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The determinants of R&D Investment: the role of Cash flow and Capabilities

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Abstract

In this paper we have estimated a behavioural equation for R&D investment. We assess the impact of liquidity constraints and capabilities, measured respectively as internal cash flow and distance from the technological frontier.

Our estimation is performed on an industry level panel covering fifteen European countries from 1996 to 2005 and on a sample of European R&D performers extracted from COMPUSTAT covering 2000-2008. Both at industry level and firm level we found that financing constraints exist and that the distance from the frontier negatively affects the decision to engage in R&D.

We claim that the implied divergence pattern opens a gap for policy intervention, but that these policies should be correctly tailored and should also promote enablers of technological change.

JEL Classification: D24, L50, O33

Keywords: R&D, liquidity constraints, technological frontier, panel data

1 Introduction

As stressed by Tirole (1988) in his classic book, the study of firms' incentives to generate new products and/or new techniques is crucial in determining industrial evolution.[1] The standard theoretical analysis investigated the strategic issues at hand (Tirole, 1988) and also the specific technological determinants (Dosi, 1988). The empirical analysis tried to quantify the importance of specific factors and to identify a causal relationship.

A longstanding debate has focused on the demand pull (Schmookler, 1966; Scherer, 1982; Piva and Vivarelli, 2007) versus technology push explanations (Mowery and Rosenberg, 1979; Boldrin and Levine, 2002). The former points out a major role for market growth, because of increasing return to scale or softening of the cash constraint, while the latter perspective claims a vision for the innovative process as a widening of the possibility frontier being immediately available to all actors, inside which firms adjust their technique according to relative prices. While both are constituent components of the technical change process, they have been criticised because they neglect the role of the opportunities factor, which is logically prior, since it *defines the feasible set* in which market signals operate. According to this last perspective, technological search is localised (Atkinson and Stiglitz, 1969; Nelson and Winter, 1982), path dependent (Rosenberg, 1982; Arthur, 1985) and persistently characterised by a variety of capabilities (Dosi, 1988; Malerba, 2005; Metcalfe, 2010) and strategies (Bogliacino and Pianta, 2009).

Empirically, we propose the distance from the frontier as a proxy for the opportunity set. In the ideal conditions of perfect information, firms who lag behind in the short run would rapidly recover and overinvest to catch up. Nevertheless, the dispersion of knowledge (and the ability to deal with it) and the documented diversity in innovative strategies may generate persistent heterogeneity. In fact, companies operating below the frontier may lack the necessary capabilities to leapfrog and may focus on catch-up strategies, mainly characterised by adoption of embodied technological change.

[1] In fact, in the last three decades, after the unsatisfactory models of exogenous growth of Solow (1956) which basically left growth unexplained, growth theory has looked at endogenous sources of knowledge generation. While someone has seen accumulation alone as the fundamental cause driving human capital (see Lucas, 2002), many studies claimed that the innovation process and the institutional framework promoting it are the main engine of growth (see Nelson and Winter, 1982; Aghion and Howitt, 1998 and Acemoglu, 2008 for a balance).

Together with this *knowledge* factor, there is a more traditional *informational* issue related with the financing of R&D. Theoretically speaking, with perfect markets the value of a company is independent of its capital structure (Modigliani and Miller, 1958) and, as a result, the amount of investment should not be correlated with cash flow. However, the pervasive uncertainty that characterises new technological generation makes it difficult for companies to use these assets as collateral. If this is the case, restrictions in access to finance exist, discouraging entrepreneurs from undertaking innovative expenditure (Hall, 2002).

Differences in the opportunity set and in the access to financial resources generate negative welfare consequences: on the one hand, both cash constraints and capability constraints tend to generate persistent divergence, since past profits from innovation feed new profits and those who operate on the frontier are also those who are more likely to push it forward; on the other hand, it is apparent that the overall amount of R&D investment is suboptimal.

In this article, we estimate an equation for R&D investment with cash flow and a measure of the distance from the frontier (namely, from a productivity measure for the technological leader measured at the two digits level). As expected, the latter impacts negatively on R&D while the former has a positive and significant effect. We carried out our empirical estimation on a sample of European firms extracted from the COMPUSTAT database for the period 2000-2008 with positive R&D investment; however, we also assess the aggregate effect by estimating the baseline equation at industry level for fifteen EU countries. The use of both industry level and company level estimation allows us to assess the existence of spillover effects.

The novelty of the contribution is threefold. First of all, we provide a reduced form of the firm problem that can easily account for structural and "evolutionary" interpretation, putting together technological opportunities and market incentives. Secondly, we provide a direct measure of the opportunity set and internal resources through the distance variable and cash flow. Thirdly, we use a database covering almost the entire R&D expenditure in Europe (and the overall one at industry level), and by using panel data we can tackle the endogeneity issue.

The existence of both constraints to innovation suggests that an ideal policy mix should act on both demand and supply. Demand is a factor that can spur innovation whenever the firm faces cash constraints, but calibrated policies on access to finance and generators of capabilities should also be designed. We will discuss some policy implications at the end of the article.

The article is organised as follows: section two presents the state of the art; section three discusses methodology and data; section four shows the results; and finally section five concludes with policy implications.

2 Related Literature

This paper contributes to three streams of literature. The first one regards the determinants of R&D investment. It is sizeable and addresses various issues. A subset is represented by a large debate on the relationship between size and innovation, usually dubbed the Schumpeterian hypothesis. A first balance for this literature can be found in Cohen and Levin (1989), with an updated version in Cohen (2010). This literature has faced quite a lot of trouble in detecting a univocal robust relationship: heterogeneity in the knowledge base associated with each sector generates different patterns in terms of entry, size, and R&D intensity (Dosi, 1988; Breschi et al, 2000). The large amount of literature generated by the availability of innovation surveys has investigated the role of various factors, including policy interventions, by exploiting the homogeneity of the variable definitions (due to the Oslo Manual, see OECD, 2005) and the variety of technological indicators (see Crèpon et al, 1998 for a previous contribution that has influenced much of the following work, and Mairesse and Mohnen, 2010 for a survey). As well as size, in the search for other factors that play a role, some contributors have tried to investigate the causal impact of R&D subsidies (Busom, 2000; Almus and Czarnitzki 2003; Gonzales et al, 2005; Czarnitzki and Licht, 2006; Czarnitzki et al, 2006; Hall and Maffioli, 2008; Aerts and Schmidt, 2008; Bérubé and Mohnen, 2009): their empirical findings are moderately supportive of a positive role, but endogeneity is a strong issue to tackle with this kind of data. Market share is found to be positively correlated with R&D in Blundell et al (1999), Raymond et al (2010) and Gonzales et al (2005). Love et al (2009) and Manez et al (2010) suggest that ownership may affect R&D: the former find different determinants of R&D between indigenous and non-indigenous plants, while the latter estimate a significant role for foreign capital.

A second important literature stream is on the role of financial constraints in R&D investment.[2] As we briefly said in the introduction, the existence of this market imperfection is seen in the

[2] Similar literature focuses on the role of financial constraints and investment, which we are not going to review here. A good discussion is included in Schiantarelli (1996). A recent contribution by Crespi and Scellato (2010) investigates the role of financing constraints and ownership structure and tries to put forward an interpretation in

asymmetry of the information available between the lender and the borrower, who is either unwilling to disclose because of partial appropriability reasons or difficulty to monitor. A review of the empirical literature can be found in Hall (2002) and Hall and Lerner (2010). A more recent contribution is from Cincera and Ravet (2010), who found that financing constraints are binding for EU companies but not US ones, using a database merging R&D Scoreboard and COMPUSTAT. The latter empirical evidence is consistent with that emerging from Brown et al. (2009) which documented that equity was a main driver of the R&D boom in the US, using COMPUSTAT data. There are also a few country studies. Harhoff (1998) finds a cash flow effect in R&D for German firms. A similar study in terms of approach and conclusions was conducted by Bougheas et al (2001) on Irish companies. Finally, Savignac (2008) estimates a negative effect of the liquidity constraint on the likelihood to engage in innovation for French companies.

Finally, the article contributes to the demand pull - technology push opportunities debate. As already mentioned in the introduction, the demand pull versus technology push and the relative role of both factors when compared to opportunities are rooted in the very first contributions to the economics of technical change (Schmookler, 1966; Rosenberg, 1976; Dosi 1988).

Mentioning previous empirical evidence in favour of the demand pull hypothesis, one should start with Scherer (1982), who used patents as a measure of innovation and tried to account for different technological trajectories. A contribution at the industry level came from Kleinknecht and Verspagen (1990), who found a positive demand effect after controlling for path dependency. A more recent contribution at the company level was from Piva and Vivarelli (2007) who assessed the role of demand for innovation in different groups of companies. We consider the higher role played by demand in the presence of liquidity constraints to be particularly interesting: our empirical approach couples opportunities with cash flow effects and suggests a potential direction for synthesis of these alternative explanations.

On the technology push side, the first extensive discussion was from Mowery and Rosenberg (1979). Much of the most recent literature, especially regarding innovation surveys data, tend to include both effects, from the well known Crèpon et al (1998) to Brower and Kleinknecht (1995), Raimond et al (2010) and Mohnen and Dagenais (2002).

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terms of agency theory of the company; Bottazzi et al (2010) investigated the role of heterogeneity in the response to financial constraints.

A large strand of contributions has tried to show the role played by the opportunity set in shaping the pattern and direction of technical change: from the old Pavitt Taxonomy (Pavitt, 1984), who proposed a grouping of firms and industry according to the innovative strategy, to Breschi et al (2000) who divided industry according to a Schumpeter Mark I and Mark II feature. The former related to a mode of evolution characterised by large entry rate, small innovative firms and high turnover, while the latter by more stable distribution, larger average size and innovation by incumbents. Finally there are some tentative conceptualisations in Dosi (1988), and more recently Malerba (2002) and (2007). Geroski et al (1993) and Leiponen (2000) indirectly suggest a similar argument: they claim that major profitability of innovators is due to their larger capability endowment.

A sub-strand of this literature focused on the "learning" conceptualisation of technological change. Knowledge exploitation is based on previous knowledge: in this framework, R&D is also an instrument to profit from knowledge produced elsewhere. This process is dubbed *absorptive capacity* (Cohen and Levinthal, 1990; see Leiponen, 2005 for a recent contribution). Past innovation performance affects the cost of learning, discouraging R&D investment for companies far from the frontier.

On the specific proxy used in our study, we also mention Bogliacino and Pianta (2010), who found a negative effect for the frontier on the propensity for R&D at an industry level for eight European countries.

3 Methodology and Data

Most of the literature regarding R&D determinants chose either to estimate a reduced form that mimics the one for investment in fixed capital, formulated either as an accelerator, or as a Euler equation (what we may call a stock approach),[3] or to use some "measurement" framework (i.e. mainly showing correlations), due to the availability of cross sectional data only (this is the typical case of innovation surveys and the well-known Crèpon et al, 1998).

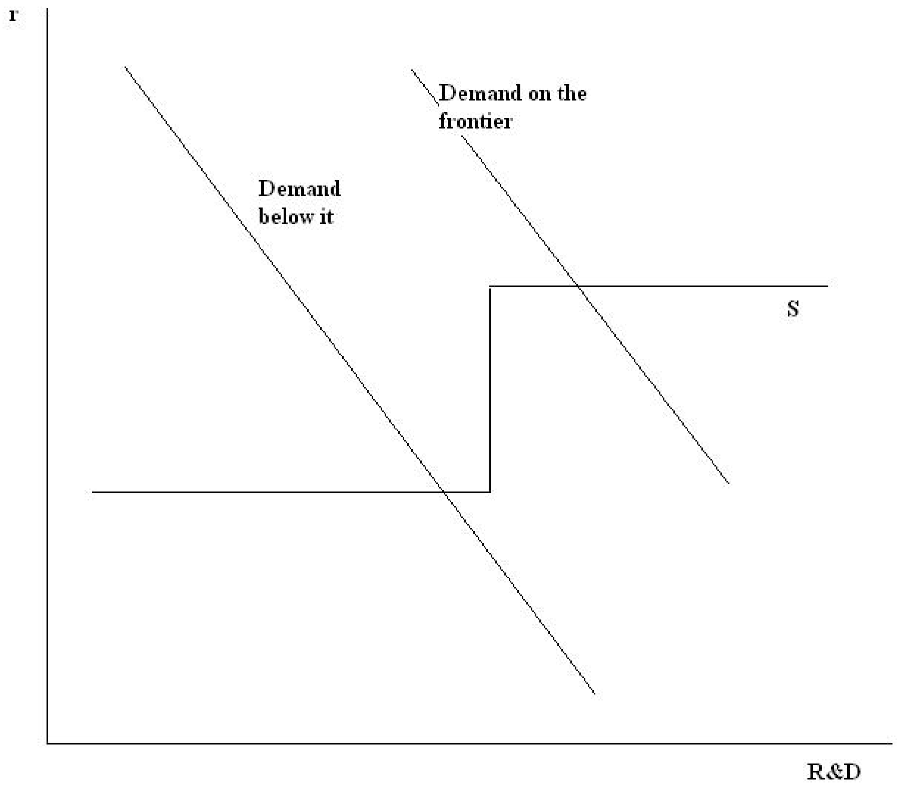
While the calculation of R&D stock is natural for studies aiming to assess its contribution to productivity and employment, we suspect that its use for estimating the determinants of R&D investment may be misspecified, due to a behavioural misinterpretation.

[3] See Cincera and Ravet (2010) for a discussion and Schiantarelli (1996) for a discussion on capital investment.

The Euler equation is meant to capture the optimal rule in a dynamic long-run problem with some termination condition, usually a transversality one. In this sense, the stock is a typical state variable of the problem. This may not be the case with R&D, which is associated with a specific product, process, organisational creation or improvement. Even in the steady state (assuming an endogenous growth framework), it is the constant *flow* of R&D which matters. In this sense we think that a correct analogy is instead the vintage capital framework.

A representation of our formulation can be seen in Figure 1 where on the y-axis there is the R&D cost and on the x-axis the R&D projects. Whenever capital markets are imperfect, the supply of funds for R&D has jumps: when cash flow or other internal resources that can be used as collateral are available, the cost is lower. Regarding the demand for projects by the firms, they can of course be ordered by profitability, so we have drawn it as a downward sloping curve, but the position with respect to the frontier represents the accumulated capabilities of the firm, and therefore the capacity to extract profitability from opportunities. The amount of R&D and its cost is given by the relative position of the two curves. This may capture the typical Schumpeterian view of evolutionary dynamics, where the selection process is not able to immediately select the fittest (Bottazzi et al, 2009), but is also the typical information problem related with the fundamental uncertainty of technology (Dosi, 1988; Olsson, 2000).

Figure 1. The R&D choice



As a result we can formulate our baseline equation in the following way:

$$\log(R\&D_{it}) = \rho\log(R\&D_{it-1}) + \alpha_0 + \alpha_1\log(DIST_{it}) + \alpha_2\log(CF_{it}) + \eta_i + \lambda_t + u_{it} \qquad (1)$$

where *R&D* is autoregressive and path dependent, *DIST* is a measure of the distance from the frontier (in terms of productivity), *CF* is the measure of internal resources and the remainder is an error component term.

We claim that the equation (1) may be consistent with a structural foundation based on individual maximisation problems.

Assuming a standard approach based on Dasgupta and Stiglitz (1980), the firm invests in R&D to gain some Schumpeterian rents, either driven by intellectual property rights, learning lags, secrecy or other forms of protection. The firms choose optimal *R&D* to maximise profits, and rents accrue stochastically, with the probability of innovation increasing and concave in the investment:

$$\begin{aligned}
&\max_{R\&D} P(R\&D)V-(1+r)R\&D \\
&\qquad\qquad s.t. \\
&r=r^1>r^2 \quad if \quad R\&D>Z \\
&r=r^2 \quad\quad\; if \quad R\&D\leq Z
\end{aligned} \tag{2}$$

where *r* is the cost of funds, *Z* represents internal resources, *P* is a probability (increasing and concave in *R&D*) and *V* is the present value of rents. *V* is a function of the industry-specific knowledge base (captured through fixed effects and time dummies) and individual capabilities, proxied by distance from the frontier.

It is easy to see that the above problem (2) implicitly defines R&D as a function of internal resources, the distance from the frontier, time invariant characteristics and time effects. Since projects are typically over many years, R&D is dynamic. After linearisation, we get (1).

The above formulation controls both for firm specific invariant effects, for firm specific technology push (through the autoregressive term) and for economy wide technology-push through the time dummies.

We estimate (1) using GMM-SYS (Blundell and Bond, 1998 and 2000) with robust standard errors and Windmeijer finite sample correction, as standard in dynamic panel data models.[4] As regards the regressors used in (1), GMM requires only sequential exogeneity as a condition for identification. In fact, all the variables are highly persistent, so the validity of the lag as an instrument is not an issue. Then, the whole identification concerns the assumptions of endogeneity versus predetermination: (a) simple accountancy rules prove that cash flow is endogenous when taken contemporaneously, so we need to instrument it; (b) the frontier should be discussed. We claim that lags in R&D productivity relationships are a valid argument for supporting predetermination of the contemporaneous term, but econometrically, the results are robust also when using the first lag at the frontier (which is predetermined by definition), both at an industry and firm level (the results can be seen in Section 4 below and the Appendix).

The next two subsections describe the data used in detail.

3.1. The industry level database

[4] The technique is already established as standard in the literature, so we need not discuss it at length. We give a reminder that GMM-SYS solve much of the efficiency problem in the first version of GMM estimators, namely

The industry level database includes manufacturing and market services for the period 1996-2005[5] in fifteen European countries, with a total of 2,295 observations (balanced panel). We used OECD STAN for most of the information: value added, production, employment, and gross fixed capital formation, with OECD ANBERD as the source of R&D expenditure. BERD expenditures are recorded according to the definition of the Frascati-Oslo Manuals (respectively, OECD, 2002 and OECD, 2005) and include business R&D regardless of the source of financing.

Taking into account availability and reliability, the countries included were: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, the Netherlands, Portugal, Spain, Sweden and United Kingdom. The sectors included are listed in the following table together with the two digit NACE classification (which at this disaggregation is identical to the ISIC one).

Table 1. Industries included in the database.

INDUSTRY	NACE
Food, drink & tobacco	15-16
Textiles	17
Clothing	18
Leather and footwear	19
Wood & products of wood and cork	20
Pulp, paper & paper products	21
Printing & publishing	22
Mineral oil refining, coke & nuclear fuel	23
Chemicals	24
Rubber & plastics	25
Non-metallic mineral products	26
Basic metals	27
Fabricated metal products	28
Mechanical engineering	29
Office machinery	30
Manufacture of electrical machinery and apparatus n.e.c.	31
Manufacture of radio, television and communication equipment and apparatus	32
Manufacture of medical, precision and optical instruments, watches and clocks	33
Motor vehicles	34

the first difference (Arellano and Bond, 1991). Our estimation is performed with the routine *xtabond2* (Roodman, 2005 and 2006) on Stata 11.

[5] The time window is essentially determined by the need to minimise holes. We had a significant drop in data availability for some variables after 2005, so we avoided what seemed like a systematic selection.

Manufacture of other transport equipment	35
Furniture, miscellaneous manufacturing; recycling	36-37
Hotels & catering	55
Computer and related activities	72
Research and development	73
Other business activities	74

Added-value has been deflated using the sectoral deflators provided by STAN, which take hedonic prices into account. All other nominal variables have been deflated using GDP deflators (taken from the IMF computations), with 2000 considered as the base year. For non-euro countries, we converted data into euros using nominal exchange rates from OECD sources. Finally, we corrected for purchasing power parities using the PPP index provided by Eurostat.

Regarding our main variables of interest, first we used operating surplus as a proxy for internal resources. Secondly, regarding the distance from the frontier, we calculated Total Factor Productivity (TFP) from both a Translog and a Cobb Douglas specification, where value added is regressed over capital and labour using a fixed effect estimator. The capital stock is calculated using the perpetual inventory method:

$$K_{i0} = \frac{I_{i0}}{g+\delta}, \qquad K_{it} = K_{it-1}(1-\delta) + I_{it} \qquad (3)$$

where *g* is the growth rate of investment (we used the average of the first five years of the period considered), *I* is capital expenditure (the flow) and δ is the depreciation rate. We differentiate the depreciation rate by the technological level, 4% for low tech, 6% for medium tech and 8% for high tech, according to the classification in Ortega-Argilés et al (2010).

We calculated the technological leader for each industry in terms of the TFP level (e.g. by confronting a specific industry for all the countries available) and considered the log difference of the leader TFP value.

Some descriptive statistics are reported in Table 2 below.

Table 4. Descriptive statistics. Industry level

		STANDARD DEVIATION		
	MEAN	TOTAL	BETWEEN	WITHIN
$R\&D$	268.72	839.20	800.75	136.58
VA	9238.10	21149.66	20862.46	2623.41
$EMPL$	171.76	348.09	341.41	34.67

OS	4412.13	14620.60	14121.02	1784.97
K	23996.68	94563.91	93121.77	13712.27
$DIST^{CD}$	13.28	90.89	52.00	73.99
$DIST^{TL}$	14.49	102.59	69.43	76.16

Where, *VA* is value added, *EMPL* is the number of employees, *OS* is operating surplus, *K* is capital, $DIST^{TL}$ is the distance calculated with a translog specification and $DIST^{CD}$ the distance calculated with a Cobb-Douglas specification. Expenditures are in millions of euros, constant 2000 prices and PPP corrected.

3.2. The firm level database

The firm level database was built with COMPUSTAT, using the *Global* database updated to the 31 January 2010. We performed the extraction using the criteria "Europe"[6] and "positive R&D" over the years 2000-2008. Given the highly unbalanced nature of the panel, we preferred not to extend the time window too much (2009 was excluded due to lack of data).

COMPUSTAT data are balance sheet data and show data for the overall group. We converted all expenditure data in millions of euros using foreign exchange data from 2008 and then deflated using GDP deflators (base year 2008). Eurostat is the source for both. After controlling for outliers, we have information on 1220 companies.

The high degree of correspondence between the R&D performers in COMPUSTAT and those in the R&D Scoreboard[7] (documented by Cincera and Ravet, 2010) suggests that no serious sample selection issue can be raised, since we covered more than 80% of the total R&D performed, i.e. almost the whole population of the performers.[8] The definition of R&D is the balance sheet one: it follows the standard IAS 38 – Intangible Assets, which is homogeneous with Frascati Manual (OECD, 2002). It includes research carried out by the company, not including that financed by public authorities.[9]

We used cash flow as a measure of internal resources. Since we used a log-log formulation and since cash flow can be negative for some of the companies, we had to rescale it by

[6] It is important to stress that the criterion is defined geographically and not politically, thus Europe includes not only the EU-27 but also Switzerland and Norway, for example.
[7] European Commission (2009).
[8] Of course R&D *per se* can be considered as a biased indicator of the overall innovation activity of companies (Archibugi and Pianta, 1996; Smith, 2005). Therefore, we chose to infer from R&D alone and not to extend the conclusions to the overall process of technological change.
[9] We should mention that, in any case, publicly financed business R&D is a small percentage of the total. According to Community Innovation Surveys (source Eurostat), it is around 2-3%of the total.

summing its minimum to avoid systematic sample selection. As a robustness check, we also used the operating surplus minus interest payments as a proxy for internal resources.

Again we used a TFP distance from the technological leader as a measure of technological opportunities. The TFP is estimated from a Cobb Douglas and a Translog production function where sales are regressed over employment and capital. Capital is built using the perpetual inventory method, according to the formula (3) above: we initialised it using the average growth rate of investment at the two digit industry level for the first two years, and used a common depreciation rate of 8% (the data are not sensitive to it, given the large time span). Capital expenditure was used as the investment variable. Again we calculated the TFP leader at two digits and then calculated the log difference of the TFP from its value.

Some descriptive statistics are shown in Table 3 below.

Table 3. Descriptive statistics. Firm level

		STANDARD DEVIATION			
	MEAN	TOTAL	BETWEEN	WITHIN	T-BAR
$R\&D$	171.85	818.58	601.43	296.29	5.25
K	4720.75	25934.00	24187.84	2419.06	7.74
$EMPL$	13.74	41.19	33.70	11.88	6.03
$SALES$	5879.88	50943.53	41094.17	26212.24	7.94
CF	921.22	14846.54	11784.92	7909.15	7.88
$DIST^{CD}$	168.65	3667.26	3510.48	2853.27	5.94
$DIST^{TL}$	683.24	20564.04	13970.67	17343.37	5.94

Where, K is investment in R&D, $EMPL$ is the number of employees, CF is cash flow, $DIST^{CD}$ is the distance calculated with a Cobb Douglas specification and $DIST^{TL}$ is the distance calculated with a Translog specification. Expenditure is in millions of euros, constant prices of 2008.

4 Results

In terms of the coefficients of the production function, at the industry level the estimated coefficient for capital is larger than that at the firm level in the Cobb Douglas specification, which is consistent with the hypothesis of spillovers (typical of endogenous growth literature). In both cases, the sum of the two elasticities is less than one, which is consistent with the hypothesis that increasing returns come from technical change, through R&D. Moreover, labour elasticity is of similar magnitude with the labour share at the aggregate level. Finally, capital enters significantly in the quadratic term in the Translog specification, both at industry and company level. In (4) and (5) below, we have reported the estimated production function. In (4) the Cobb Douglas specification is included, while in (5) the Translog specification is shown. Robust standard errors are reported in brackets below the estimated coefficients.

$$\begin{cases} (Industry) \qquad \log Y = \underset{[0.40]}{3.54} + \underset{[0.08]}{0.54} \log L + \underset{[0.04]}{0.21} \log K \\ \\ (Firm) \qquad \log Y = \underset{[0.21]}{4.46} + \underset{[0.03]}{0.78} \log L + \underset{[0.04]}{0.14} \log K \end{cases} \tag{4}$$

$$\begin{cases} (Industry) \qquad \log Y = \underset{[0.40]}{3.54} + \underset{[0.23]}{0.76} \log L + \underset{[0.00]}{0.03} \log^2 K - \underset{[0.02]}{0.05} \log K \log L \\ \\ (Firm) \qquad \log Y = \underset{[0.24]}{4.48} + \underset{[0.11]}{0.78} \log L + \underset{[0.00]}{0.03} \log^2 K \end{cases} \tag{5}$$

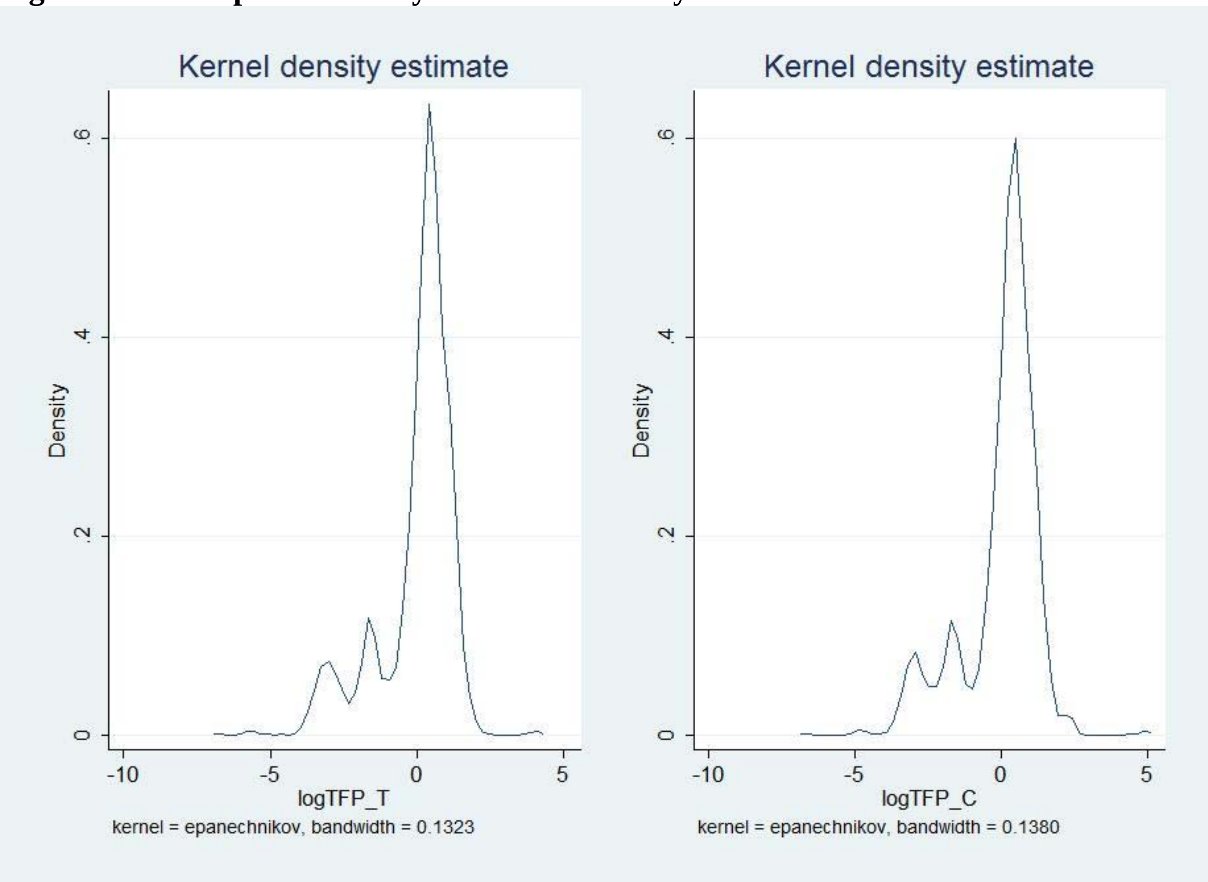
Before the econometric analysis, the issue of heterogeneity is discussed. In the two figures below, the kernel density estimation of the TFP for both industry and firm level data, Cobb Douglas and Translog, are given. In Figure 2 we show the estimated (log) TFP at industry level, while in Figure 3 we report the same empirical distributions for companies.

As can be seen, the support of the distribution is considerably large. The most productive company is more than ten times more productive than a company on the left bound of the support. Moreover, the distribution is asymmetric and shows fat tails: both skewness and kurtoses are not consistent with a Gaussian hypothesis. Finally, even at an industrial level the same features are maintained.

Incidentally, if recalculating for various years, we cannot see any tendency for the support to shrink. This persistent heterogeneity is consistent with the proposition that different actors are endowed with alternative opportunity sets and capabilities to exploit them. Even intra-sectoral analysis confirms these patterns, as shown by Dosi et al (2010).

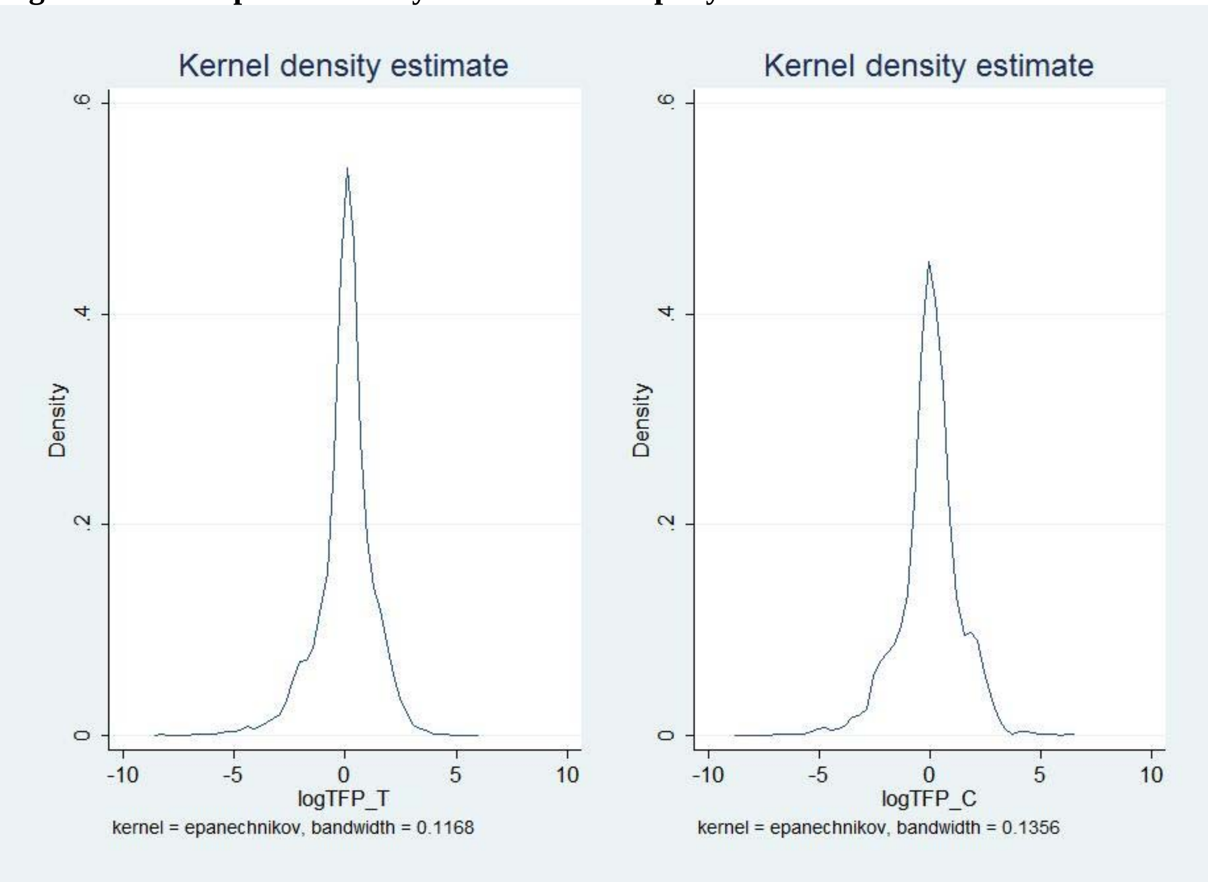
A further component should be stressed in the choice of this proxy for opportunities. One of the reasons why we are very confident that our proxy is not just a pure residual measure, is that it is necessarily correlated with human capital. In fact, we estimated the production function using absolute figures for employment, i.e. without considering skill levels, because of data availability. As a result, part of the human capital effect, both in terms of tacit knowledge and general skills, are included in it. There is indeed evidence in favour of skills as a determinant of innovative expenditure, as discussed by Piva and Vivarelli (2009).

Figure 2. The empirical density of TFP at industry level



Notes: On the left panel, the estimated TFP (in log scale) is taken from a Translog specification; on the right panel, from a Cobb Douglas specification.

Figure 3. The empirical density of TFP at a company level



Notes: On the left panel, the estimated TFP (in log scale) is taken from a Translog specification; on the right panel, from a Cobb Douglas specification.

4.1. Meso Analysis

We start from an aggregate appraisal of the relationship performing the analysis at industry level.

To keep the number of moment conditions under control, given the limited sample size at industry level, we used the first distance lag, which is predetermined and we instrumented the operating surplus. Moreover, we divided all the variables by the number of employees in the industry to compensate for size.

The results are shown in Table 3. The first column provides the estimation using the TFP taken from a Cobb Douglas specification, and the second column from a Translog one.

Table 4. Dependent variable: log of R&D per employee

	(1) GMM-SYS	(2) GMM-SYS
$\log(R\&D/EMPL)_{it-1}$	0.907	0.907
	[0.036]***	[0.036]***
$\log(DIST_{it}^{TL})$	-0.100	
	[0.058]**	
$\log(DIST_{it}^{CD})$		-0.133
		[0.060]**
$\log(OS/EMPL)_{it}$	0.105	0.107
	[0.046]**	[0.046]**
const.	1.098	1.128
	[0.519]**	[0.523]**
Time dummies	Yes	Yes
N Obs	1793	1793
Hansen	32.74	32.99
p value	0.624	0.613
AR(1)	-3.90	-3.90
p value	0.000	0.000
AR(2)	0.13	0.13
p value	0.894	0.893

Where, Robust standard errors are in brackets. *OS* is cash flow, *EMPL* is employment, $DIST^{CD}$ is the distance calculated with a Cobb Douglas specification and $DIST^{TL}$ distance that calculated with a Translog specification. One, two and three stars indicate significance at the 10, 5 and 1 percent level, respectively.

As can be seen from the Table, the diagnostic tests do not reject the specification: the AR test confirms the AR(1) nature and so the possibility of instrumenting using the second lag onwards; the Hansen is not rejected.[10] Moreover, the 95% interval of the autoregressive coefficient never includes one, which supports the hypothesis of stationarity of the panel.

The coefficients came out as expected and are significant and robust to distance specification. We confirmed the existence of an internal resource effect. We must stress that the coefficient we estimate is very close to that estimated by Bogliacino and Pianta (2010), who used a long difference approach at industry level. Moreover, the empirical results suggest that the capability effect is of a comparable size. A ten percent distance reduces the amount invested in R&D by one percent, with a significant effect on productivity (Ortega-Argilés et al, 2010) and employment (Bogliacino and Vivarelli, 2010).

We come now to the firm level study to better address the causality problem.

[10] We reported only the Hansen and not the Sargan, since the latter is just a special case of the former and is valid under the assumption of homoschedasticity, which is violated both at the firm and industry level.

4.2. Firm Level analysis

Coming to the main bulk of the analysis, we ran the same baseline estimation at a firm level. As mentioned in the data section above, to avoid sample selection, we rescaled cash flow when performing the log transformation.

As can be seen from Table 5, the main results are confirmed.

Table 5. Dependent variable: log of R&D expenditure

	(1) GMM-SYS	(2) GMM-SYS
$\log(R\&D_{it-1})$	0.953	0.951
	[0.014]***	[0.016]***
$\log(DIST_{it}^{TL})$	-0.037	
	[0.020]*	
$\log(DIST_{it}^{CD})$		-0.040*
		[0.025]
$\log(CF_{it})$	0.293	0.329
	[0.116]**	[0.125]***
const.	-2.540	-2.889
	[1.103]**	[1.175]**
Time dummies	Yes	Yes
N Obs	5107	5107
Hansen	65.76	60.70
p value	0.316	0.487
AR(1)	-5.53	-5.55
p value	0.000	0.000
AR(2)	-0.54	-0.56
p value	0.589	0.578

Where, Robust standard errors are in brackets, *CF* is cash flow, $DIST^{CD}$ is the distance calculated with a Cobb Douglas specification and $DIST^{TL}$ distance that calculated with a Translog specification. One, two and three stars indicate significance at the 10, 5 and 1 percent level, respectively.

The diagnostic tests are satisfactory. The AR(1) structure is not rejected and overidentifying restrictions pass the test. Again, non stationarity of the panel can be rejected at five percent level.

In terms of coefficients, the evidence does not reject our hypotheses. R&D is path-dependent both at an industry and firm level. The impact of internal resources is even stronger at a micro level. Finally, the negative effect of the distance from the frontier is confirmed both using the Cobb Douglas and the Translog measure.

The distance coefficient is greater for industries than for companies, since the latter take advantage of spillovers from other firms. An industry in a country, on the other hand, is constrained by the environment and characteristics of the economy (especially institutional ones), so distance is a greater obstacle to overcome. It must be remembered that most of our companies are multinational, while industry level data only includes business activity in the reference country.

In Appendix A.1 we provide some robustness checks, specifically using a measure of demand, through market share and size, as well as using different lags for the frontiers and proxies for cash flows. The results are confirmed.

5 Conclusions & policy implications

This article studies the determinants of R&D investment. We focused in particular on two factors that may hamper innovation: (1) the complicated access to finance to cover the R&D cost, and the subsequent role played by internal cash flows; (2) the differences in terms of capabilities for building and exploiting knowledge and technological opportunities.

We used data at industry level for twenty five industries over fifteen European countries (1996-2005), and a sample of R&D investors located in Europe taken from COMPUSTAT (2000-2008). We have balance sheet data for 1220 companies.

After calculating productivity measurements accounting for different capital intensity, namely TFP from alternative specifications, we see that there are consistent differences in terms of capabilities.

Moreover, using GMM-SYS estimators, we found evidence of a positive effect for internal cash flow, which signals the presence of a liquidity constraint, and a negative effect for the distance from the frontier. This suggests a capability effect: firms that lag behind are either more prone to invest in less formalised innovative strategies (as suggested in Bogliacino and Pianta, 2010), such as the adoption of new, labour-saving machinery or another form of embodied technical change; or they simply lack the ability to innovate enough (as suggested by Cohen and Lenvithal, 1990), and the selection process is not rapid enough to eliminate the unfit and to rapidly relocate resources. Significantly, the effect exists both at the firm and industry level.

From this evidence we infer two broad set of policy implications. On the one hand, we confirm that there is space to think of a variety of policy instruments to promote R&D, through fiscal tools, direct subsidies or institutional mechanisms, such as the development of a venture capital market. Although we cannot deduce, *per se*, the effectiveness of such an intervention,[11] it seems clear that there is a gap for a policy to improve efficiency. On this issue, our results are in line with the existing literature (see Hall 2002, Hall and Lerner, 2009; Cincera and Ravet, 2010).[12]

On the other hand, our evidence of a productivity lag effect suggests that normal incentive policies may be ineffective if not coupled with policies that work on enablers, namely human capital, organisational capital and entrepreneurship. As stated above, there is an implied tendency to divergence in terms of economic performance. By creating a proper set of capabilities, the possibility of leapfrogging increases and new sets of opportunities are created.

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[11] As usual, there is a problem of deadweight loss and additionality. Nevertheless, there is much literature on monitoring and evaluating the impact of policies, as with R&D, e.g. Fahrenkrog et al (2002).

[12] We did not provide components for the existing debate regarding EU and US financial constraints, which is beyond the scope of this paper, focusing on the European economy.

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Appendix

A.1 Robustness check

To test for robustness, we first run the baseline regression controlling for market share, which is a measure of market power and thus of the competitive pressure to innovate, and the number of employees. We expected a negative coefficient for the former and a positive for the latter (due to the debate mentioned in the section on the state of the art).

Table A.1 Dependent variable: log of R&D per employee. Industry Level

	(1) **GMM-SYS**	**(2)** **GMM-SYS**
$\log(R\&D_{it-1})$	0.893	0.883
	[0.025]***	[0.027]***
$\log(DIST_{it}^{TL})$	-0.0545	
	[0.029]***	
$\log(DIST_{it}^{CD})$		-0.068
		[0.023]***
$\log(MKT\_SHARE_{it-1})$	-0.079	-0.058
	[0.032]**	[0.026]**
$\log(EMPL_{it})$	0.152	0.124
	[0.052]***	[0.047]***
$\log(CF_{it})$	0.313	0.365
	[0.111]***	[0.120]***
const.	-3.288	-3.463
	[1.079]***	[1.153]***

Time dummies	Yes	Yes
N Obs	5107	5107
Hansen	173.74	177.13
p value	0.000	0.000
AR(1)	-5.37	-5.40
p value	0.000	0.000
AR(2)	-0.57	-0.60
p value	0.571	0.549

Where, Robust standard errors are in brackets. *CF* is cash flow, *EMPL* is employment, *MKT_SHARE* is market share, $DIST^{CD}$ is the distance calculated with a Cobb Douglas specification and $DIST^{TL}$ distance that calculated with a Translog specification. One, two and three stars indicate significance at the 10, 5 and 1 percent level, respectively.

Results are confirmed and the value of the coefficients for the relevant variables does not vary substantially. It is true that there is now a problem with the Hansen test, but we are not particularly concerned. Firstly, the results are robust to different numbers of instruments and lags. Secondly, we should mention that the endogeneity may be influenced by the presence of the employment variable, as discussed in the literature review. Thirdly, it is well known (Bowsher, 2002; Roodman, 2006) that the test itself is prone to weaknesses, e.g. when – as in this case – the autoregressive term is high.

Finally, as a further robustness test, the following Table A.2 shows the results of the same estimation as Table A.1 using the first lag of the distance, as in the industry level case: column (1) has the Translog computed distance and column (3) the Cobb Douglas one. In columns (2) and (4), we used an alternative measure of cash flow, namely the gross margin, i.e. the operating surplus minus the interest expenditure. Basic findings are again confirmed.

Table A.2 Dependent variable: log of R&D. Firm Level

	(1) GMM-SYS	(2) GMM-SYS	(3) GMM-SYS	(4) GMM-SYS
$\log(R\&D_{it-1})$	0.845	0.839	0.849	0.841
	[0.034]***	[0.035]***	[0.033]***	[0.035]***
$\log(DIST^{TL}_{it-1})$			-0.062	-0.052
			[0.024]***	[0.023]**
$\log(DIST^{CD}_{it-1})$	-0.070	-0.063		
	[0.027]***	[0.025]**		
$\log(MKT\_SHARE_{it-1})$	-0.129	-0.130	-0.130	-0.126
	[0.043]***	[0.041]***	[0.044]***	[0.042]***
$\log(EMPL_{it})$	0.272	0.284	0.264	0.273
	[0.066]***	[0.067]***	[0.068]***	[0.066]***

$\log(CF_{it})$	0.275		0.288	
	[0.163]*		[0.167]*	
$\log(OS_{it})$		0.258		0.262
		[0.160]		[0.155]*
const.	-3.243	-3.160	-3.375	-3.172
	[1.620]**	[1.568]**	[1.644]**	[1.510]**
Time dummies	Yes	Yes	Yes	Yes
N Obs	4641	4560	4641	4560
Hansen	183.22	175.97	183.64	176.26
p value	0.000	0.000	0.000	0.000
AR(1)	-4.93	-4.93	-4.94	-4.93
p value	0.000	0.000	0.000	0.000
AR(2)	-0.48	-0.82	-0.58	-0.88
p value	0.635	0.412	0.561	0.381

Where, Robust standard errors are in brackets. *CF* is cash flow, *EMPL* is employment, *MKT_SHARE* is market share, *OS* is operating surplus net of interest payments, $DIST^{CD}$ is the distance calculated with a Cobb Douglas specification and $DIST^{TL}$ the distance calculated with a Translog specification. One, two and three stars indicate significance at the 10, 5 and 1 percent level, respectively.

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Abstract

In this paper we have estimated a behavioural equation for R&D investment. We assess the impact of liquidity constraints and capabilities, measured respectively as internal cash flow and distance from the technological frontier.

Our estimation is performed on an industry level panel covering fifteen European countries from 1996 to 2005 and on a sample of European R&D performers extracted from COMPUSTAT covering 2000-2008. Both at industry level and firm level we found that financing constraints exist and that the distance from the frontier negatively affects the decision to engage in R&D.

We claim that the implied divergence pattern opens a gap for policy intervention, but that these policies should be correctly tailored and should also promote enablers of technological change.

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