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AN EMPIRICAL INVESTIGATION OF THE DETERMINANTS OF R&D COOPERATION

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Abstract

This paper is a contribution to the empirical literature on R&D cooperation. It explores the variables that determine a firm's R&D collaborative expenditure by means of a sample of Italian firms. A tobit model, adjusted for heteroscedasticity and non-normality (Inverse Hyperbolic Sin transformation to the dependent variable), is used to deal with the large number of zero responses. Size, public grants and innovation are found to be effective in determining the level of cooperative R&D expenditure. Absorptive capacity, expressed by the in-house stable R&D effort, also plays an important role. This is in line with the idea that internal R&D is required if a firm is to take advantage of the outcomes of external R&D investment.

Keywords: Truncated and censored models; R&D cooperation; firm behaviour.

JEL Classification: C24; D21; O31; O32.

1 INTRODUCTION

Over the past decades it has been widely recognised that investment in research and development is a critically important factor in driving innovation and economic growth. Firms have devoted considerable resources to R&D in order to improve their innovation trajectories and their technological capabilities by means of new R&D organisational practices and external partnerships. Cooperation has become an important organisational component of the innovation process particularly in sectors where innovation is growing in complexity, such as biotechnology and information technology. An increasing numbers of firms no longer rely exclusively on their internal R&D and have started collaborative relationships with a variety of partners, ranging from suppliers to customers and research organizations. R&D partnerships between firms have aroused great political and academic interest. National governments and the European Union have pursued research support policies which clearly encourage cooperative R&D projects.

Several scholars from different disciplines, such as managerial literature (Contractor and Lorange, 2002), transaction cost approaches and industrial organization literature have investigated the determinants of R&D collaboration (Kleinknecht and Reijnen, 1992; Fritsch and Lukas, 2001; Cassiman and Veugelers 2002; Tether, 2002; Belderbos *et al.*, 2004a,b).

One of the main findings of recent research is that the objectives and determinants of R&D collaboration differ, depending on the type of R&D and partner. Several arguments have been suggested to explain the motivations that encourage firms to enter R&D partnerships. These fall into two main categories:

knowledge spillovers: incoming and outgoing knowledge spillovers (D'Aspremont and Jacquemin, 1988). A stream of literature in industrial organization theory has investigated the relationships between R&D cooperation, R&D investment, and inter-firm knowledge flows, focusing particularly on the potential impact of these on R&D investment levels.

Incoming spillovers concern whether the firm can absorb and use knowledge produced by other firms. In such cases partnerships may allow superior learning efficiency. In these models access to complementary knowledge (Hite and Hesterly 2001; Aurora and Gambardella, 1990; Cohen and Levinthal, 1990; Vonortas, 1994; Belderbos *et al.*, 2004,a; Miotti and Sachwald, 2003) is seen as a way to efficiently absorb from the partner resources which are internally weak (Hagedoorn *et al.*, 2000). Firms enter into partnerships to acquire information which is complementary to their internal resources or to repatriate comparative advantages if the partner is a foreign firm (Miotti and Sachwald, 2003). For Japanese firms, knowledge complementarity is one of the main reasons for co-operating in R&D (Sakakibara, 1997). According to this literature, in order to carry out innovations firms need complementary intangible assets, i.e. tacit knowledge and know-how, which are not easily acquired through market-based transactions. Cooperation agreements may be a useful way of mitigating these problems and encouraging acquisition and creation of new knowledge (Katsoulakos and Ulph, 1998; Caloghirou *et al.*, 2003).

By contrast outgoing spillovers occur when knowledge that is generated by the firm flows out and benefits other firms. However these kinds of spillovers may turn out to be problematic if a firm's appropriability mechanisms are weak, with possibly serious disincentives on the level of investment in R&D. In such cases R&D partnerships may be an efficient way of internalising them (Steurs 1995; De Bondt, 1996; Cassiman and Veugelers 2002; Belderbos *et al.*, 2004a; Lopez, 2008); and of overcoming market failures in the innovation process (D'Aspremont and Jacquemin, 1988; Kamien *et al.*, 1992; De Bondt, 1996). An increase in the level of spillovers leads to an increase in the probability that a firm's cooperation will have beneficial effects on it's efficiency and performance. Cincera *et al.* (2003), for instance, show that international R&D cooperation affects a firm's productivity growth positively. Lööf, and Broström (2008) observe that collaboration between universities and firms increases the probability that firms will apply for a patent and has a positive impact on innovative sales.

Cost and risk-sharing in technological projects. This second category sees research cooperation as a way to share risks and costs, which are usually high in this field, as well as to exploit economies of scale and scope in R&D (Sakakibara 1997; Tether, 2002). Aschhoff and Smidt (2008) investigate the effect of past R&D cooperation on a firm's current innovative performance. However, along with potential benefits, there might well rise problems of information appropriability. The literature on industrial organization has built models to explore incentives and the risks of R&D co-operation. This literature also focuses its analysis on the risks involved in co-operation, with respect to involuntary 'outgoing spillovers' to partners (Veugelers and Cassiman, 1999).

Finally, several arguments have also highlighted the reasons why firms choose to collaborate with other firms or research institutes. The choice of different types of partners (e.g. customers or suppliers, competitors, public or private research institutions) is likely to be influenced by the nature of the R&D projects and by the cost of a particular commitment (Cassiman *et al.*, 2005). Presumably if a firm seeks complementarities and know how it will prefer asymmetric partnerships. Conversely, if the partnership is designed to internalize outgoing spillovers, symmetrical partnerships may be preferred.

This work investigates the determinants that influence the decision of firms to engage in cooperative research, in the case of a sample of Italian manufacturing firms. The econometric framework is based on the Tobit (1958) censored dependent variable framework, adjusted to allow for heteroscedasticity and non-normality of error terms, and applied to a data set of 1231 firms engaged in research. In order to overcome the inconsistencies deriving from non-normality of error terms, an Inverse Hyperbolic Sine (HIS) transformation to the depend variable is applied (Johnson, 1949; Burbidge *et al.*, 1988).

The remainder of the paper is organized as follows. The next section describes the data and the descriptive statistics. Section III contains the econometric model and the results. Section IV outlines the conclusions.

2 DATA AND VARIABLE DESCRIPTION

The data used in this study are taken from the Survey of Manufacturing Firms (SMF), carried out by the Area Studi of Capitalia Bank (2003). The SMF surveyed a stratified sample of Italian firms with 11 to 500 employees. It also included all manufacturing firms with more than 500 employees. The data was stratified according to the number of employees, the sector, and the geographical location. It used the Census of Italian Firms as a benchmark. The SMF contains questionnaire information about firms' structure and behaviour, and fifteen years of data on their balance sheets (1989-2003). Unfortunately, access to longitudinal data is limited. Since only a small fraction of the observations overlap, only the 2001-2003 survey is used in the empirical application. This prevents the analysis from addressing long-term considerations.

The survey contains information about the total amount of R&D investment and the amount of R&D investment dedicated to projects with external partners, such as other firms and research organizations. The questionnaire also supplies information on the way total R&D

investment is financed, i.e. venture capital, self-financing, credit, free grants and tax reductions. Self-financing is by far the most important and covers more than 80% of total R&D expenditure. In this paper firms are considered to be subsidised if they received free R&D grants or tax reductions for R&D, or both.

There are three questions in the survey that can be used to evaluate the firm's access to the credit market directly: 1) whether at the current market interest rate the firm wants additional credit; 2) whether the firm is willing to pay a higher interest rate to obtain that additional credit; 3) whether the firm has applied for this credit but it has been refused. If the firm answers "yes" to the second or third questions, it is considered to be credit rationed. In this work this variable is used as a proxy for firm financial distress.

Table 1 shows the descriptive statistics for R&D collaborating and R&D non-collaborating firms. There are a total of 1231 companies which invest in research, 591 of which choose to co-operate in R&D. There are some interesting differences between the two groups. Firms which collaborate are larger than non-collaborating firms in terms of number of employees. They also invest more in terms of private R&D per worker, though they have the same research/workers ratio. Although internal processes to acquire new technological knowledge are prevalent, external research partnerships represent a sizeable amount of the total (42 percent of intramural private research expenditure).

The capital per worker ratio is slightly larger for collaborating firms, which also appear to have less debts and are less credit rationed. Interestingly, such firms also receive more grants from the government for both R&D and other forms of public financial support. The proportion of innovating firms is slightly higher for collaborating firms, while the proportion of exporting firms is similar for the two groups.

There are no differences in terms of industry classification between the traditional 'supplier dominated' ($PAVITT_1$) and 'specialized equipment suppliers' ($PAVITT_3$). Cooperating firms are slightly less 'scale-intensive' ($PAVITT_2$) (13 percent versus 16 percent), while they are somewhat more 'science-based' ($PAVITT_4$) than the non-cooperating ones (7 percent versus 4 percent). Considering that the two groups may also differ in their unobservable characteristics, the evidence from table (1) in support of the random hypothesis is not unambiguous.

Before proceeding further, it will be briefly described the variables that are considered in this work. These may influence a firm's decision on whether or not to engage in R&D collaboration at a particular time.

The model considers a set of explanatory variables which are supported by previous research and empirical models. However, given the lack of unambiguous theoretical indications the analysis is still rather explorative.

The variable of interest is the amount of collaborative R&D expenditure over the three year period. This is divided by the number of workers to provide a measure of the intensity of R&D collaboration ($COLL\text{-}R\&D_{EMP(2001\text{-}2003)}$). Hence, unlike many other studies, this work considers continuous dependent variables when exploring the relative importance of different factors in R&D partnerships.

In line with the existing literature, firm size is included as an explanatory variable. This variable is measured as the logarithm of the number of employees and refers to the initial year ($LogEMP_{(2001)}$). Most empirical studies show that that firm size is a key variable for predicting whether a firm will engage in cooperative R&D (Sakakibara, 1997; Veugelers, 1997; Bayona *et al.*, 2001; Fritsch and Lukas, 2001; Miotti and Sachwald, 2003). For any given level of R&D intensity, larger firms are also more likely to have the absorptive capacity required to exploit the benefits of R&D cooperation better, and are also more likely to be involved in multiple technologies that may require different R&D partnerships. However, the relationship between firm size and R&D partnership is not necessarily clear. On one hand, cooperation may be more beneficial for small companies, as it allows them to share fixed research costs. On the other, the resources required for partnerships may be high for them. The effect of size may vary according to the partners and purposes of the partnership (Kleinknecht and Reijnen, 1992; Tether, 2002). Nevertheless a firm's absorptive capacity can be expected to be related to its R&D activities rather than simply to its size.

A measure of stable R&D commitment ($LogEMP_{R\&D\text{-}EMPL(2001)}$), measured as the number of R&D personnel compared to total personnel at the initial period, is also considered. This supplies a proxy for a firm's engagement in R&D and approximates the firm's human capital intensity. Knowledge is a crucial intangible asset in R&D cooperation partnerships. Many studies have emphasized that in order to absorb external knowledge, an effective absorptive capacity of understanding and using this knowledge effectively is essential (Cohen and Levinthal, 1989; Griffith *et al.*, 2004; Bönte and Keilbach, 2005). A stable R&D structure has a positive influence on their propensity to cooperate in R&D projects (Cohen and Levinthal, 1989; Kleinknecht and Reijnen, 1992; Veugelers, 1997; Bayona *et al.*, 2001).

A firm having its own R&D department is considered a factor that reduces risks, while increasing the probability of finding partners (Kleinknecht and van Reijnen, 1992). Particularly when the level of spillovers is high, cooperative research is associated with higher levels of R&D expenditure (D'Aspremont and Jacquemin, 1988; Kamien *et al.*, 1992). For example, Piga and Vivarelli (2004) find that the decision to engage in a R&D partnership is linked to the firm's prior choice to carry out its own R&D activity and Leiponen (2001) suggests that a very large absorptive capacity might be required in order to absorb scientific knowledge from universities. Fritsch and Lukas (2001) and Belderbos *et al.* (2004a) find that firms engaged in R&D cooperation tend to have a higher proportion of R&D employees.

Capital intensity, expressed in logarithmic term ($Log(K_{INT})$), is measured as physical assets per employee, to account for the fact that firms in more technology-intensive sectors may have a higher propensity to conduct R&D collaboration than those in more labour-intensive sectors. This may be because capital intensive firms tend to produce standardized goods employing standardized technology and are less worried about external R&D appropriability issues.

The model checks for the possible role of R&D subsidies by including a dummy variable which indicates whether the firm received R&D subsidies during the three year period ($GRANT_{R\&D}$). Market failures in real and financial markets offer justification for public support, as the return may be not sufficient to justify private investment. The broad consensus on the use of public support is based on the inefficiencies of the market. These create a gap between the private and social return on R&D and, as a result, less than optimal levels of research. This is because of incomplete appropriability of research output and externalities deriving from the public good nature of R&D (Nelson, 1959; Arrow, 1962). As a result, public funding tends to have a positive influence on firms' R&D spending and an indirect influence on the propensity to co-operate in R&D (Veugelers, 1997). Kleinknecht and Reijnen (1992) find that various types of government support for innovation increase the probability that firms cooperate in R&D.

An export dummy (*EXPORT*) is included because firms that compete in foreign markets tend to be more innovative than others (Arnold and Hussinger, 2005), and hence more likely to collaborate. Operating in more competitive environments, exporting firms are more inclined to invest in research and to improve R&D strategies, including cooperation. There may also be an indirect effect, deriving from the richer network of customers, suppliers or competitors that exporting firms may have access to, which may make cooperation more likely.

Industry dummies are included among the regressors in order to control for potential sectoral systematic differences in cooperation. These are: traditional 'supplier dominated', 'scale-intensive', 'specialized equipment suppliers' and 'science-based' (PAVITT classification). The rationale for this is that there may be various technology dimensions such as technological opportunity, appropriability regimes, dynamic aspects and cumulativeness whose characteristics may vary among the industrial sectors. A typical claim is that the propensity to co-operate on R&D is higher for firms from sectors with relatively high R&D intensity.

A binary variable which indicates the innovation status of the firms is also included (*INNOV*). The effect of this variable on collaboration is expected to be positive, since innovative firm normally have a higher level of R&D expenditure, and should thus be more inclined to form external partnerships (absorptive hypothesis).

A measure of the financial constraints is also included (*RATION*). Such constraints are in general good at explaining under-investment in technology and in R&D expenditure. This variable provides a proxy of credit market efficiency. The total cost of research may vary across firms due to differences in the availability and cost of financial resources. Arguments such as risks, sunk costs and other forms of market failures are commonly seen as having particularly severe effects in this field. Financial constraints are in general good at explaining under-investment in research and so they may well affect the amount of cooperative R&D.

A measure of indebtedness is also included in order to control for the potential of the firms to find financial sources to support the costs of R&D. It is expressed as the ratio of debt to banks over average value added ($DEBT\text{-}AV_{RATIO}$). Finally, $GRANT_{OTHER}$ is a dummy=1 if the firm received other public grants.

3 THE ANALYTICAL FRAMEWORK

Not all firms in the sample are engaged in R&D collaboration, so some observations are left censored. The presence of "zero" observations makes the relationship between the R&D collaboration variable and the independent variables more complex than it is assumed to be by traditional regression models. The standard tobit model (Tobin, 1958) has typically been employed to estimate censored models. By assuming that an unobservable latent framework generates the data (i.e.

the censored data have the same distribution of errors as the uncensored data) the model can be written as:

$$COLL_i^* = X_i^{'}\beta + \varepsilon_i \qquad (1)$$

Where $COLL_i^*$ is the unobserved latent variable, X_i is the matrix of the regressors, b the parameter vector to be estimated and e_i ~ N(m, s^2) is the random term.

The observed dependent variable is:

$$COLL_i = \begin{cases} COLL_i^* & if \quad X_i^{'}\beta + \varepsilon_i > 0 \\ 0 \text{ otherwise} \end{cases} \qquad (2)$$

The model is estimated employing maximum likelihood estimation procedures. The log-likelihood for the censored regression model is (Green 2003):

$$\ln L = \sum_{y_i > 0} -\frac{1}{2}\left[\log(2\pi) + \ln\sigma^2 + \frac{(y_i - x_i^{'}\beta^2)}{\sigma^2}\right] + \sum_{y_i = 0} \ln\left[1 - \Phi + \left(\frac{x_i^{'}\beta}{\sigma}\right)\right] \qquad (3)$$

The two parts represent the traditional regression for the non-limit observations and the relevant probabilities for the limit observations respectively. Where s is the standard deviation to be estimated and Φ represents the cumulative density function of the standard normal distribution. There are two basic assumptions underlying the tobit model. It turns out that if the disturbance s^2 is either heteroscedastic or non-normal, then the ML estimates are inconsistent (Arabmazar and Schmidt, 1981, 1982).

To check for such a possibility, a Lagrange Multiplier test on the basis of the homoscedastic model is applied. The number of employees and the researchers intensity proved to affect the variance. Since heteroscedasticity is detected (LR: 684.058, prob > χ^2 = 0.000, Table 3), to overcome the inconsistency of both the standard error and the coefficients the maximum-likelihood specification was flexibilized by modelling the variance using multiplicative heteroscedasticity of the form:

$$\sigma_i = \sigma \cdot \exp\,(z_i^{'}a) \qquad (4)$$

where z_i are the continuous variables causing heteroscedasticity and a the additional coefficients to be estimated.

In addition a conditional moment test for testing the null hypothesis that the disturbances in the Tobit have a normal distribution (Pagan and Vella, 1989) casts doubt on the non-normality of the tobit residuals (table 3). The statistic (229.22) resulted in a Prob > χ^2 = 0.000, so the normality assumption is clearly rejected. This is not surprising, since the variable *COLL-R&DEMP(2001-2003)* is strongly skewed by the zero values.

In this case the logarithmic transformation may provide a solution. However, this is likely to create problems due to the presence of the zero observations, particularly if this part of the sample is central to the analysis. As a possible solution to non-normal error structure, Yen (1993) incorporates the Box-Cox transformation of the dependent variable in the double-hurdle-model. This implies more flexible parameterization and distributional assumptions than the standard tobit does. However, there are some drawbacks associated with the Box-Cox transformation. The dependent variable is strictly normal only if the Box-Cox transformation parameter is zero. It is also not scale-invariant, which means that the empirical results may be affected by the unit of measurement employed.

In order to overcome the inconsistencies deriving from non-normality of error terms, this work applies an inverse hyperbolic sine (IHS) transformation to the depend variable (Johnson, 1949; Burbidge *et al.*, 1988). This is, in fact, an alternative transformation to the Box-Cox transformation.[1]

The IHS transformation is scale invariant (MacKinnon and Magee, 1990) and includes as special cases a straightforward linear transformation (θ=1) and the logarithmic transformation ($\theta\rightarrow 0$):

$$T(\theta y_i) = \log\left[\theta\, y_i + \left(\theta^2 y_i^2 + 1\right)^{1/2}\right] / \theta \;=\; \sinh^{-1}\left(\theta\, y_i\right)/\theta \qquad (5)$$

[1] The Box-Cox transformation is defined as $y^T = \dfrac{y^\lambda}{\lambda}$ where for $\lambda\rightarrow 0$ coincides with the logarithmic transformation and for $\lambda\rightarrow 1$ coincides with the linear transformation.

where $\theta \geq 0$ is an unknown parameter which can be used to obtain ML estimates $\hat{y}$ and $\hat{\sigma}_i^2$.

The likelihood equation for the adjusted model, allowing for heteroscedasticity and non-normality structure of errors, can be expressed as:[2]

$$L = \prod_{COLL_i=0}\left[1-\Phi(w_i'a)\Phi\left(\frac{x_i'\beta}{\sigma_i}\right)\right] \bullet \prod_{COLL_i=1}\left[\Phi(w_i'a)\sigma_i^{-1}\phi\left(\frac{T(\theta y_i)-x_i'\beta}{\sigma_i}\right)\left(1+\theta^2 y_i^2\right)^{-1/2}\right] \quad (6)$$

4 ESTIMATION RESULTS

Equation (6) is estimated for the overall amount of R&D collaboration per employee. Since non-normality and heteroscedasticity are detected only the results of the IHS heteroscedastic tobit model, these are reported in Table 2, while the results of the homoscedastic and the heteroscedastic models are reported in appendix A1. In order to provide a comparison the same procedure on the logarithmic transformation of the dependent variable is also used (results in appendix A.2).[3]

The HIS parameter (θ) is strongly significant, supporting this specification. To corroborate the validity of such a model a likelihood-ratio test has been applied to the alternative tobit and heteroscedastic tobit models (table 3). The IHS tobit nests the tobit model and a likelihood-ratio test suggests that the tobit model is too restrictive (χ^2 = 695.42 so Prob > χ^2 = 0.00). The corresponding tests of HIS-tobit versus heteroscedastic tobit (χ^2 (2) = 805.44 so Prob > χ^2 = 0.00) show that it can be rejected, so that the less flexible models are not too restrictive. Thus the IHS dominates both the tobit and the heteroscedastic tobit, which it nests.

[2] Applications of the IHS transformation can be found in Jensen and Yen (1996) and Yen and Jones (1997), Newman *et al.* (2003) Keelan *et al.* (2008). In this work all estimations are performed using STATA. To program the code, the code for a Box Cox Double Hurdle Model in STATA has been adapted. This code was written by Moffatt (2005) and recently applied by Keelan *et al.* (2008).

[3] It is worth highlighting that the results show smaller standard errors in the IHS heteroscedastic tobit model than do the homoscedastic and the heteroscedastic ones of the log dependent variable model.

As expected firm size has a positive and statistically strong impact on a firm's decision to cooperate, whatever the kind of collaboration. Larger firms are more likely to have the threshold size and technical capability to enter R&D partnerships than small firms do.

Similarly, in line with the idea that firms have to be engaged in their own research in order to be able to understand and absorb external research, the results indicate that researchers are important in determining the level of external collaboration in research. An increase in stable intramural R&D would result in increases in its marginal absorptive capacity.

The level of capital intensity, the financial constraint variable and the export status do not seem to influence the decision on the level of cooperative R&D.

Obtaining a R&D subsidy has a positive and highly significant effect, suggesting that public R&D programmes help to mitigate barriers to cooperation (Busom and Ribas, 2007). Public grants not for R&D purposes are found to exert no statistically significant influence on collaboration. In the same way, the financial constraint status and the export dummy do not seem to be correlated with R&D collaboration.

The debt variable is negative and significant, implying that more indebted firms are less likely to engage in external R&D commitments. Innovative firms are shown to be significantly more inclined to collaborate in R&D projects.

As expected, the results suggest differences among sectors in the attitudes to cooperation, due to the different technological trajectories. Traditional 'supplier dominated', 'scale-intensive' and 'specialized equipment suppliers' industries are different from 'science based' firms. Their coefficients are, in fact, negative and strongly significant. Such firms are likely to rely more on innovative strategies based on the acquisition of innovation embodied in capital goods developed by external suppliers. By contrast the more high-tech ($PAVITT_4$) category tend to have a stronger propensity to participate in collaborative research.

The hypothesis that the estimated slope coefficients of the industry dummies are jointly zero can thus be safely rejected at one percent significance, confirming that there are differences in the intensity in R&D collaboration among industries. To further corroborate the consistency of the estimation results, a constrained model excluding the PAVITT industry dummies has also been estimated (table 3). In all three models the LR test supports the more informative industry variable model

(14.35, 24.72, 19.86 for the tobit, heteroscedastic tobit and HIS heteroscedastic tobit respectively).

It is worth recognising that if R&D subsidies are conditional on cooperation, there will be a positive correlation between subsidies and cooperation, and estimates of the effects of policy decisions will be inconsistent (Colombo and Garrone, 1996; Veugelers, 1997; Kaiser, 2002). Indeed a public agency is likely to decide whether or not to award a public grant depending on some characteristics of the firm or project. However, the Italian National law N. 46/82, the most important R&D grant awarded to the sample of firms used in this work, does not specifically require the applicants to engage in innovative activities jointly with other partners. Nevertheless, the possible endogeneity of this variable is investigated by performing a Durbin–Wu–Hausman test.

The variable *GRANT* is regressed on the same set of covariates, employing the total amount of industry grant per worker as an instrument that affects the potentially endogenous variable but has no significant effect on the $COLL_{R\&D}$ equation. The R&D equation is then regressed on the same set of covariates and the residuals from the first stage. Exclusions are the instrument, the export and industry dummies, as they do not significantly affect the collaboration equation (Davidson and MacKinnon, 1993). Since the coefficient of residuals is highly insignificant, the hypothesis that *GRANT* is correlated with unobserved factors can be rejected (Table 3).

It must be admitted that the variable researcher over employees might suffer from the same problem. Total R&D investments may increase if cooperation makes one's own R&D endowments more effective due to, for instance, incoming spillovers from simple information sharing among partners. Unfortunately the data do not allow one to identify a proper instrument for checking for potential endogeneity of R&D employees intensity. Nevertheless it is very plausible that the possible endogeneity problem is not too severe in this study. In fact the choice of such a variable, rather than R&D expenditure, was driven by such a worry. R&D expenditure captures differences in R&D equipment intensity or costs, while personnel indicates a more permanent component of a firm's R&D commitment, and is possibly less influenced by temporary joint research programmes. Furthermore, such variable refers to the initial period. For these two reasons simultaneity may be limited.

5 CONCLUSION

This paper is aimed at exploring the determinants for R&D cooperation in a sample of Italian manufacturing firms. From the methodological point of view, the study shows the importance of correcting for heteroscedasticity and non-normality when dealing with a large number of zero response data. Lagrange Multiplier and Likelihood ratio tests strongly support the Hyperbolic Sin Transformation specification employed in this work. However a limitation of this study is that it could not control for the duration of the cooperation. In fact, the data allows to observe whether or not firms are involved in R&D cooperation, but not when the partnerships started.

Unlike many other studies, this work uses continuous dependent variables to investigate the relative importance of the factors which affect R&D partnerships.

The estimation results indicate that firm size is a key variable for predicting whether a firm will engage in cooperative R&D. Larger firms are also more likely to have the absorptive capacity required to exploit the benefits of R&D cooperation better.

In line with previous research, this work provides evidence that the existence of a stable R&D structure is relevant for research cooperation. This variable supplies a proxy for a firm's absorptive capacity which is crucial in absorbing and utilizing extra-mural knowledge. This can be explained by the fact that one's own R&D department is very likely to reduce the risks and increase the probability of finding partners, particularly when the level of spillovers is high and a large absorptive capacity is required to absorb scientific knowledge.

In agreement with prior expectations, the effect of the innovation variable on collaboration is positive. Since innovative firm normally have a higher level of R&D expenditure they tend to be more inclined to share technological knowledge with external partners.

More indebted firms are less likely to engage in external R&D partnerships. This highlights the importance of a firm's financial structure in the dynamics of extra-mural research business commitments. The level of capital intensity, the financial constraint variable and the export status are shown to not have an influence on the decision to participate in cooperative R&D.

As expected the results show significant differences among sectors in the attitude to cooperation. This is largely explained by the different technological trajectories that characterize different industries. Science-based firms rely relatively more on external cooperation than do their counterparts in the supplier dominated, scale-intensive and specialized equipment suppliers sectors. Traditionally these latter rely more on innovative strategies based both on the acquisition of innovation embodied in capital goods developed by external suppliers and on receiving information and skills.

Finally, in terms of policy the results of this study suggest that public support specifically aimed at research activity plays an important and significant role in increasing a firm's willingness to share its know-how. This is in line with theoretical considerations on market failures in real and financial markets. As a result public financial support tends to have a positive influence on a firm's R&D spending and indirectly influences the propensity to co-operate in R&D. By contrast public financial support not specifically aimed at R&D does not have a statistically significant influence on collaboration.

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Table 1
Descriptive statistics

	Coll-firms obs: 591		Non-Coll-firms obs: 640	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
Employees (2001)	181.58	600.29	129.34	328.82
Private R&D per employee (€, triennium average)	2857.43	3875.91	2225.39	3161.43
R&D employees over total employees (€, 2001)	0.07	0.08	0.07	0.07
R&D collaboration intensity (€ per worker, triennium average)	1205.21	2334.25	0	0
Fixed capital per worker (€, 2001)	51.76	65.14	46.47	47.16
Bank credit over value added (€, triennium average)	0.64	2.11	0.76	0.84
RATION =1 if firm is credit rationed	0.07	0.25	0.06	0.24
GRANT R&D =1 if firm receives public R&D incentives	0.34	0.47	0.24	0.43
OTHER SUBSIDIES=1 if firm has received other types of public grants	0.2	0.4	0.14	0.35
INNOVATION=1 if firm has innovated	0.9	0.3	0.82	0.38
EXPORT=1 if firm has exported	0.89	0.31	0.88	0.32
$PAVITT_1$	0.43	0.5	0.44	0.5
$PAVITT_2$	0.13	0.33	0.16	0.36
$PAVITT_3$	0.37	0.48	0.36	0.48
$PAVITT_4$	0.07	0.26	0.04	0.2

Table 2

IHS Heteroscedastic Tobit: Determinants of R&D collaboration

	Dependent variable: collaborative R&D intensity	
Variables	Coef.	(Std. Err.)
$LogEMP_{(2001)}$	68.2***	18.02
$LogEMP_{R\&D\text{-}EMPL(2001)}$	71.51***	15.42
$Log(K_{INT})_{2001}$	14.66	17.05
$DEBT\text{-}AV_{RATIO}$	-16.73*	9.63
$RATION^{(Ж)}$	78.93	70.07
$GRANT_{R\&D}^{(Ж)}$	147.03***	37.94
$GRANT_{OTHER}^{(Ж)}$	61.00	43.64
$INNOV^{(Ж)}$	136.08***	53.08
$EXPORT^{(Ж)}$	-8.14	58.14
$PAVITT_1^{(Ж)}$	-270.66***	75.91
$PAVITT_2^{(Ж)}$	-368.57***	86.02
$PAVITT_3^{(Ж)}$	-263.30***	75.89
cons	-75.29	123.25
Heteroscedastic terms		
$LogEMP_{2001}$	-0.09***	0.03
$LogEMP_{R\&D\text{-}EMPL(2001)}$	0.07***	0.03
cons	6.82***	0.14
IHS term	0.003***	0.000
# of obs. 1231 640 left-censored 591 uncensored		
Log likelihood	-5458.088	
Test on joint significance of industry dummies χ^2 (3)	18.43 ***	

Standard errors in parentheses.
(***, **, *) indicate a significance level of 1%, 5%, 10%
$^{(Ж)}$ dummies
Linear-log-form estimate: 1% change in the regressors leads to $\beta_i/100$ unit change in the endogenous variable.

Table 3: testing results

Tests on HIS tobit:	
Lagrange multiplier test for heteroscedasticity H_0: Homoscedasticity	LR: 689.55 Prob > $\chi^2_{(2)}$= 0.000 Reject H_0
Conditional moments test for non-normality H_0: Normality	CM: 229.22 Prob > χ^2 = 0.000 Reject H_0
Likelihood ratio test for IHS heteroscedastic tobit model: IHS heteroscedastic tobit *versus* tobit model	LR: 695.42 Prob > χ^2 = 0.000 Reject H_0 in favour of IHS tobit
Likelihood ratio test for IHS heteroscedastic tobit model: IHS heteroscedastic tobit *versus* heteroscedastic tobit model	LR: 805.44 Prob > χ^2 = 0.000 Reject H_0 in favour of IHS tobit
Tests on the PAVITT industry variable model	
Likelihood ratio test for tobit model: Industry variable model *versus* constrained model	LR: 14.35 Prob > χ^2 = 0.002 Reject H_0 in favour of industry variable model
Likelihood ratio test for heteroscedastic tobit model: Industry variable model *versus* constrained model	LR: 24.72 Prob > χ^2 = 0.000 Reject H_0 in favour of industry variable model
Likelihood ratio test for IHS heteroscedastic tobit model: Industry variable model *versus* constrained model	LR: 19.86 Prob > χ^2 = 0.000 Reject H_0 in favour of industry variable model

Table 4:
Durbin–Wu–Hausman (augmented regression test) for endogeneity:

Equation	Estimated coefficient of residuals	t value
COLL R&D	.03	0.07
Hy: coeff. residuals = 0		
F (1, 345) = 0.01 Prob > F = 0.942		
Since the coefficient of residuals is highly insignificant the hypothesis of exogeneity cannot be rejected		

APPENDIX A.

Table A.1

Determinants of R&D collaboration

	Dependent variable: collaborative R&D intensity			
	Homoscedastic Tobit		Heteroscedastic Tobit	
Variables	Coef.	(Std. Err.)	Coef.	(Std. Err.)
$LogEMP_{2001}$	155.22*	88.96	381.62***	70.06
$LogEMP_{R\&D\text{-}EMPL(2001)}$	421.43***	69.33	166.91**	69.41
$Log(KAPINT)_{2001}$	-11.89	86.10	10.79	75.96
$DEBTAV_{RATIO}$	-30.74	50.26	-47.38	41.01
$RATION^{(Ж)}$	670.92*	351.98	406.34	306.51
$GRANT_{R\&D}^{(Ж)}$	594.21***	190.80	499.88***	160.98
$GRANT_{OTHER}^{(Ж)}$	223.66	227.84	301.30*	185.82
$INNOV^{(Ж)}$	798.41***	268.64	512.75**	232.74
$EXPORT^{(Ж)}$	-465.10*	284.90	-553.00**	260.45
$PAVITT_1^{(Ж)}$	-980.03***	376.84	-1376.99***	318.96
$PAVITT_2^{(Ж)}$	-1612.14***	428.17	-1783.29***	351.80
$PAVITT_3^{(Ж)}$	-1033.39***	380.01	-1322.38***	318.35
cons	227.81	617.30	-709.06	533.92
Heteroscedastic terms				
$LogEMP_{2001}$			-0.16***	0.03
$LogEMP_{R\&D\text{-}EMPL(2001)}$			0.14***	0.02
cons			8.82***	0.11
# of obs. 1231 640 left-censored 591 uncensored				
Log likelihood	-5860.81		-5805.80	
Test on joint significance of industry dummies χ^2 (3)	14.42 ***		26.04***	

$^{(Ж)}$ dummies

(***, **, *) indicate a significance level of 1%, 5%, 10%

Table A.2

Determinants of R&D collaboration

	Dependent variable: Log of collaborative R&D intensity			
	Homoscedastic Tobit		Heteroscedastic Tobit	
Variables	Coef.	(Std. Err.)	Coef.	(Std. Err.)
$LogEMP_{2001}$	0.55***	2.97	0.76***	0.18
$LogEMP_{R\&D\text{-}EMPL(2001)}$	0.83***	0.15	0.76***	0.14
$Log(KAPINT)_{2001}$	0.16	0.18	0.15	0.18
$DEBTAV_{RATIO}$	-0.18*	0.11	-0.19*	0.11
$RATION^{(Ж)}$	0.48	0.75	0.57	0.75
$GRANT_{R\&D}^{(Ж)}$	1.35***	0.40	1.38***	0.40
$GRANT_{OTHER}^{(Ж)}$	0.84*	0.48	0.88*	0.47
$INNOV^{(Ж)}$	1.89***	0.56	1.80***	0.56
$EXPORT^{(Ж)}$	0.08	0.60	0.13	0.62
$PAVITT_1^{(Ж)}$	-1.70**	0.80	-1.95**	0.78
$PAVITT_2^{(Ж)}$	-2.60***	0.90	-2.82***	0.88
$PAVITT_3^{(Ж)}$	-1.73**	0.81	-1.94**	0.79
cons	-0.67	1.30	-1.51	1.33
Heteroscedastic terms				
$LogEMP_{2001}$			-0.09	0.03
$LogEMP_{R\&D\text{-}EMPL(2001)}$			/	/
cons			2.12	0.14
# of obs. 1231 640 left-censored 591 uncensored				
Log likelihood	-2322.06		-2318.15	
Test on joint significance of industry dummies χ^2 (3)	8.36**		10.36**	

$^{(Ж)}$ dummies

(***, **, *) indicate a significance level of 1%, 5%, 10%

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