The relation between human capital and innovation at a firm level
A study on a sample of European firms.

Rosamaria d'Amore[1]
Roberto Iorio[2]

Abstract

In this paper we try to verify if the human capital "embodied" in the workforce has in itself (being constant the effort in R&D) a relation with the innovative capabilities of the firm. We also investigate if this link is linear or it is better expressed by non-linear expressions and if there is an interaction, and of what sign, between the education of the workforce and the R&D effort of the firm. Besides, we verify if the relationship between human capital and innovation has different strength in different countries. The empirical analysis is performed on data coming from a survey (EFIGE) run in seven European countries concerning the period 2007-2009. Linear regression models, also with instrumental variables, probit and tobit are the utilized statistical techniques. The results show a statistically significant and positive relationship between the ratio of graduated employees and the percentage of turnover from innovative products, being constant the share of personnel employed in R&D. This relationship appears not linear, as the quadratic terms are negative and significant. Besides, the intensity of this link is higher when firm's R&D intensity increases. We also find some significant differences n the magnitude of the human capital/innovation link across different countries.

1. Introduction

The aim of this paper is to empirically verify the relation between human capital and innovation. More precisely, we desire to verify if the human capital "embodied" in the workforce has in itself a link with the innovative capabilities of the firm, even controlling for the level of firm's R&D. Besides we want to verify if this relationship is linear and if its intensity depends on the level of firm's R&D. We also check if the magnitude of the relationship significantly differ in different countries.

It is easy to suppose a relationship between the education of the workforce and the innovative capacity of the firm: more educated workers may introduce more innovations and they are needed to import and manage innovations created by other firms. Indeed, the link between human capital

[1] University of Salerno: rmdamore@unisa.it
[2] University of Salerno: riorio@unisa.it

and innovation has been largely investigated at a macroeconomic level, with a special emphasis on the externalities, but not enough at the firm level. Besides, the relationship between education and innovation is evident if we consider the personnel with high education working in R&D laboratories. We inquiry if an high education of workforce is important for innovation even excluding R&D activities. Hence the simple empirical idea of our paper: verify the relationship between the share of workers with tertiary education and the percentage of turnover deriving from innovative product, being constant the share of workers directly occupied in R&D activities (obviously even controlling for several other factors that may have an effect on the innovation).

The theoretical framework can be considered the knowledge production function, in which innovation at the firm level is related with the cognitive capital present in the firm itself, where this is, precisely, not only the expenses formalized in R&D but also by the level of internal human capital (Audretsch and Feldman, 2004).

Another aspect of our analysis is the enquiry on the interaction between these two components of the firm's "cognitive capital". It is possible to hypothesize both a complimentarity and a substitutability relationship. In fact it is possible to imagine that a qualified workforce may multiply the innovative potential coming from research laboratories: in this case the higher is the human capital embodied in the workforce, the higher is he effect of R&D on innovation (and *vice versa*); this is a relationship of complimentarity. On the other side, it is possible to suppose that, if R&D expenditure is absent or low, the innovative strength particularly belongs to the qualified personnel not working in laboratories; in this case the lower is the expenditure in R&D, the higher the effect of human capital on innovation; in this case there is a relationship of substitutability.

The empirical analysis is performed on data coming from a survey (EFIGE) run in seven European countries and concerning the period 2007-2009. This survey is better described in the third section. The results of this study may be compared with the results of a similar study, performed by the same authors, on a panel of Italian firms covering the period 1998-2006 (D'Amore, Iorio and Lubrano Lavedera, 2014). The results obtained in these two studies are similar, letting to overcome the limits of the two analyses taken separately: the cross-section nature of the present study and the one-country characteristic of the previous one: the results of the two studies therefore reciprocally reinforce.

The article is structured as follows: the second section presents a review of the relevant literature on the relationship between human capital, R&D and innovation; in the third paragraph, we describe the data analyzed (first sub-section), present the results of the empirical analysis, univariate and bivariate first (second section), then of the multivariate analysis with a synthesis of the results; then the conclusions of the paper follow.

2. **Human capital, R&D and innovation: looking for a microeconomic literature**

The link between human capital , R&D and innovation has been usually considered on a macroeconomic point of view. In the theory of growth the importance of human capital and R&D are almost immediately acknowledged, but in the “classical” Solow’s model of growth (1956) they remain in a sort of “black box”. Mankiw, Romer and Weil (1992), extending the Solow’s model with the inclusion of human capital, managed to explain almost two thirds of the variability of growth rate among different national economies. The new theory of growth gives particular emphasis to the importance of human capital (Lucas, 1988) and R&D (Romer, 1990 a, b) for growth. Even if the models of these authors have a microfoundation, the context remains macroeconomic.

An important theoretical and empirical breakthrough is the introduction of the knowledge production function of Griliches (1979), and because the scope of the theoretical formulation is explicitly microeconomic, and because in this formulation the output is no longer production but directly the Innovation and the input is knowledge. The latter being a term with a clear economic meaning, but empirically abstract, it needs to be explained: as Audretsch and Feldman (2004) underline, calling Cohen and Klepper (1991 and 1992), the main source of knowledge in firm is generally considered R&D, which is therefore the term that underpins most empirical investigations; other elements in which the knowledge "translates" vary with the specific objective of the study. The formulation with which Audretsch and Feldman (2004) set forth the production function of knowledge includes, in addition to R&D, human capital, but the adoption of this second term is far from universal. Also, the scope of application was created as empirical microeconomic (studies at the firm level) but it extends to industry, geographic area or country, highlighting the role of spillovers and externalities: innovation output of each firm depends only partly from internal sources of knowledge; it largely depends on the research done in other companies, in the public and private centres of research, geographically contiguous, on the human capital present in the geographic area of the firm (see, for an analysis of the Italian case, Audretsch and Vivarelli, 1996); therefore, when it is studied the link between input and output of knowledge at the firm level, this is often weak, while, if the unit of analysis is wider, the relationship becomes clearer. In the decades since the introduction of the theoretical model of the knowledge production function there are numerous and important contributions, even empirical, that substantiate this approach (Griliches and Mairesse, 1983; Hall and Mairesse, 1995; Crepon, Duguet and Mairesse, 1998). The idea is that a company, an industry or a geographical area (Jaffe, 1986; Acs, Audretsch and Feldman, 1992; Feldman, 1994) have to invest in R&D expenses (input) in order to increase production of innovations (output), in turn able to support the increase of the added value (species through product innovations) and productivity (particularly through process innovations). In the years the original formulation was significantly and suitably enriched through the consideration of the effects of feedback (Kline and Rosenberg, 1986), as well as through the realization that knowledge spillovers can take root only in the presence of a sufficient level of absorptive capacity (Cohen and Levinthal, 1989), that is an adequate level of internal knowledge resources that can, in fact, "absorb" the external knowledge. Therefore in the sophisticated context of the evolutionary theory of the firm, it is reclaimed the idea of Nelson and Phelps (1966), born in the macroeconomic sphere, that “internal” knowledge is needed to absorb new knowledge produced outside, showing a kind of inverse causal process between intellectual capital and innovation. In any case, despite these important theoretical refinements, the setting of this prevailing trend of studies remains focused on the role of the R&D as a primary factor capable of generating innovation, therefore, to support the productivity, the competitiveness of products and, in ultimately, economic growth.

Compared to the abundance of studies on the effects of human capital in the macroeconomic sphere or on the effects of R&D at the firm level, there are less frequent studies on the effects of human capital on performance and innovation at the firm level. In many cases the link highlighted is indirect, in the sense that human capital is seen as a prerequisite for investment in other factors or other changes in 'firm that in turn lead to innovation. For example Arrighetti, Landini and Lasagni (2011), in a study on Italian data, referring to a vision based on *capabilities,* stress that the propensity to invest in *intangible assets,* whose impact on innovation and firm performance is established, depends on the level of human capital in the firm, on the firm size, on the organizational complexity and on a number of other highly firm specific factors. Abowd *et alii* (2002), studying US data, show that human capital affects the productivity of businesses or directly or with its complementary role with respect to the most advanced technologies, business models and organizational practices. Even Piva, Santarelli and Vivarelli (2005), still on Italian data, highlight the link between organizational change and demand for workers with high levels of *skills.* Investigations that approach, without however coincide with the one presented in this work, are performed by Ballot, Fakhfakh and Taymal (2001) and Bugamelli *et alii* (2012): both works, in fact, take into account both the human capital and R&D at the firm level. The first work, based on data from France and Sweden, consider the effect of R&D and human capital on firm performance, measured by the value added, finding a positive effect; similar to our work, it is also considered the interaction between these two factors (the effect of this interaction on the added value is estimated as positive); however, differently from our study, human capital, is understood as the training conducted at the firm level. The second work is based on EFIGE data. The share of graduated workers in the firm is placed in connection with the introduction of an innovation in firm, as well as with the number of patents filed at the European Patent Office (the report found is positive); expenditure on R&D is not included in the same estimation of the determinants of innovation, but it is placed in relation to human capital, in the sense that the latter (measured with the share of graduates) positively affects the expenditure on R&D. As highlighted above, the latter two studies are close to our since linking a measure of *output* of the company with the components of the cognitive capital of the firm. Our study, although part in this empirical strand, however, represents a new element because of the specific relations considered, as the *output* variable is innovation and human capital and R&D are determinants

As reported in the Introduction, the present paper is an ideal continuation of a previous study of the same authors (D'Amore, Iorio and Lubrano Lavadera et al., 2014). In that paper the empirical analysis is performed on a rotating *panel* of Italian firms, for a period of nine years, ranging from 1998 to 2006: these are three consecutive waves (VIII, IX and X) of the questionnaire Capitalia-Mediocredito Centrale-Unicredit on a sample of Italian firms. The continuity between the two study is assured by the fact that EFIGE data, used in the present paper, are a development in international direction of the Capitalia survey, with the questionnaire that remained largely unchanged. Moreover, the central empirical question is analogous; in fact among one of the questions wonders whether it was or not introduced during the period considered a product innovation; another asks whether it was or not introduced a process innovation. The answers to these questions are the dependent variables of the analysis. The determinants under investigation are the number of graduates, the number of employees in R&D and the interaction between these two variables; then there is a set of control variables: investment, total and in informatics, outsourcing of research, export, firm size, type of business according to the Pavitt classification. The results of the estimation show a statistically significant and positive relationship between the number of graduates and the number of employees in R&D, on the one hand, and the likelihood of introducing both a product and a process innovation on the other. The interaction term between graduates and R&D has a negative sign: it seems to prevail an effect of "substitution" between the two components of the cognitive capital of the firm, so the relationship between human capital and innovation is stronger where the level of R&D is lower.

3. **The empirical analysis**

3.1 Description of the database

The analyzed data were extracted from the survey EU-EFIGE/Bruegel-UniCredit dataset, a unique firm-level database of representative samples of manufacturing firms (with a lower thresholod of 10 employees) in seven European countries: France, Italy, Spain, Germany, United Kingdom, Austria and Hungary. The sample includes 14,759 firms. The survey has been run in early 2010 and questions cover the period 2007-2009.

3.2 Objectives of the empirical analysis; univariate and bivariate analysis

The goal of this work is to correlate the innovativeness of the firm with the cognitive capital of the firm: as a measure for the first one, we take two variables into consideration, both deriving from two specific questions of the EFIGE survey: the first one is a dummy variable assuming value 1 if the firm introduced any product innovation in the years 2007-2009; the second one is the average percentage of turnover from innovative products sales on average in the same years[3]; the cognitive capital is measured by the share of graduates and personnel engaged in R&D. The interaction of the two components of the cognitive capital is also taken into consideration. It is investigated, therefore, not only if and to what extent human capital and R&D are related to innovation at the firm level, but even the linearity or not of the relationship and the interactions of the two components of the cognitive capital. Referring to the review of the literature of the previous chapter, we can say that our theoretical reference is the function of knowledge production à la Audretsch and Feldman (2004), in which innovation at the firm level (I) is a function of R&D (RD) and the internal human capital (HK), as well as of an error term; the non-linear formulation of the function then implies the existence of effects of interaction between the two inputs (the effect of one depends on the size of the other):

$$I_i = \alpha RD^{\beta}{}_i HK^{\gamma}{}_i \varepsilon_i$$

Table 1 shows, in the first column the percentage of firms that claim to have introduced product innovations, in the second the mean percentage of turnover deriving from innovative products, in the third the same mean as before but only considering innovative firms

[3] In the EFIGE questionnaire only those who have introduced a product innovation are invited to indicate the percentage of turnover deriving from innovative product sales; therefore, for those who declared to have not introduced any product innovation, we clearly supposed that percentage was zero.

Table 1- Percentage of innovative firms

Firms introducing Product innovation (a)	Average percentage of turnover from innovative product sales-all firms	Average percentage of turnover from innovative product sales-only innovative firms
49.1%	10,2%	21.2%

Table 2 shows the correlation between the product innovation (the variable assumes value 1 if the firm has introduced at least one product innovation in the three years considered in the survey, value 0 if no product innovation has been introduced) , the percentage of turnover deriving from innovative products, the percentage of university graduates in the workforce and the percentage of employees involved in R&D activities .

Table 2- Pearson correlations

	Product innovation	Percentage of turnover from innovative products sales	Share of workers with university degree
Percentage of turnover from innovative products	0.56***	-	
Share of workers with university degree	0.15***	0.19***	-
Share of workers involved n R&D	0,18***	0.22***	0.26***

***Significant al 99%

All correlations are positive and significant at 99%. So there is a positive relationship between the components of the cognitive capital of the firm and the innovativeness of the firms. On the other hand, there is a strong relationship between the number of graduates and the number of employees in R&D: that is natural considering that, among those involved in the R&D, there is definitely a high percentage of science graduates. In order to highlight the effect of each of the two components of cognitive capital on the innovation it is therefore necessary a multivariate analysis, which also takes into account a number of other “control” variables , correlated both to innovation and to the cognitive capital firm.

3.3 Multivariate analysis

In the multivariate analysis, the dependent variables are:

- *innoprod,* a dummy variable assuming value 1 if the 'firm introduced any product innovation in the period 2007-2009;
- *innoturn,* the average percentage of turnover deriving from innovative product sales.

The independent variables under study are:

- *gradperc,* the percentage of university graduates in the workforce ;
- *gradperc2,* the quadratic term of *gradperc*;
- *rdperc,* the percentage of employees involved in R&D activities;
- *rdperc2,* the quadratic term of *rdperc*;
- *Xgradrdperc,* the product of the variables *gradperc* and *rdperc*
- *grad_[name country],* the product of the variable *gradperc* and the dummy variables for countries.

In the regression with instrumental variable, we use as instrument for *gradperc* the variable:

- *extceo,* a dummy variable assuming value 1 if the chief executive office (CEO) is a manager recruited outside of the firm, 0 otherwise (if he is a member of the proprietary family or a manager appointed within the firm).

Control variables are:

- *workforce*, the total number of employees in the firm’s home country;
- *export,* dummy variable indicating whether the firm is exporting or not; in fact a broad literature identifies a link between innovation and export (see, among others, Dosi, Pavitt and Soete, 1990);
- dummy variables indicating which of the groups identified by Pavitt taxonomy (Pavitt, 1984) the firm belongs to: the reference category is the first group, the *supplier dominated* firms; the second group is that of *business scale intensive* firm*,* the third one is the group of *specialised suppliers* and the fourth group is that of the *science based* firms*;*

- dummy variables for countries (the reference variable is United Kingdom).

We tested other control variables in the models, but they resulted non significant or they were missing in several observation, reducing therefore the number of the observation, without modifying significantly the effectiveness of the estimation.

In the regressions having *innoprod as* dependent variable, being this variable dicothomous, we adopted a probit model; the dependent variable *innoturn* is continuous but, being a percentage, it assumes positive values only, from 0 to 100, and there are several zeros (the non innovative firms); therefore, besides the linear regression model, we also estimates a *tobit* regression.

In studying the relation between human capital and innovation, problems of endogeneity and reverse causality may arise, as our data are cross-sectional. Therefore we also estimated linear and tobit regression with instrumental variables.

We always made robust estimations.

We estimated several models: Model 1 is the "basic" model, including only first degree terms for human capital and R&D variables, without interactions, plus the control variables illustrated above. Model 2 includes the quadratic terms of human capital and R&D variables and the interaction term between the first degree terms for human capital and R&D, plus the usual control variables. Model 3 includes the first degree terms for human capital and R&D variables and the interaction terms between the human capital variable and the dummies for countries, plus the control variables. Because Models 2 and 3 include interaction terms, and the interpretation of the results of the estimation for such terms in non-linear models is not very intuitive, we avoided to estimate the probit and tobit models for them;.

In the following we report the formulas for each models (for the sake of simplicity, when the dependent variable is *innoturn* we report only the linear model, even though we also estimated it with a tobit model regression), the result of the estimations and a brief comment.

Model 1

Φ^{-1} $(innoprod_i) = \beta_0 + \beta_1\ gradperc_i + \beta_3\ rdperc_i + \beta_3 workforce + \beta_4\ export + \boldsymbol{\beta}_{\mathbf{5\text{-}7}}$ (Pavitt dummies) + $\boldsymbol{\beta}_{\mathbf{8\text{-}13}}$ (country dummies) $+\varepsilon_i$

$innoturn_i = \beta_0 + \beta_1\ gradperc_i + \beta_3\ rdperc_i + \beta_3 workforce + \beta_4\ export + \boldsymbol{\beta}_{\mathbf{5\text{-}7}}$ (Pavitt dummies) + + $\boldsymbol{\beta}_{\mathbf{8\text{-}13}}$ (country dummies) $+\varepsilon_i$

Table 3. *Probit* model for product innovation - Model 1

Probit regression

Number of obs	= 14046
Wald chi2(13)	= 1278.23
Prob > chi2	= 0.0000
Log pseudolikelihood = -8921.3554 / Pseudo R2	= 0.0835

innoprod	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
gradperc	.0087067	.0010071	8.64	0.000	.0067327	.0106806
rdperc	.0142054	.0011429	12.43	0.000	.0119654	.0164454
workforce	.0012745	.0001221	10.44	0.000	.0010352	.0015137
export	.4938415	.0230864	21.39	0.000	.4485931	.5390899
pavitt2	.0176448	.0268885	0.66	0.512	-.0350556	.0703453
pavitt3	.1911369	.0331552	5.76	0.000	.1261538	.25612
pavitt4	.3493677	.0590043	5.92	0.000	.2337214	.465014
Italy	-.2532718	.0373082	-6.79	0.000	-.3263945	-.1801491
France	-.3625953	.0382103	-9.49	0.000	-.4374862	-.2877044
Spain	-.3067286	.0381894	-8.03	0.000	-.3815785	-.2318788
Germany	-.2917109	.0383727	-7.60	0.000	-.3669201	-.2165018
Austria	.0931285	.0789958	1.18	0.238	-.0617003	.2479574
Hungary	-.4028654	.0671842	-6.00	0.000	-.5345439	-.2711868
_cons	-.3893795	.0375074	-10.38	0.000	-.4628927	-.3158664

Table 4. *Linear regression* for percentage of turnover from innovation -Model 1

Linear regression

Number of obs	= 13727
F(13, 13713)	= 66.70
Prob > F	= 0.0000
R-squared	= 0.0934
Root MSE	= 17.899

innoturn	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
gradperc	.1754271	.0174242	10.07	0.000	.1412733	.2095809
rdperc	.2418161	.0173181	13.96	0.000	.2078703	.2757619
workforce	.0009923	.0015803	0.63	0.530	-.0021052	.0040898
export	4.629817	.3141745	14.74	0.000	4.013992	5.245642
pavitt2	-.0922813	.3700672	-0.25	0.803	-.8176637	.6331012
pavitt3	1.359839	.4791699	2.84	0.005	.4206003	2.299078
pavitt4	2.93052	.9232081	3.17	0.002	1.120905	4.740134
Italy	-.156633	.5903667	-0.27	0.791	-1.313833	1.000567
France	-3.72075	.5615414	-6.63	0.000	-4.821448	-2.620052
Spain	-2.594998	.5670331	-4.58	0.000	-3.70646	-1.483535
Germany	-2.930309	.565456	-5.18	0.000	-4.03868	-1.821937
Austria	2.216505	1.23559	1.79	0.073	-.2054205	4.63843
Hungary	-3.622725	.9999313	-3.62	0.000	-5.582727	-1.662723
_cons	5.473909	.5290554	10.35	0.000	4.436888	6.51093

Table 5. *Tobit* model for percentage of turnover from innovation -Model 1

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Tobit regression                                  Number of obs   =      13727
                                                  F(  13,  13714) =      92.44
                                                  Prob > F        =     0.0000
Log pseudolikelihood = -33718.605                 Pseudo R2       =     0.0238

------------------------------------------------------------------------------
             |               Robust
    innoturn |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    gradperc |   .3192083   .0286044    11.16   0.000     .2631397    .3752769
      rdperc |   .4757322   .0295595    16.09   0.000     .4177914    .5336729
   workforce |   .0170955   .0028515     6.00   0.000     .0115062    .0226848
      export |    13.7759    .730763    18.85   0.000      12.3435    15.20829
     pavitt2 |   .1893155   .8122343     0.23   0.816    -1.402775    1.781406
     pavitt3 |   4.292902    .947698     4.53   0.000     2.435285     6.15052
     pavitt4 |   6.901602   1.544187     4.47   0.000     3.874784    9.928419
       Italy |  -2.189238   1.117493    -1.96   0.050    -4.379677    .0012009
      France |  -9.828366   1.156489    -8.50   0.000    -12.09524   -7.561489
       Spain |  -7.229497   1.145394    -6.31   0.000    -9.474627   -4.984367
     Germany |   -5.78185   1.106095    -5.23   0.000    -7.949948   -3.613752
     Austria |   4.456305   2.100749     2.12   0.034     .3385482    8.574061
     Hungary |  -11.97903   2.271211    -5.27   0.000    -16.43091   -7.527142
       _cons |  -18.66204   1.129189   -16.53   0.000    -20.87541   -16.44868
-------------+----------------------------------------------------------------
      /sigma |   32.88587   .5072689                      31.89155    33.88018
------------------------------------------------------------------------------
  Obs. summary:       7615  left-censored observations at innoturn<=0
                      5925     uncensored observations
                       187 right-censored observations at innoturn>=100
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The positive and significant (at 99% level) sign for *rdperc* was largely expected: firms with an higher ratio of employees involved R&D have an higher degree of innovativeness (an higher probability to introduce an innovation and, if introduced, innovation are more significant in terms of returns). The sign for *gradperc* is positive and significant (atn 99% level) too: this means that, even controlling for the employees in R&D, an higher ratio of graduated workers is associated with an higher level of innovativeness. As for the control variables, we observe that exporting firms are more innovative than non exporting ones; the innovativeness increases with the size (expressed by the number of workers) of the firm. Regarding the Pavitt classification, we may conclude that, as expected, the *specialized suppliers* and *science based* firms are more innovative than *supplier dominated* firms. All these result are significant at 99& level in all the regression models.

The signs and significance of the coefficients for country dummy variables show that the firms of United Kingdom have an higher probability to introduce product innovation and have an higher percentage of turnover deriving from innovative product sales than all the other countries except Austria. This result is significant at 99%, except for *innoturn* with Italy : according the linear regression model, the difference between UK and Italy is not significant, according to the tobit model the difference is significant at 95%.

Model 2

$innoturn_i = \beta_0 + \beta_1\, gradperc_i + \beta_2\, gradperc2_i + \beta_3\, rdperc_i + \beta_4\, rdperc2_i + \beta_5\, Xgradrdperc_i +$

$+ \beta_6\, workforce + \beta_7\, export + \mathbf{B_{8\text{-}10}}$ (Pavitt dummies) $+ \boldsymbol{\beta_{11\text{-}15}}$ (country dummies) $+\varepsilon_i$

Table 6. *Linear regression* for percentage of turnover from innovation - Model 2

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Linear regression                                      Number of obs =   13727
                                                       F( 16, 13710) =   76.85
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.1199
                                                       Root MSE      =  17.637
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innoturn	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
gradperc	.1591773	.0321306	4.95	0.000	.0961969	.2221577
gradperc2	-.0009358	.0005131	-1.82	0.068	-.0019415	.00007
rdperc	.6537717	.0338228	19.33	0.000	.5874744	.7200689
rdperc2	-.0064127	.0004177	-15.35	0.000	-.0072315	-.0055939
Xgradrdperc	.002631	.0009124	2.88	0.004	.0008427	.0044194
workforce	.0021519	.0015632	1.38	0.169	-.0009122	.0052161
export	3.751529	.3144605	11.93	0.000	3.135144	4.367915
pavitt2	.0321688	.364172	0.09	0.930	-.6816582	.7459958
pavitt3	1.035168	.4716206	2.19	0.028	.1107273	1.959609
pavitt4	1.913212	.9141112	2.09	0.036	.1214284	3.704995
Italy	-.2704123	.5807529	-0.47	0.641	-1.408768	.867943
France	-3.889011	.5518945	-7.05	0.000	-4.9708	-2.807223
Spain	-2.551425	.5561729	-4.59	0.000	-3.6416	-1.46125
Germany	-3.249012	.5565409	-5.84	0.000	-4.339908	-2.158115
Austria	2.321506	1.191	1.95	0.051	-.0130177	4.65603
Hungary	-2.409339	.9868325	-2.44	0.015	-4.343666	-.4750123
_cons	4.498693	.5162907	8.71	0.000	3.486692	5.510693

A comparison between the value of the R-square for this model (0.1199) and the value obtained in the linear regression for Model 1 (0.0934) suggests that the introduction of the quadratic and interaction terms of *gradperc* and *rdperc* increases the goodness of fit and the explicative power of the model. The results of the estimation demonstrate the non linearity of the relationship between the human capital embodied in the workforce and the R&D intensity of the firm on one side and the innovativeness of the firm on the other; in fact the term of first degree of *gradperc* and *rdperc* are positive and significant (at 99% level) while their square terms are negative and significant (respectively at 90% and 99% level): when the percentage of graduated employers in the firm is low, an increase in that percentage is associated with an high increase of the percentage of turnover deriving from product innovations; when the percentage of graduated employers is high, an increase of this percentage is associated with a low increase of innovative turnover. The same holds for the percentage of employers involved in R&D activities. In other words, these results are consistent with decreasing returns, both for human capital embodied in the workforce and for the firm's R&D intensity. The interaction term between *gradperc* and *rdperc* is negative and significant (at 99% level): this means that, when R&D intensity increases, an increase of the percentage of graduated workers is associated with a stronger increase of the innovativeness of the firm; at the same time, when the percentage of graduated workers increases, an increase in the percentage of R&D workers is associated with a stronger increase of the innovativeness. In other words, it possible to think to a multiplicative effect between human capital and R&D in term of firm innovativeness.

If we desire to give a graphic representation of these results, having the percentage of graduated workers on the x-axis and the percentage of turnover deriving from innovative sales on the y-axis, we obtain an increasing concave curve; this curves shift upwards when the percentage of R&D employers increases..

Model 3

$innoturn_i = \beta_0 + \beta_1\ gradperc_i + \beta_3\ rdperc_i + \beta_3 workforce + \beta_4\ export + \boldsymbol{\beta_{5\text{-}7}}$ (Pavitt dummies) + $+ \boldsymbol{\beta_{8\text{-}13}}$ (country dummies) + $\boldsymbol{\beta_{14\text{-}18}}$ (dummies *grad*_[name country]) $+\varepsilon_i$

Table 7. *Linear regression* for percentage of turnover from innovation - Model 3

```
Linear regression                                      Number of obs =   13727
                                                       F( 19, 13707) =   46.22
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.0958
                                                       Root MSE      =  17.879
------------------------------------------------------------------------------
             |               Robust
   innoturn  |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    gradperc |   .3068089   .0504234     6.08   0.000     .2079721    .4056457
      rdperc |   .2416866   .0172852    13.98   0.000     .2078052    .2755681
   workforce |   .0011179   .0015788     0.71   0.479    -.0019768    .0042126
      export |   4.586007   .3133924    14.63   0.000     3.971715    5.200299
     pavitt2 |  -.0840212   .3688617    -0.23   0.820    -.8070406    .6389983
     pavitt3 |   1.435223   .4784739     3.00   0.003     .4973483    2.373097
     pavitt4 |   2.885817    .927913     3.11   0.002     1.066981    4.704654
       Italy |   1.287418   .6962766     1.85   0.064    -.0773799    2.652215
      France |  -2.458487     .67405    -3.65   0.000    -3.779717   -1.137256
```

Spain	-1.034757	.6620819	-1.56	0.118	-2.332528	.2630141
Germany	-1.449764	.6603288	-2.20	0.028	-2.744099	-.1554288
Austria	1.911613	1.347811	1.42	0.156	-.7302824	4.553508
Hungary	-.9291187	1.341998	-0.69	0.489	-3.559618	1.70138
grad_Italy	-.1683641	.0680423	-2.47	0.013	-.3017364	-.0349919
grad_France	-.1397931	.0648007	-2.16	0.031	-.2668114	-.0127748
grad_Spain	-.1669016	.0581212	-2.87	0.004	-.2808271	-.0529761
grad_Germany	-.1576652	.0590911	-2.67	0.008	-.2734919	-.0418384
grad_Austria	.1234266	.1718765	0.72	0.473	-.2134749	.4603281
grad_Hungary	-.2295327	.0894942	-2.56	0.010	-.4049537	-.0541117
_cons	4.288061	.5890181	7.28	0.000	3.133505	5.442617

This model has both the dummy variables for the seven countries and the interactions of such dummy variables with *gradperc:* we suppose therefore that the relation between *gradperc* and *innoturn* is represented by different lines for different countries where these lines have not only different vertical intercepts (expressed by the intercepts of the dummy variables for countries), like in the previous models, but also different shapes (expressed by the coefficients of the interaction terms between *gradperc* and the dummy variables for countries). We test therefore if the magnitude of the relationship between the human capital and the innovativeness of the firm is significantly different across different countries. We find that in the United Kingdom this magnitude is significantly (at 95% level) higher then in five of the other six countries; the only exception is Austria, where this magnitude is higher (but not significantly) than in UK.

Instrumental variables

In the text above, we usually preferred to use the term *relationship* between human capital and innovativeness rather than *effect* of the first one on the second. This is because the causal relationship between the human capital and innovation may be twofold: as reported in the introduction and confirmed by several contributions in the literature, reported above, more educated workers may introduce more innovations but it is also true that they are needed to absorb and manage innovations. For this inverse causal relationship, it is possible to think to the skill biased technical change theory: the introduction of more sophisticated technologies requires an upgrade of the workers' skills (Sanders, 2004). Therefore more human capital may imply more innovation, but more innovation may require more human capital. This twofold relation may imply endogeneity of the relation, therefore a correlation with the residuals of the regression model, therefore bias in the estimation. In an our previous, already cited paper enquiring the relationship between human capital and innovation (D'Amore, Iorio and Lubrano Lavadera, 2014) we tried to overcome this problem through lagged variables; this was possible thanks to the panel nature of the data. In this case data are cross-sectional, therefore the only way to manage the problem is the use of instrumental variables.

As an instrument for the percentage of graduated workers we used the variable *extceo*, indicating if the management of the firm is external or internal (belonging to the same family who owns the firms or appointed within the firm). In fact we find that an external management has an higher propensity to assume more qualified workers: the variable *exteceo* is significantly correlated with *gradperc* and the relationship exists even in a multivariate analysis, controlling for the same control variables of the analyses above. Besides, including *extceo* among the covariates of Model 1 it results not significant (at 90%), but, if *gradperc* is excluded from the covariates, *extceo* becomes significant at 90%. Therefore *extceo* meets the requirement for an instrumental variable: it is correlated with the covariate which may suffer from endogeneity (*gradperc*), but, having an impact on the dependent variable only through that covariate, it results not correlated with the residuals.

We estimated Model 1, both for *innoprod* (probit model) and *innoturn* (linear regression and tobit) having *extceo* as instrumental variable for *gradperc*. As in the linear regression model *workforce* completely looses its significance, we excluded it from the final estimation

Table 8. IV probit model model for product innovation - Model 1

```
Probit model with endogenous regressors            Number of obs   =       9743
                                                   Wald chi2(13)   =    1048.59
Log pseudolikelihood = -43385.291                  Prob > chi2     =     0.0000
```

	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
gradperc	.051243	.0187587	2.73	0.006	.0144766	.0880095
rdperc	.004192	.0049164	0.85	0.394	-.0054439	.0138279
workforce	.0010177	.0003564	2.86	0.004	.0003192	.0017162
export	.3446045	.1099031	3.14	0.002	.1291984	.5600106
pavitt2	.1548517	.0714086	2.17	0.030	.0148933	.29481
pavitt3	.1857094	.0409703	4.53	0.000	.1054091	.2660096
pavitt4	.0559214	.1776016	0.31	0.753	-.2921712	.4040141
Italy	-.1461566	.0586458	-2.49	0.013	-.2611004	-.0312129
France	-.2933474	.0484381	-6.06	0.000	-.3882844	-.1984105
Spain	-.3583724	.0507299	-7.06	0.000	-.4578011	-.2589436
Germany	-.3561179	.0472322	-7.54	0.000	-.4486913	-.2635444
Austria	.2241066	.0915863	2.45	0.014	.0446007	.4036124
Hungary	-.6026069	.1352604	-4.46	0.000	-.8677125	-.3375014
_cons	-.6045883	.0803507	-7.52	0.000	-.7620728	-.4471038
/athrho	-.4889063	.2775827	-1.76	0.078	-1.032958	.0551457
/lnsigma	2.39584	.020499	116.88	0.000	2.355662	2.436017
rho	-.453348	.2205327			-.7750921	.0550899
sigma	10.97741	.2250261			10.54511	11.42743

Instrumented: gradperc

Instruments: rdperc workforce export pavitt2 pavitt3 pavitt4 Italy France Spain Germany Austria Hungary MG

Wald test of exogeneity (/athrho = 0): chi2(1) = 3.10 Prob > chi2 = 0.0782

Table 9. IV *Linear regression* for percentage of turnover from innovation -Model 1

Instrumental variables (2SLS) regression

Number of obs = 9538
F(12, 9525) = 43.74
Prob > F = 0.0000
R-squared = 0.0268
Root MSE = 18.251

innoturn	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
gradperc	.571292	.3514523	1.63	0.104	-.1176293	1.260213
rdperc	.1386347	.0608746	2.28	0.023	.0193075	.2579619
export	3.741487	1.071217	3.49	0.000	1.641675	5.8413
pavitt2	1.453008	1.30899	1.11	0.267	-1.112891	4.018906
pavitt3	1.867142	.6384786	2.92	0.003	.615588	3.118696
pavitt4	1.422453	2.410654	0.59	0.555	-3.302942	6.147848
Italy	1.185257	.7876714	1.50	0.132	-.3587468	2.729261
France	-3.239473	.835603	-3.88	0.000	-4.877433	-1.601513
Spain	-3.099182	1.163113	-2.66	0.008	-5.379132	-.8192319
Germany	-3.331742	1.119107	-2.98	0.003	-5.525429	-1.138054
Austria	3.702725	1.647514	2.25	0.025	.4732471	6.932203
Hungary	-5.181235	2.854719	-1.81	0.070	-10.77709	.4146224
_cons	2.646931	2.194885	1.21	0.228	-1.655511	6.949374

Instrumented: gradperc
Instruments: rdperc export pavitt2 pavitt3 pavitt4 Italy France Spain Germany Austria Hungary MG

Table 10. IV *Tobit* model for percentage of turnover from innovation -Model 1

Tobit model with endogenous regressors

Number of obs = 9538
Wald chi2(13) = 664.18
Log pseudolikelihood = -59953.741
Prob > chi2 = 0.0000

	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
gradperc	1.448739	.768076	1.89	0.059	-.0566619	2.954141
rdperc	.2242983	.1331579	1.68	0.092	-.0366864	.4852831
workforce	.0138492	.0069895	1.98	0.048	.0001501	.0275483
export	10.78522	2.197507	4.91	0.000	6.478189	15.09226
pavitt2	4.366887	2.805205	1.56	0.120	-1.131214	9.864987
pavitt3	5.084627	1.298237	3.92	0.000	2.540128	7.629126
pavitt4	1.401001	5.100819	0.27	0.784	-8.59642	11.39842
Italy	.5929135	1.565463	0.38	0.705	-2.475338	3.661165

France	-8.824661	1.772862	-4.98	0.000	-12.29941	-5.349917
Spain	-9.062609	2.524204	-3.59	0.000	-14.00996	-4.11526
Germany	-7.89742	2.273637	-3.47	0.001	-12.35367	-3.441172
Austria	8.119335	3.178804	2.55	0.011	1.888994	14.34968
Hungary	-17.15319	6.261437	-2.74	0.006	-29.42539	-4.881004
_cons	-25.31951	4.639954	-5.46	0.000	-34.41365	-16.22537
/alpha	-1.113213	.768852	-1.45	0.148	-2.620136	.3937088
/lns	3.47699	.018435	188.61	0.000	3.440858	3.513122
/lnv	2.391229	.0205884	116.14	0.000	2.350877	2.431582
s	32.36217	.5965966			31.21374	33.55286
v	10.92692	.2249676			10.49477	11.37687

```
Instrumented:  gradperc
Instruments:   rdperc workforce export pavitt2 pavitt3
               pavitt4 Italy France Spain Germany
               Austria Hungary MG
------------------------------------------------------------------------------
Wald test of exogeneity (/alpha = 0): chi2(1) =     2.10  Prob > chi2 = 0.1476
```

The coefficient of *gradperc* is positive in the three regressions; it is significant at 99% level in the probit having *innoprod* as dependent variable, at 90% in the tobit and slightly below 90% in the linear regression; therefore it is possible to conclude that an increase in the percentage of graduate workers increases the probability to obtain one or more product innovations and the effectiveness of that/those innovation(s) in terms of share of turnover deriving from their sales.

As for the linear regression model, the Heckman test confirms, at 99% level of significance, that IV estimation is required[4]. The Wald test of exogeneity is applied to tobit and probit models: at 95% level we accept the hypothesis of exogeneity of IV estimation.

As the variable *extceo* is binary, its square term is perfectly correlated with the term of first degree, therefore it was not possible to estimate Model 2 with instrumental variables; Model 3 includes all the interactions of *gradperc* with the country dummies and all of these variables should be instrumented; they could be instrumented with the interactions of *execeo* with the country dummies and we tried to estimated such model but, perhaps because of the high number of instrumented variables, perhaps because of the low variability of such instrumental variables (both *extceo* and the country dummies are binary variables) all these variables resulted largely not significant.

[4] The Heckman test can not be calculated on robust estimations. Therefore we calculated it on non robust estimations, but we reported the results of the robust estimation. In the non robust estimation the coefficient of *gradperc* is positive and significant at 95%.

Synthesis of results

We may summarize the results of our analysis in this way: there is a positive, significant relation between the human capial embodied in the workforce (expressed by the percentage of graduated workers) and the innovativeness of the firm (expressed by its probability to introduce a product innovation and the percentage of turnover deriving from innovative product sales) and this relation exists even controlling for the R&D intensity (expressed by the percentage of employees involved in R&D activities). Such relation is not linear: results suggest an increasing but concave relation both between human capital and innovativeness and between R&D intensity and innovativeness; besides, there is a multiplicative effect of these two components of the "cognitive capital" of the firm: when R&D is higher the magnitude of the relation between human capital and innovativeness increase. Another result is that the magnitude of the relation between human capital and innovativeness is significantly different across different countries. Because of the cross-sectional nature of our data, these results should be read more in terms of "relation" than of "effect", but the analysis with instrumental variable supports their interpretation as a positive effect of the human capital embodied in the workforce on the innovative capability of the firm.

4. Conclusions

Several studies theorize or empirically test the link between human capital and economic growth at a macroeconomic level. Less frequent are the studies investigating this relationship at a microeconomic level. At the firm level the link between human capital and innovation is often seen as indirect, in the sense that a skilled workforce is considered a precondition for those elements (R&D investments in information technology, business organization, etc.) that generate innovation. The intent of this work is to empirically verify whether there is a direct relationship between the skills of the workforce and the innovative capacity of the firm, even "controlling" for other crucial factors for innovation (especially R&D) The analysis, conducted on data of firms of seven European countries in the period 2007-2009, reveals that an increase in the share of graduated workers in the firm increases the likelihood of introducing a product innovation and the share of turnover deriving from such innovation; the human capital and the R&D intensity at firm level show decreasing returns, but they have reciprocally a multiplicative effect: the effectiveness, in an innovative sense, of the "human capital" embodied in the workforce is higher in those firms where the ratio of workers employed in R&D services higher; i.e. an higher education of the workforce has a multiplicative effect on the R&D intensity of the firm. We also find that the intensity of the relationship between human capital and innovativeness at firm level is significantly different across countries.

This study has of course some limits: from the cross-sectional nature of the data, to the lack of detailed information on the innovations. The information on the level of education of the workforce is limited too (there is only the distinction between graduates and non-graduates, therefore not the type of degree, nor the exact level of study reached), Nevertheless, even with the limitations just mentioned, this analysis, conducts to interesting results, both because relatively little explored and because it seems may have important implications in terms of *policy:* it appears evident that the education of workforce is crucial for industry, as it may boost its innovative capacity, both for a direct effect and through a multiplicative effect on the R&D function. It is therefore clear that the way to reverse the downward trend in the competitiveness of European firms necessarily steps to increase attention and resources for investment, public and private, in human capital.

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