 3.6%; over the same time span, 32% of the firms have subsidies and 5% have skilled employees.

In term of production factors, we notice the following statistics: firms have 110 employees (physical capital) and spend 111.720 mil. € of R&D expenses (knowledge capital) on average, while there are 2979 graduates weighted by marks (human capital) on average distributed on the area in which firm is located (see for more details Tables 1 and 3).

Multicollinearity among the regressors is assessed by computing the variance inflation factor (VIF). The empirical specification is based on a sample about 9000 observations.

5 The empirical evidence

5.1 The drivers of product and process innovation

The coefficients of the multivariate probit[3] (in our case bivariate probit) regressions are reported for various specifications in Tables 4 (Models A1–A8) and 5 (Models B1–B8). The standard errors of the coefficients have been clustered around the region in which the firm is located.

Table 4 reports the coefficients for Eq. 13 in which product innovation is considered as dependent variable. In order to have a complete overview of our analysis and for the sake of exposition and interpretation of the results, we present the empirical evidence taking into account the three production factors (physical capital, knowledge capital and human capital) as described both in the theoretical and empirical framework, on firms' innovation. This way of proceeding will allow us to better highlight the differences in the contribution of the three production factors to the firm's innovation.

First, we proceed separating the effect of these factors on product innovation. As noted in the empirical set-up, physical capital (proxied by the number of employees in the firm) is the only factor being significant, even if weakly (to 10%), while human and knowledge capital do not have some influence to product innovation. In other words, physical capital favours the probability to do product innovation. According to R&D controls, we find that R&D collaborations with universities/research labs and with other firms/consultants are positive and highly significant. R&D intensity is also positive and statistically significant. Public incentives and skilled employees are also positive and highly significant. The age of a firm, being a proxy of reputation, has a positive and statistically significant effect on product innovation. The dummy for very small firm size is highly significant and negative. Commercial firms are more likely to innovate their products with respect to cooperative ones. Finally, the time trend, being a proxy of technological change, is highly significant and positive.

Table 4 reports the coefficients for Eq. 13 in which process innovation is used as dependent variable. As before, we want to understand how production factors driven the probability to innovate, but in this case their processes. Again physical capital is the only factor being positive, but now his contribution to process innovation is not weakly significant (significant to 5%).

Process innovation is strongly determined by R&D collaboration both with universities/research labs and with other firms. R&D intensity and skilled employees are positive and highly significant. Process innovation is also favoured by public incentives. Very small and small firms are less likely to innovate their processes as well as proprietorship. Commercial firms are less likely to innovate their processes with respect to cooperative ones. Finally, the time trend, being a proxy for technological change, is highly significant and positive.

From these results we can conclude that physical is the main factor/driver that contributes to firms' innovation. There is a growing research current to explore output-oriented innovation indicators in such a way that the aspects of innovative activities relative to occupational effects are evidenced. A possible economic intuition of this effect is that the process of learning involves successful implementation rather than just the resources doveted to the innovation investments (Blundell et al. 1993; Crépon et al. 1998; Llorca 2002; Peters 2009).

[3] For brevity of space we only report the marginal effects associated to any variables in our analysis, while the coefficients are available on request.

Table 4 Biprobit regression: marginal effects for the dependent variable (existence of) product innovation

	(A1) All firms dF/dx	(A2) All firms dF/dx	(A3) All firms dF/dx	(A4) All firms dF/dx	(A5) All firms dF/dx	(A6) All firms dF/dx	(A7) All firms dF/dx	(A8) All firms dF/dx
Physical capital	0.0000*	0.0000					0.0000	0.0000
Knowledge capital			0.0000	0.0000			0.0000	0.0000
Human capital					0.0000	0.0000	0.0000	0.0000
R&D collab. with univ/res labs	0.1593***	0.1468***	0.1674***	0.1562***	0.1707***	0.1586***	0.1568***	0.1451***
R&D collab. with other firms/cons	0.2653***	0.2538***	0.2638***	0.2535***	0.2675***	0.2565***	0.2625***	0.2518***
R&D intensify	0.0103***	0.0095***	0.0083***	0.0077***	0.0085***	0.0079***	0.0101***	0.0094***
Subsidy dummy	0.1292***	0.1315***	0.1287***	0.1311***	0.1293***	0.1315***	0.1290***	0.1313***
Skilled employees	0.0008***	0.0006***	0.0008***	0.0006***	0.0010***	0.0007***	0.0007***	0.0006***
Firm age	0.0007***	0.0008***	0.0007***	0.0008***	0.0007***	0.0008***	0.0007***	0.0008***
Very small firm size	−0.0869***	−0.0812	−0.0871	−0.0799	−0.0901	−0.0820	−0.0856	−0.0803
Small firm size	−0.0265	−0.0268	−0.0267*	−0.0257*	−0.0297*	−0.0280*	−0.0251	−0.0258
Medium firm size	0.0009	−0.0039	0.0017	−0.0027	−0.0018	−0.0053	0.0027	−0.0026
Large firm size	0.0052	0.0023	0.0074	0.0059	0.0050	0.0041	0.0064	0.0031
No cooperatives firms	0.1363***	0.0980**	0.1409***	0.1033**	0.1418***	0.1039**	0.1356***	0.0976**
Rend	0.1414***	0.1422***	0.1412***	0.1419***	0.1387***	0.1399***	0.1432***	0.1436***
Area fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	No	Yes	No	Yes	No	Yes	No	Yes
Observations	8861	8853	9119	9111	9119	9111	8861	8853

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$; Area fixed effects include dummies for: North-West. North-East and South (Centre used as benchmark group); Industry fixed effects (controlling for heterogeneity effects) include dummies for: 11 NACE-CLIO

Table 5 Biprobit regression: marginal effects for the dependent variable (existence of) process innovation

	(B1) All firms dF/dx	(B2) All firms dF/dx	(B3) All firms dF/dx	(B4) All firms dF/dx	(B5) All firms dF/dx	(B6) All firms dF/dx	(B7) All firms dF/dx	(B8) All firms dF/dx
Physical capital	0.0001**	0.0001**					0.0001**	0.0001**
Knowledge capital			0.0000	0.0000			0.0000	0.0000
Human capital					0.0000	0.0000	0.0000	0.0000
R&D collab. with univ/res labs	0.1274***	0.1224***	0.1325***	0.1296***	0.1342***	0.1311***	0.1267***	0.1219***
R&D collab. with other firms/cons	0.0890**	0.0900**	0.0894**	0.0906**	0.0917**	0.0929**	0.0880**	0.0893**
R&D intensity	0.0048***	0.0050***	0.0040***	0.0042***	0.0041***	0.0042***	0.0047***	0.0049***
Subsidy dummy	0.1360***	0.1337***	0.1359***	0.1337***	0.1362***	0.1338***	0.1357***	0.1334***
Skilled employees	0.0006*	0.0005	0.0007	0.0006	0.0008**	0.0006	0.0005	0.0005
Firm age	0.0010***	0.0010***	0.0009***	0.0010***	0.0009***	0.0010***	0.0010***	0.0010***
Very small firm size	−0.0986***	−0.0994***	−0.1067***	−0.1074***	−0.1081***	−0.1086***	−0.0980***	−0.0988***
Small firm size	−0.0350**	−0.0369**	−0.0429***	−0.0440***	−0.0445***	−0.0454***	−0.0345**	−0.0366**
Medium firm size	0.0062	0.0075	0.0009	0.0021	−0.0010	0.0003	0.0068	0.0079
Large firm size	0.0580***	0.0579***	0.0572***	0.0579***	0.0559***	0.0567***	0.0583***	0.0581***
No cooperatives firms	0.0353***	0.0400***	0.0376***	0.0377***	0.0382***	0.0382***	0.0352***	0.0400***
Trend	0.0572***	0.0541***	0.0561***	0.0527***	0.0547***	0.0515***	0.0579***	0.0547***
Area fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	No	Yes	No	Yes	No	Yes	No	Yes
Observations	8861	8853	9119	9111	9119	9111	8861	8853

*$p<0.10$, **$p<0.05$, ***$p<0.01$; Area fixed effects include dummies for: North-West. North-East and South (Centre used as benchmark group); Industry fixed effects (controlling for heterogeneity effects) include dummies for: 11 NACE-CLIO

6 How do some factors explain the differences in firm's innovation?

6.1 The drivers of product and process innovation: the size class effect

In order to quantify the "size class" effect on the estimation, we run our regression considering five different groups of firms: (1) 10–19 employees (MINOR); (2) 20–49 employees (SMALL); (3) 50–99 employees (MEDIUM); (4) 100–249 employees (LARGE) and (5) more than 250 employees (MAJOR). Results[4] are summarised, for all the dependent variables of the biprobit regression, in Tables 6 (Models C1–C12) and 7 (Models D1–D12).

The main results confirm that all production factors (physical, knowledge and human capital) have no effect on product innovation for large firms. In other words, these factors do not drive product innovation for these firms. On the other hand, for small and medium firms, we find that the three production factors strongly contribute to the product innovation, while only physical capital would still be the main driver explaining process innovation. This finding is confirmed in the relative literature. Indeed, according to many empirical studies, the employment (i.e. physical capital) is an important determinant of structural change and growth (Caves 1998; Bartelsman and Doms 2000; Kruger 2008; Dosi and Peters 2010; Dachs et al. 2017).

6.2 The drivers of product and process innovation: the technological effects

In order to quantify the technological effect, we grouped firms in the four PAVITT classes[5] (Pavitt 1984). Results are summarised, for all the dependent variables of the biprobit regression, in Tables 8 (Models E1–E8) and 9 (Models F1–F8).

Physical capital is found to be an important driver for product innovation, especially in those firms that have a lower technology (or firms that need less technology implementing in the production process—$PAVITT_1$ and $PAVITT_3$), while knowledge capital is an important driver in the case of firms with a higher propensity to technology (or firms that need more technology implementing in the production process—$PAVITT_2$). In order to avoid problem of selection bias and attrition due to a low number of observations when the model is assessed considering $PAVITT_4$ (around 405 observations), we combine $PAVITT_2$ and $PAVITT_4$ (therefore constructing $PAVITT_{24}$). $PAVITT_2$ and $PAVITT_4$ include all those firms that have the most technology. As expected, being firms that need more skilled

[4] Since the main findings are confirmed, we report only the main specification and the main variables of production factors, i.e. physical capital, physical and human capital.

[5] Pavitt's taxonomy is a classification of the product sectors based on the sources and the nature of technological opportunities and innovations, the intensity of research and development (R&D intensity), and the type of knowledge flows (see Pavitt 1984). On the basis of the above mentioned criteria, Pavitt identified four large sectoral groupings: ($PAVITT_1$) Supplier dominated—"dominated by suppliers"—which includes: textiles (textiles); footwear (footwear); food and beverage sectors (food and beverages); paper and printing (paper and printing); timber (wood). ($PAVITT_2$) Intensive scale—"scale-intensive"—which includes: base metals (basic metals); motor vehicles and related engines (motor-vehicles, trailers and semitrailers). ($PAVITT_3$) Specialized suppliers—"specialized suppliers"—which includes: agricultural and industrial machinery (machinery and equipment); office machines (office, accounting and computing machinery); optical, precision and medical instruments (medical, precision, and optical instruments). ($PAVITT_4$) Science based—"science based"—which includes: chemistry (chemicals); pharmaceutical (pharmaceuticals); electronics (electronics). Each grouping is considered characterized by internal regularities regarding: the potential sources of innovation; the type of innovations; their degree of appropriability; the height of barriers to entry; the average size of the companies.

Table 6 Biprobit regression: marginal effects for the dependent variable (existence of) product innovation—the size class effects

	(C1) Only minor firms	(C2) Only minor firms	(C3) Only small firms	(C4) Only small firms	(C5) Only medium firms	(C6) Only medium firms	(C7) Only large firms	(C8) Only large firms	(C9) Only minor firms	(C10) Only minor firms	(C11) Large and minor firms	(C12) Large and minor firms
	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Physical capital	0.0082**	0.0089***	0.0033***	0.0033***	0.0020***	0.0018***	0.0004	0.0004	0.0000	0.0000	0.0000	0.0000
Knowledge capital	0.0000***	0.0000***	0.0000*	0.0000*	0.0000***	0.0000***	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Human capital	0.0000***	0.0000**	0.0000***	0.0000**	0.0000***	0.0000**	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R&D collab. with univ/res labs	0.2182**	0.1984*	0.1361***	0.1400***	0.1085***	0.1038***	0.1527***	0.1305***	0.1523***	0.1410***	0.1564***	0.1408***
R&D collab. with other firms/cons	0.2192***	0.2171**	0.3171***	0.3055***	0.2726***	0.2653***	0.1182**	0.1205**	0.1591***	0.1445***	0.1339***	0.1288***
R&D intensity	0.0088***	0.0088***	0.0112***	0.0099***	0.0055	0.0046	0.0034	0.0039	0.0160***	0.0140***	0.0045*	0.0045*
Subsidy dummy	0.1338***	0.1437***	0.0623***	0.0635***	0.1484***	0.1569***	0.1537***	0.1561***	0.1208***	0.1049***	0.1432***	0.1390***
Skilled employees	−0.0014	−0.0020**	−0.0024***	−0.0028***	−0.0043***	−0.0043***	0.0025*	0.0018	0.0024***	0.0024***	0.0025***	0.0023***
Firm age	0.0006***	0.0007***	0.0011***	0.0011***	−0.0005	−0.0002	0.0017***	0.0017***	−0.0011*	−0.0012*	0.0005**	0.0005**
No cooperatives firms	0.0099	−0.0100	0.1482	0.1277	0.2280**	0.1823*	0.1253	0.0623	0.0777	0.1111	0.1142*	0.0532
Trend	0.1720***	0.1743***	0.1690***	0.1725***	0.2352***	0.2239***	0.1679***	0.1650***	0.2200***	0.2121***	0.1935***	0.1890***
Industry fixed effect	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

Table 6 (continued)

	(C1)	(C2)	(C3)	(C4)	(C5)	(C6)	(C7)	(C8)	(C9)	(C10)	(C11)	(C12)
	Only minor firms	Only minor firms	Only small firms	Only small firms	Only medium firms	Only medium firms	Only large firms	Only large firms	Only minor firms	Only minor firms	Large and minor firms	Large and minor firms
	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Observations	1975	1974	2951	2951	1684	1684	1080	1077	626	622	1706	1699

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$; Industry fixed effects (controlling for heterogeneity effects) include dummies for: 11 NACE-CLIO

Table 7 Biprobit regression: marginal effects for the dependent variable (existence of) process innovation—the size class effects

	(D1) Only minor firms	(D2) Only minor firms	(D3) Only small firms	(D4) Only small firms	(D5) Only medium firms	(D6) Only medium firms	(D7) Only large firms	(D8) Only large firms	(D9) Only minor firms	(D10) Only minor firms	(D11) Large and minor firms	(D12) Large and minor firms
	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Physical capital	0.0048	0.0043	0.0024*	0.0026**	0.0018**	0.0018**	−0.0004	−0.0004	0.0000	0.0000	0.0000	0.0000
Knowledge capital	−0.0000	−0.0000	0.0000	0.0000	−0.0000	−0.0000	0.0000**	0.0000	0.0000	0.0000	0.0000	0.0000
Human capital	0.0000	0.0000	−0.0000	−0.0000	−0.0000	−0.0000	0.0000	0.0000	−0.0000	−0.0000	−0.0000	−0.0000
R&D collab. with univ/res labs	0.1901***	0.1930**	0.1119***	0.1137***	0.0937***	0.0871***	0.1203**	0.1134***	0.1440***	0.1364***	0.1366***	0.1330***
R&D collab. with other firms/cons	0.2209***	0.2097***	0.0983**	0.1012**	0.1132*	0.1077*	−0.0090	−0.0134	0.0100	0.0151	−0.0047	−0.0008
R&D intensity	0.0042***	0.0048***	0.0073**	0.0072**	0.0047	0.0048	0.0073***	0.0069***	−0.0003	−0.0002	0.0041**	0.0037*
Subsidy dummy	0.1705***	0.1651***	0.1134***	0.1108***	0.0685***	0.0697***	0.1835***	0.1724***	0.1323***	0.1318***	0.1686***	0.1607***
Skilled employees	−0.0013	−0.0010	0.0013	0.0010	−0.0010	−0.0011	0.0029***	0.0025***	0.0002	0.0003	0.0005	0.0005
Firm age	0.0017***	0.0016***	0.0005	0.0005*	0.0004	0.0004	0.0011*	0.0012*	−0.0001	−0.0003	0.0006	0.0006
No cooperatives firms	−0.0272	−0.0316	0.0359	0.0399	−0.0092	0.0192	0.1643	0.1668	−0.0110	0.0219	0.1075	0.1156*

Table 7 (continued)

	(D1)	(D2)	(D3)	(D4)	(D5)	(D6)	(D7)	(D8)	(D9)	(D10)	(D11)	(D12)
	Only minor firms	Only minor firms	Only small firms	Only small firms	Only medium firms	Only medium firms	Only large firms	Only large firms	Only minor firms	Only minor firms	Large and minor firms	Large and minor firms
	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Trend	0.1068***	0.1038***	0.0660***	0.0642***	0.0203	0.0172	0.0682**	0.0650*	0.1083**	0.1023**	0.0879***	0.0873***
Industry fixed effect	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Observations	1975	1974	2951	2951	1684	1684	1080	1077	626	622	1706	1699

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$; Industry fixed effects (controlling for heterogeneity effects) include dummies for: 11 NACE-CLIO

Table 8 Biprobit regression: marginal effects for the dependent variable (existence of) product innovation—the technological effects

	(E1) Only $PAVITT_1$ dF/dx	(E2) Only $PAVITT_1$ dF/dx	(E3) Only $PAVITT_2$ dF/dx	(E4) Only $PAVITT_2$ dF/dx	(E5) Only $PAVITT_3$ dF/dx	(E6) Only $PAVITT_3$ dF/dx	(E7) Only $PAVITT_{24}$ dF/dx	(E8) Only $PAVITT_{24}$ dF/dx
Physical capital	0.0001*	0.0001*	0.0000*	0.0000	0.0001	0.0001*	0.0000	0.0000
Knowledge capital	0.0000	0.0000	0.0000***	0.0000**	0.0000	0.0000	0.0000	0.0000
Human capital	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000**	0.0000**
R&D collab. with univ/res labs	0.1914***	0.1911***	0.2069***	0.1669***	0.0960***	0.0929***	0.1429***	0.1286***
R&D collab. with other firms/cons	0.2708***	0.2670***	0.2816***	0.2406***	0.2183***	0.2165***	0.3184***	0.3036***
R&D intensity	0.0077***	0.0072***	0.0191*	0.0155*	0.0111***	0.0112***	0.0185**	0.0157**
Subsidy dummy	0.1194***	0.1239***	0.0539**	0.0509**	0.1834***	0.1815***	0.0746***	0.0787***
Skilled employees	0.0007	0.0007*	−0.0005	−0.0002	−0.0002	−0.0001	0.0009	0.0007
Firm age	0.0011***	0.0011***	0.0008	0.0009*	0.0000	−0.0001	0.0008	0.0011*
Very small firm size	−0.0932***	−0.0878***	−0.1174**	−0.0984**	−0.0144	−0.0169	−0.1173***	−0.1082**
Small firm size	−0.0219	−0.0192	−0.0276	−0.0296	−0.0136	−0.0164	−0.0330	−0.0324
Medium firm size	0.0011	−0.0030	−0.0302	−0.0271	0.0293	0.0261	−0.0327	−0.0270
Large firm size	−0.0373	−0.0390	0.0488	0.0413	0.0689**	0.0657**	0.0244	0.0253
No cooperatives firms	0.1315***	0.1133**	0.1292	0.0910	−0.1164	−0.1156	0.1461*	0.0942
Trend	0.1534***	0.1591***	0.1626***	0.1490***	0.1063***	0.1047***	0.1501***	0.1522***
Area fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	No	Yes	No	Yes	No	Yes	No	Yes
Observations	4476	4472	1604	1603	2379	2377	1972	1971

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$; Area fixed effects include dummies for: North-West. North-East and South (Centre used as benchmark group); Industry fixed effects (controlling for heterogeneity effects) include dummies for: 11 NACE-CLIO

Table 9 Biprobit regression. Marginal effects for the dependent variable (existence of) process innovation. The technological effects

	(F1) Only $PAVITT_1$ dF/dx	(F2) Only $PAVITT_1$ dF/dx	(F3) Only $PAVITT_2$ dF/dx	(F4) Only $PAVITT_2$ dF/dx	(F5) Only $PAVITT_3$ dF/dx	(F6) Only $PAVITT_3$ dF/dx	(F7) Only $PAVITT_{24}$ dF/dx	(F8) Only $PAVITT_{24}$ dF/dx
Physical capital	0.0001***	0.0002***	0.0000	0.0000	0.0001**	0.0001**	0.0000	0.0000
Knowledge capital	0.0000**	0.0000**	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Human capital	0.0000	0.0000	0.0000	0.0000	0.0000***	0.0000**	0.0000	0.0000
R&D collab. with univ/res labs	0.1877***	0.1882***	0.1069**	0.1080**	0.0592	0.0423	0.1061**	0.1079**
R&D collab. with other firms/cons	0.1023**	0.1078**	0.1337**	0.1270**	0.0569	0.0473	0.1224	0.1190*
R&D intensity	0.0066***	0.0066***	0.0166***	0.0152***	0.0036	0.0030*	0.0043**	0.0040**
Subsidy dummy	0.1520***	0.1497***	0.1253***	0.1118***	0.1123***	0.0869***	0.1269***	0.1232***
Skilled employees	0.0005	0.0005	−0.0004	−0.0003	0.0016***	0.0013***	0.0001	0.0001
Firm age	0.0012***	0.0012***	0.0014***	0.0013***	0.0001	0.0001	0.0014***	0.0014***
Very small firm size	−0.0699**	−0.0717**	−0.1278***	−0.1181***	−0.0869***	−0.0729***	−0.1405***	−0.1325***
Small firm size	−0.0038	−0.0053	−0.0632*	−0.0576*	−0.0436*	−0.0374**	−0.0687	−0.0616
Medium firm size	0.0211	0.0247	−0.0278	−0.0259	0.0152	0.0091	−0.0181	−0.0147
Large firm size	0.0562***	0.0582***	0.0655*	0.0594	0.0645*	0.0519*	0.0558	0.0580
No cooperatives firms	0.0322	0.0396	−0.0127	−0.0032	−0.0021	−0.0007	0.0099	−0.0027
Trend	0.0622***	0.0599***	0.0027	0.0013	0.0603***	0.0486***	0.0246	0.0253
Area fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	No	Yes	No	Yes	No	Yes	No	Yes
Observations	4476	4472	1604	1603	2379	2377	1972	1971

*$p<0.10$, **$p<0.05$, ***$p<0.01$; Area fixed effects include dummies for: North-West. North-East and South (Centre used as benchmark group); Industry fixed effects (controlling for heterogeneity effects) include dummies for: 11 NACE-CLIO

workers to produce highly technological goods, we find that human capital is the main factor driving product innovation (see for instance Caves 1998; Bartelsman and Doms 2000; Kruger 2008; Dosi and Peters 2010; Dachs et al. 2017).

Summing up, physical capital and knowledge capital are the most important factors for process innovation when $PAVITT_1$ has been considered, while physical capital and human capital are the main factors when $PAVITT_3$ is taken into account. For the other variables the results are confirmed.

On the hand, physical capital has a weakly (to 10%) positive impacts on product innovation for $PAVITT_1$ classification, knowledge capital has a strongly (to 1%) positive influences on product innovation for $PAVITT_2$ classification and finally human capital positive (to 5%) contributes on product innovation for $PAVITT_{24}$ classification. On the other hand, physical capital has strongly (to 1% and 5%) positive impacts on process innovation for $PAVITT_1$ and $PAVITT_3$ classification, knowledge capital has a strongly (to 5%) positive influences on product innovation for $PAVITT_2$ classification and finally human capital negative (to 5%) contributes on product innovation for $PAVITT_3$ classification.

6.3 The drivers of product and process innovation: the territorial effect

Finally, in order to quantify the territorial effect, we run our regression on four groups in which the firms are located: North-West (N-W), South, North-East (N-W) and Centre. Results are summarised, for all the dependent variables of the biprobit regression, in Tables 10 (Models G1–G8) and 11 (Models H1–H8).

Physical capital is an important factor to product innovation when North-West is taken into account, while human capital does not seem to have the same contribution. Although weakly, knowledge capital seems to be the main factor when we consider the Southern region. The same result arises when product innovation is considered as dependent variable.

Specifically, in the North-West of the country the physical capital favors, even if slightly (to 10%), product innovation, while human capital does not contribute (to 5%) to product innovation. In the South of the country, on the other hand, knowledge capital is the only factor that has a positive influence, even if only slightly (at 10%), of product innovation.

As far as process innovation is concerned, we find that physical capital contributes, albeit weakly (to 10%), especially to the North-West, while a negative relationship with human capital (at 1%) has been found. In the South and North-East, on the other hand, we find that knowledge capital has a positive influence, albeit weakly (at 10%).

Finally, but not least, the most important result seems to be the positive effect of human capital in the Centre of the country. We rationalize this result in term of "convergence theory".

The more efficient macro regions who produce highly skilled graduates have, in a sense, saturated their contribution on firms' innovation (i.e. that have already reached their steady state). On the other hand, the less efficient macro areas in which universities have more space for improving their performances, through the development of human capital and skills, being far away from their optimal point.

In fact, scholars recognize that the local availability of higher human capital represents significant knowledge spillovers. According to "convergence theory", our analysis suggests that these positive spillovers can arise because the firms, by using more qualified workforce at the provincial level, generate more technology innovation than those located in areas with higher educational attainment workforce.

Table 10 Biprobit regression: marginal effects for the dependent variable (existence of) product innovation—the territorial Effects

	(G1) North-West dF/dx	(G2) North-West dF/dx	(G3) South dF/dx	(G4) South dF/dx	(G5) North-East dF/dx	(G6) North-East dF/dx	(G7) Centre dF/dx	(G8) Centre dF/dx
Physical capital	0.0001*	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002
Knowledge capital	0.0000	0.0000	0.0000*	0.0000*	0.0000	0.0000	0.0000	0.0000
Human capital	0.0000*	0.0000**	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R&D collab. with univ/res labs	0.1375***	0.1262***	0.2167***	0.2234***	0.1923***	0.1728***	0.0362	0.0227
R&D collab. with other firms/cons	0.2784***	0.2621***	0.2817***	0.2815***	0.2222***	0.2189***	0.2180***	0.2214***
R&D intensity	0.0161***	0.0154***	0.0004	0.0001	0.0222***	0.0199***	0.0060**	0.0053**
Subsidy dummy	0.1392***	0.1405***	0.1047***	0.1087***	0.1378***	0.1335***	0.0971***	0.1046***
Skilled employees	0.0007	0.0004	0.0004	0.0004	0.0002	−0.0001	0.0003	0.0000
Firm age	0.0006**	0.0006**	0.0014***	0.0014***	0.0005	0.0006	0.0004	0.0007
Very small firm size	−0.0843***	−0.0776***	−0.1285	−0.1251	−0.0811***	−0.0643**	0.0180	0.0339
Small firm size	−0.0204	−0.0172	−0.0509	−0.0382	−0.0153	−0.0163	0.0408	0.0520
Medium firm size	0.0399	0.0391*	−0.0361	−0.0366	−0.0213	−0.0286	0.0611	0.0646
Large firm size	0.0234	0.0259	−0.0434	−0.0423	0.0272***	0.0263**	0.0334	0.0318
No cooperatives firms	0.3728***	0.3180***	0.1005***	0.0974**	0.1473**	0.0817*	−0.0086	−0.0656
Trend	0.1281***	0.1272***	0.2151***	0.2225***	0.1271***	0.1238***	0.1822***	0.1880***
Industry fixed effect	No	Yes	No	Yes	No	Yes	No	Yes
Observations	3480	3477	1248	1248	2640	2637	1493	1491

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$; Industry fixed effects (controlling for heterogeneity effects) include dummies for: 11 NACE-CLIO

Table 11 Biprobit regression: marginal effects for the dependent variable (existence of) process innovation—the territorial effects

	(H1) North-West dF/dx	(H2) North-West dF/dx	(H3) South dF/dx	(H4) South dF/dx	(H5) North-East dF/dx	(H6) North-East dF/dx	(H7) Centre dF/dx	(H8) Centre dF/dx
Physical capital	0.0001**	0.0001*	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002
Knowledge capital	0.0000	0.0000	0.0000*	0.0000	0.0000*	0.0000*	0.0000	0.0000
Human capital	0.0000***	0.0000***	0.0000	0.0000	0.0000	0.0000	0.0000***	0.0000**
R&D collab. with univ/res labs	0.0733***	0.0677***	0.0833	0.0803	0.1725***	0.1662***	0.1597***	0.1561***
R&D collab. with other firms/cons	0.1693***	0.1753***	0.0948*	0.0990	−0.0013	0.0026	0.0467	0.0445
R&D intensity	0.0056***	0.0059***	0.0016	0.0018	0.0065**	0.0053**	0.0034***	0.0037***
Subsidy dummy	0.1087***	0.1067***	0.1733***	0.1717***	0.1427***	0.1362***	0.1444***	0.1394***
Skilled employees	0.0017***	0.0018***	0.0021**	0.0022**	0.0001	−0.0002	−0.0004	−0.0005
Firm age	0.0005*	0.0006**	0.0017**	0.0019**	0.0018*	0.0018*	0.0008	0.0006
Very small firm size	−0.0901***	−0.0851***	−0.1773***	−0.1760***	−0.0843***	−0.0863***	−0.0257	−0.0143
Small firm size	−0.0067	−0.0039	−0.0633	−0.0698	−0.0636***	−0.0686***	0.0232	0.0309
Medium firm size	0.0497***	0.0580***	−0.0312	−0.0339	−0.0255	−0.0277	0.0264	0.0357
Large firm size	0.0786***	0.0838***	−0.0170	−0.0243	0.0347	0.0328	0.1663***	0.1791***
No cooperatives firms	0.0554	0.0326	0.0181	0.0090	0.1101	0.1317	−0.0119	−0.0020
Trend	0.0443***	0.0428***	0.0721**	0.0646*	0.0449***	0.0464***	0.1098***	0.1060***
Industry fixed effect	No	Yes	No	Yes	No	Yes	No	Yes
Observations	3480	3477	1248	1248	2640	2637	1493	1491

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$; Industry fixed effects (controlling for heterogeneity effects) include dummies for: 11 NACE-CLIO

7 Concluding remarks and implications

This paper examined the extent to which production factors, in particular human capital, and firm characteristics (such as R&D collaborations, the presence of skilled employees in the firm, firm age and so on) may influence and enhance firm' innovation (product and process).

In general, our analysis suggests that human capital generates more technology innovation than those firms located in areas with higher educational attainment workforce. We rationalized this finding in the sense of "convergence". In fact, the more efficient macro regions who produce highly skilled graduates have, in a sense, saturated their contribution on firms' innovation (i.e. that have already reached their steady state). On the other hand, the less efficient macro areas in which universities have more space for improving their performances, through the development of human capital and skills, being far away from their optimal point.

Particularly, separating the effect of production factors on product innovation, we find that physical capital, proxied by the number of employees in the firm, is the only inputs being significant, even if weakly. R&D collaborations with universities/research labs and with other firms/consultants are positive and highly significant. R&D intensity is also positive and statistically significant. Public incentives and skilled employees are also positive and highly significant. The age of a firm has a positive and statistically significant effect on product innovation. Commercial firms are more likely to innovate their products with respect to cooperative ones.

In term of size class effects, the empirical evidence confirms that all production factors (physical, knowledge and human capital) do not drive product innovation for large firms. In term of technological effects, physical capital is found to be an important driver for product innovation, especially in those firms that have a lower technology, while knowledge capital is found to be an important driver in the case of firms with a higher propensity to technology. In term of territorial effects, the interesting result is that human capital is the main factor for process innovation when we consider firms located in the Centre of the country. Following the convergence theory, ceteris paribus, the presence of graduates allows a greater diffusion of knowledge and skills, thus producing a greater growth (see also Barra and Zotti 2017) of firms, encouraging process and product innovation.

From the policy viewpoint, the empirical findings sustain our theoretical hypothesis suggesting that (1) local availability of higher human capital represents significant knowledge spillovers; (2) physical capital is an important factor to contribute to the innovation, especially in that macro region in which the presence of graduates allows a greater diffusion of knowledge and skills that can guarantee more economic performance; (3) R&D collaborations, which allow the exchange of new ideas, have a positive effect to firms' innovation; (4) the R&D intensity and public incentives improve the firms' innovation.

Overall, from this analysis emerges that regulators and policy makers can stimulate innovation in the manufacturing system in the following ways: (1) promote the increase in employment (i.e. physical capital), being the main production factor, guaranteeing greater growth; (2) improve the level in employment (physical capital) and expenses in R&D (knowledge capital), especially for small and medium firms; (3) promote the increase in employment (physical capital) and expenses in R&D (knowledge capital), especially for science-based firms and finally (4) ensure a clear improvement in the number of graduates (human capital), especially in the Southern region; this allows to reduce the gap (in term of employment and then economic performance) between Northern and Southern region.

We believe that our methodological approach is robust because tries to explain the phenomenon investigated not only from a theoretical point of view, but also from an empirical point of view. In particular, it allows to consider and to control for channels, factors and mechanisms otherwise hidden, making the findings generalizable and less influenced by some types of distortion. So we think that this way of proceed could be applied to other studies that deal with analyzing the phenomenon above described.

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