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HETEROGENEITY IN R&D COOPERATION: AN EMPIRICAL INVESTIGATION

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Heterogeneity in R&D Cooperation:
An Empirical Investigation

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Abstract

This work explores the roles of potential simultaneity and heterogeneity in determining firms' decisions to engage in R&D collaboration, using a sample of Italian manufacturing firms. Partnerships with other firms, research institutions, universities and other small centres are considered jointly by applying a multivariate probit specification. This allows for systematic correlations among different cooperation choices. The results support the hypothesis that the four cooperation decisions are interdependent. The decision to cooperate in R&D differs significantly depending on the cooperation options. Public support, the researcher intensity and the size are all of importance in determining R&D alliance strategies.

Keywords: Applied Econometrics; R&D cooperation; firm behaviour.

JEL Classification: C24; D21; O31; O32.

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1 Introduction

In recent years investment in research and development has been widely recognised as an important factor in driving innovation and economic growth. Firms have spent considerable resources on R&D, in order to improve their innovations and their technological skills by means of new R&D organisational practices and external partnerships. Cooperation has become crucial in the innovation process particularly in sectors where innovation is becoming the more and more complex. Indeed for an increasing numbers of firms internal R&D is no longer the only way to innovate and they have started technological collaboration with a variety of partners. Alliances with other firms in R&D can allow them to access external resources and stimulate knowledge transfer, resource exchange, and organizational learning (Becker and Dietz 2004). Firms also use R&D partnerships to access information and build R&D networks. Aiello and Cardamone (2008), for instance, show that R&D spillovers have a positive effect on firms' production. Aschhoff and Smidt (2008) investigate the effect of past R&D cooperation on a firm's current innovative performance and find that joint research activities have a positive effect on the success of process innovations.

For all these reasons frequent and heterogeneous knowledge exchanges have been a crucial driving force for the growing number of domestic and international technological alliances in recent decades. R&D partnerships have attracted political and academic interest. National governments and the European Union have pursued policies to support research which are clearly aimed at stimulating technological partnerships.

This work investigates the determining factors that influence the decision of firms to undertake cooperative research, and checks for possible interdependence among different research alliance strategies. The analysis is carried out on a sample of Italian manufacturing firms. Italy is one of the advanced countries which lags behind both in terms of R&D spending and the amount of R&D collaboration. Hence from this perspective Italy is a litmus test for R&D related issues.

Most previous research has investigated the frequency of R&D collaboration, in order to identify which characteristics result to be more beneficial to R&D alliances (Fritsch and Lukas 2001; Narula 2002). Some scholars have focused particularly on the simultaneous relationship between R&D partnerships and intramural research activities. They generally conclude that the level of internal R&D investment still plays an important role in determining whether a firm will participate in technological alliances (Becker and Dietz 2004; Cassiman and Veugelers

2002; Colombo and Garrone 1996; Veugelers 1997). This line of argument is explicitly followed in this work.

The econometric framework is based on the multivariate probit specification. This allows to explore whether firms consider different cooperation agreements simultaneously in order to maximise results. By applying a system method of estimation for dichotomous variables this model is suitable for estimating how the characteristics that influence the firm's decision affect the likelihood of opting for a given strategy. Several authors have recently highlighted the possible complementarity between various forms of R&D partnership (Belderbos et al. 2004,a; Veugelers and Cassiman, 2003).

The results from the multivariate analysis support the idea of interdependence between the four cooperation decisions considered (non-zero correlations in the stochastic components that refer to the different types of R&D cooperation). To be more precise, correlations indicate complementarity among R&D collaboration strategies when there are universities among the partners, while they suggest substitution effects between partnership with small centres, institutional research centres and other firms. Coefficients also differ sensibly across the equations, revealing heterogeneity in the cooperation strategies, and this supports the use of of these disaggregated R&D cooperation types instead of one aggregated R&D cooperation indicator.

The analysis indicates that participating in a public R&D programme has a positive and statistically significant impact on a firm's decision to cooperate. Firms with higher absorption capacity, expressed here as the number of R&D workers over total employees, are more inclined to participate in research partnerships. This supports the hypothesis that internal technological skills are crucial for taking advantage of externally acquired knowledge. The results also indicate that firm size has a positive impact on the choice of strategy. Lastly, receiving production inputs and services from external partners is significantly important only for the group of firms collaborating with other firms suggesting that industrial networks may facilitate intra-firms collaboration.

2. Motivation for R&D cooperation

Recent academic work shows that the objectives and determining factors in research alliances may differ, depending on the characteristics of the R&D and the partners. Several arguments have been put forward to explain what motivates firms to participate in joint R&D projects. The most common reasons mentioned in theoretical and empirical literature are: a) knowledge spillovers and b) cost/risk sharing. The motivation may be either one of these or a combination of the two (Tether 2002).

For spillovers, one must distinguish between incoming and outgoing spillovers. Incoming spillovers depend on whether the firm can absorb and use knowledge produced by other firms. In such cases partnerships may result in superior learning efficiency. In these models access to complementary knowledge (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 absorb, efficiently, resources from the partner in which the host firm is weak (Hagedoorn et al. 2000).

Outgoing spillovers are those where internally generated knowledge flows out and benefits other firms. However spillovers are greatly affected by their heterogeneity and the appropriability conditions. For R&D activities which are close to basic research, for instance, the spillover level tends to be generally high. According to Belderbos et al. (2004,a) in collaborations between competitors the distance in basic research is less than that in collaborations with suppliers or customers. In joint research activities between universities and research institutes the distance is even less and thus the spillover level is highest.

Nevertheless spillovers can be a problem if the firm does not have appropriate mechanisms to protect their know-how easily. However high appropriability constrains potential free-riding and generally leads to low flows of spillovers. To be more precise, alliances with competitors tend to have the highest appropriability following that with institutional partners and vertical collaboration.

Legal protection and strategy protection may be a way of preventing rivals from accessing commercial information. From the strategic perspective, R&D partnerships may be of great help for internalising information (Steurs 1995; De Bondt, 1996; Cassiman and Veugelers 2002; Belderbos et al. 2004a; Lopez, 2008) and for overcoming market failures in the innovation process (D'Aspremont and Jacquemin, 1988; Kamien et al. 1992; De Bondt, 1996).

Research cooperation is often seen as a way of sharing share risks and costs, which are usually high at the R&D stage, and also as a way of exploiting economies of scale and scope in R&D (Sakakibara 1997; Beath et al. 1998; Tether, 2002). Risks and costs hinder R&D, and collaboration may be one way of overcoming this. A firm's ability to reduce costs also depends on several factors such as the type of R&D, complementarities, size, and the intensity of the R&D. The more R&D activities are related to basic research, the higher the reduction in costs is likely to be (Kaiser, 2002).

Both knowledge spillovers and cost/risk reduction are closely related to the absorptive capacity of the firms. Many studies have emphasized that firms must be capable of absorbing and using knowledge effectively if they are to benefit from external knowledge (Cohen and Levinthal, 1989; Griffith et al. 2004; Bönte and Keilbach, 2005). A firm's experience of past participation in collaboration projects may encourage them to repeat the experience as well as making them more technically capable of doing so. This is crucial for assimilating and exploiting the external available knowledge (Cohen and Levinthal, 1989; Negassi, 2004). This latter depends, in turn, on the intensity of its R&D and the level of human capital.

A firm engaged in R&D can choose between different strategies. It can generate the R&D internally or in relationship with outside organizations. In the latter case, it may choose to purchase technical information or to undertake research projects jointly with external partners. Several papers have studied the substitutability or complementarity of internal and external R&D (Aurora and Gambardella, 1990; Cohen and Levinthal, 1990; Veugelers and Cassiman, 1999). In particular Belderbos et al. (2004, a) found that the factors that determine whether or not a firm decides to collaborate in R&D with external parties varied considerably.

3 Data and variables 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, since only a fraction of the firms overlap in the surveys, access to longitudinal data is constrained by the loss of a considerable amount of observations on the dependent variables employed in this work. Hence only the 2001-2003 survey is used in the empirical application. This obviously prevents from including long-term considerations in the analysis.

The survey contains information on the total amount of R&D investment and the amount of R&D investment dedicated to projects with external partners. This latter information is used to construct the variables of observation (dependent) considered in this work which are four dichotomous variables referring to four collaborative groups namely alliances with other firms ($COLL_{FIRMS}$), research institutions ($COLL_{CENTRES}$), universities ($COLL_{UNI}$), and other small centres ($COLL_{OTHER}$). These latter are small private research centres and professionals who support firms in projecting and designing products and/or processes.

There are three questions in the survey that can be used to evaluate a firm's ability to access 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. This variable is used in the empirical analysis as a proxy for a firm's financial distress.

3.1 Variables affecting cooperation and background

Among the regressors the model includes a dummy variable indicating 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. As a result, public funding tends to have a positive influence on firms' R&D spending (Carboni, 2011) and an indirect influence on the propensity to co-operate in R&D (Veugelers, 1997), since they might help to mitigate barriers to cooperation (Busom and Ribas, 2007).

Since participation and R&D collaboration may be determined simultaneously, there could be a positive correlation between subsidies and cooperation, due to a simultaneous relationship between the two rather than as a result of subsidies. Estimates of the effects of policy will be inconsistent unless this issue is properly considered (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 certain characteristics of the firm or project. However the Italian National law N. 46/82, which covers the most important R&D grants 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.

Despite this it is tested the possible endogeneity of this variable by performing a Durbin–Wu–Hausman test. Hence the R&D collaboration variable ($COLL_{ALL}$) is regressed on the set of covariates there will be used in the multivariate analysis below, 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 $COLL_{ALL}$

equation. This latter is then regressed including the same set of covariates and the residuals from the first stage. Exclusion restrictions are: the instrument, the export and the debt dummies, as they do not significantly affect the collaboration equation (Davidson and MacKinnon, 1993). The results of the Hausman test shown in the appendix (table A.1) suggest that the R&D subsidies variable is not endogenous to research partnerships.

A measure of stable R&D commitment is included as an explanatory variable. Such variable is the number of R&D workers as a percentage of total workers and it is expressed in logarithm ($LogEMP_{R\&D\text{-}EMPL(2001)}$). This provides a proxy for a firm's engagement in R&D and approximates to a firm's human capital intensity. A firm's knowledge capital is a crucial intangible asset in R&D cooperation partnerships. Many studies have emphasized that to absorb external knowledge, an effective absorptive capacity which is able to understand and use this knowledge is fundamental (Cohen and Levinthal, 1989; Griffith et al. 2004). Fritsch and Lukas (2001), Belderbos et al. (2004,a) and Hernan et al. (2003) found that firms engaged in R&D cooperation tend to have a higher share of R&D employees.

A stable R&D structure has a positive influence on the propensity of firms to cooperate in R&D projects (Cohen and Levinthal, 1989; Kleinknecht and Reijnen, 1992; Veugelers, 1997; Bayona et al. 2001). This is a factor that reduces risks while increasing the probability of finding partners. Particularly when the level of spillovers is high, cooperation research is associated with higher levels of R&D expenditure than competitors (D'Aspremont and Jacquemin, 1988; Kamien et al. 1992). For example, Piga and Vivarelli (2004) found that the decision to engage a R&D partnership is linked to the firm's prior choice to carry out its own R&D activity and Leiponen (2001) suggested that a very large absorption capacity might be required when absorbing scientific knowledge from universities.

Admittedly, also this variable might be simultaneously determined with collaboration, since collaboration can produce positive spillovers which may in turn stimulate firms to invest more in R&D. Nevertheless, R&D staff represents only a small proportion of all the workers in the firms considered (6-8 per cent). Hence, even though collaboration can have some influence on the number of R&D employees, it is very possible that this change is relatively small compared to the number of all workers (Almus and Czarnitzki, 2003). Furthermore, since they represent a more long-term expenditure than the R&D budget or intensity, they are likely to be less influenced by collaboration, which may well be only temporary.[1] These two arguments may reduce the severity of the potential endogeneity between collaboration and both the receipt of R&D subsidies and the researchers intensity.

Following the mainstream literature, firm size is included as an explanatory variable. This variable is expressed as the logarithm of the number of employees and refers to the initial year ($LogEMP_{(2001)}$). Most empirical studies show the importance of firm size in predicting whether a firm will engage in cooperative R&D (Sakakibara, 1997; Veugelers, 1997; Bayonaet al. 2001; Fritsch and Lukas, 2001; Miotti and Sachwald, 2003). Larger firms are also more likely to have the absorptive capacity necessary for benefitting more from R&D cooperation. However the relationship between firm size and joint research activities is not necessarily unambiguous. The effect of size may vary according to the partners and purposes of the partnership (Kleinknecht and Reijnen, 1992; Tether, 2002).

Capital intensity, measured as physical assets per employee and expressed in logarithmic terms ($Log(K_{INT})$) is used to control for the fact that firms in more technology-intensive sectors may be more likely to engage in R&D partnerships than firms in more labour-intensive sectors.

An export dummy (*EXPORT*) is included in the analysis. It is often claimed that firms that compete in foreign markets are more likely to innovate than others (Arnold and Hussinger, 2005) and hence more likely to collaborate. There may also be indirect effects, due to the richer network of customers, suppliers or competitors that exporting firms may have access to, which may make cooperation easier.

Two controls for potential financial constraints are also included in the analysis. Financial constraints (*RATION*) are in general a good candidate for explaining under-investment in research and thus may possibly affect the amount of cooperative R&D. A measure of indebtedness is also considered in order to control for a firm's ability to find sources of finance to support the costs of R&D($DEBT_{2001}$). It is the

[1] The decision to take part in an external research relationship and the decision on the R&D budget may be determined simultaneously. That is, R&D investments may increase if cooperation makes one's own R&D activities more efficient. Colombo and Garrone (1996), Veugelers (1997), and (Kaiser, 2002), for instance, find that using R&D intensity as an explanatory variable may produce endogeneity problems when exploring the choice of R&D cooperation. By contrast, Miotti and Sachwald (2003), and Cassiman and Veugelers (2002), in their study of French and Belgian firms, find that permanent R&D did not influence the firms' propensity to cooperate formally with vertically related firms.

ratio of debt to banks over total average debts as an indicator of the firm's financial structure and refers to the initial period. $GRANT_{OTHER}$ is a dummy =1 if the firm received public grants other than R&D.

A binary variable indicating whether a firm acquires inputs and services from outsourcing agreement (EXT_{SOU}) is included among the regressors. The effect of such variable on collaboration is expected to be positive. Firms relying on outsourcing agreements for their production should find it easier to share technological knowledge with external partners since they can take advantage of the intra-industry distribution channels and contacts.

Finally, industry dummies are employed to control for potential sectoral systematic differences in cooperation. These are: traditional 'supplier dominated'($PAVITT_1$), 'scale-intensive'($PAVITT_2$), 'specialized equipment suppliers' ($PAVITT_3$), and 'science-based'($PAVITT_4$). The rationale for this is that there may be various aspects of technology such as technological opportunity, appropriateness, dynamic aspects and accumulation whose characteristics may differ among sectors. Hence, the attitude to R&D partnerships may be more positive in companies operating in sectors with relatively high R&D intensity. In addition in order to mitigate the simultaneity problem, wherever possible, variables refer to the initial period.

3.2 Descriptive statistics

Table 1 shows descriptive statistics for R&D non-collaborative firms and for the four collaborative groups considered in this work. A total of 1231 companies invested in research and 591 of these chose to co-operate in R&D.

R&D collaborative firms have more employees than non-collaborative ones, whatever the type of partnership. This is particularly true in the case of partnerships with centres and universities.

The same is true with regard to the level of research intensity (R&D expenditure per employee). Firms engaged in partnership with other firms and universities invested more (€ 3,663 and € 3,851 respectively). Interestingly, despite such differences, the percentage of researchers over total workers is very similar among all the groups.

Collaborative firms also have higher capital intensity while the ratio of debts over added value is similar among the five groups, with the exception of the $COLL_{FIRMS}$ which appear to be less indebted. Credit rationed firms are more frequent in the $COLL_{OTHER}$ group (9 per cent) and less in the $COLL_{UNI}$ group (4 per cent).

Public grants for R&D are not uniformly distributed among the firms. Collaborative firms make more use of public support than do non-collaborative ones. The $COLL_{FIRMS}$ and the $COLL_{UNI}$ group in particular benefit most (39% and 43% respectively). The same is true for non-R&D grants. Contrary to prior expectations, there is no difference in involvement in the export market between collaborating and non-collaborating firms. There emerge large differences concerning the outsourcing variable. Firms involved in research ventures show to be far more inclined to external acquisition of inputs and services whatever the type of collaboration.

When looking at the industry classes, it is worth noting that the 'high-tech' sector ($PAVITT_4$) and the 'scale-intensive' sector ($PAVITT_2$) are the least common among the firms in the sample and, with the exception of the $COLL_{OTHER}$ group (5 per cent), collaborating firms are always appreciably more technological than the non-collaborating ones (4 per cent). The 'traditional sector' ($PAVITT_1$) is the most common among the firms, ranging from 31 per cent to 47 per cent. 'Specialized equipment suppliers' ($PAVITT_3$) are the second most important group.

Bearing in mind that the two groups may also differ in their unobservable characteristics, the evidence from table (1) in support of the random hypothesis between collaborative firms and their non-collaborative counterparts is not unambiguous.

Among the 591 collaborating firms there are 161 firms which are involved in multiple R&D partnerships. Observing the combination of the various forms of collaboration (last four rows in table 1 and table 2), it emerges that $COLL_{FIRMS}$ are by far the most common (215 exclusive cases and 281 in total) and firms committed to this form of partnership tend to rely less on the remaining forms (12 per cent with research centres, 8 per cent with small private centres and 18 per cent with universities). $COLL_{OTHER}$ represents the second most common form (102 exclusive cases and 139 total). There are 96 firms engaged in two forms of alliance, 19 firms engaged in three types of collaboration and only 4 with all the four types of partnership considered.

4 Multivariate probit analysis

This section deals with the fact that firms may consider simultaneous different cooperation agreements in their maximization process. Possible complementarities between various forms of R&D collaboration have been recently highlighted by Veugelers and Cassiman, (2003) and Belderbos et al. (2004,a). The multivariate probit specification used here allows for systematic correlations between choices for different forms of cooperation. This model applies a system method of estimation for dichotomous variables. It is appropriate for estimating how the characteristics that influence the firm's decision affect the likelihood of opting for a particular strategy, although it is not able to distinguish between the two sources of correlation.

Theoretically such correlations may derive from complementarities or substitutabilities between different forms of cooperation. If there are correlations, the separate (probit) estimations of the cooperation decisions turn out to be inefficient. In such cases the multivariate limited dependent variable (multivariate probit) model on the binary decision of whether or not to engage in collaboration can be used.

More precisely, the following analysis explores the role of potential simultaneity and heterogeneity in determining firms' decisions to engage in the four forms of R&D collaboration described above ($COLL_{FIRMS}$, $COLL_{CENTRES}$, $COLL_{UNI}$ and $COLL_{OTHER}$). R&D firms may also choose no cooperation at all. Firms attempting to maximise profits select the cooperation strategy from the alternatives which is best suited to do this. The profit related to each strategy is an unobservable factor and is dependent on the specifics of the firm and industry. However, the firm's final choice can be observed from the dataset.

The type of collaboration chosen by the firm will most likely be determined by several factors such as the industry, the technological level of R&D projects, costs and the level of the firm's knowledge capital. Thus there might be differences in the various types of cooperative R&D.

In the sample used here there is no information about characteristics of the partners for each cooperative agreement. Nevertheless, it is very likely that cooperation agreements involve partners with different R&D intensity and motivations for the partnership. If a firm's purpose is to gain complementary assets and skills, asymmetric partnerships may be the best strategy. Conversely if the reason for cooperation is to internalize outgoing spillovers or to increase market share, symmetric partnerships may be more likely (Busom and Ribas, 2007). Firms with high-intensity R&D have a higher level of knowledge appropriation and are therefore less worried about the inherent risks of sharing knowledge that are part and parcel of partnerships.

The following details the specification of the multivariate probit model (MVP) that is used to fit the distribution of different collaboration-types. The model is computed for four binary choice equations equal to one if the firm is committed to any of the R&D partnerships described above.[2] Conditional on there being at least one

[2] Fritsch and Lukas (2001), distinguish between cooperation customers, suppliers, other firms and public funded research institutions and find some evidence for the notion that the propensity to cooperate with different kinds of partners is driven by the same factors.

form of cooperation, it can be observed any $2^{COLL_{i,M}} - 1$ combinations of the M different claim-types. There are then four dependent variables $COLL_{i,M}$ and the MVP can be specified as a linear combination of deterministic and stochastic components:

$$COLL_{i,M} = \begin{cases} 1 \quad if \;\; \beta_M X'_{i,M} + \omega_{i,M} > 0 \\ 0 \quad \text{otherwise} \qquad\qquad i = 1,.....,N; \quad M = 1,..,4 \end{cases} \tag{1}$$

i=1,....,N represent the independent observations. $X_{i,M}$ are the explanatory variables which do not differ for each collaboration-type (the deterministic component) and β_M are parameters, including an intercept, to be estimated. ω_{iM} are error terms distributed as multivariate normal, each with a mean of zero, and variance–covariance matrix Σ. The stochastic component may be thought of as consisting of those unobservable factors which explain the marginal probability of making a type M collaboration: $\omega_{i,M} \sim N\,(0, \Sigma)$.

Σ is the covariance matrix with values of 1 on the leading diagonal and because of symmetry in covariances, it necessarily has correlations $\varrho_{jM}=\varrho_{Mj}$ as off-diagonal elements:

$$\begin{matrix} 1 & \rho_{12} & \cdots & \rho_{14} \\ \rho_{21} & 1 & \cdots & \rho_{24} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{41} & \rho_{42} & \cdots & 1 \end{matrix} \tag{2}$$

ϱ_{jM}, represents the unobserved correlation between the stochastic component of jth and Mth types of collaboration. It is worth underlining that this covariance matrix is similar to that of the multinomial probit, except the variances here are normalized to unity.

The rational for the joint estimation of correlated collaboration-types is in the possibility to estimate the joint probabilities of the outcomes. The error terms may be correlated because of omitted variables in the choice process. If such a possibility is neglected, for example by running separate probit equations, the estimators are likely to be inefficient. Actually what is at stake is the joint probability of possible non-independent outcomes. If there is dependence, the estimate picks some bivariate joint distribution where a coefficient (*rho*) measures the extent to which the two distributions are correlated. The estimate includes the set of explanatory variables of the four equations in order to check if their impact on the R&D partnership strategies considered is different.

In the specific case of four choices M=4, the quadrivariate probit case, the log-likelihood function for a sample of N independent observations is given by:

$$L = \sum_{i=1}^{N} w_i \log \Phi_4 (\mu_i; \Omega) \tag{3}$$

where w_i is an optional weight for observation i= 1, . . . , N. Φ_4 (.) is the quadrivariate standard normal distribution with arguments μ_i and Ω, where

$$\mu_i = (K_{i1}\, \beta_1'\, X_{i1},\ K_{i2}\, \beta_2'\, X_{i2},\ K_{i3}\, \beta_3'\, X_{i3},\ K_{i4}\, \beta_4'\, X_{i4}) \tag{4}$$

with $K_{iM} = 2^{\mathrm{COLL}_{i,M}}-1$ for each i, and M=1, ..,4. Matrix Ω has constituent elements Ω_{jM}, where:

$$\begin{aligned}
&\Omega_{MM} = 1 \text{ for M} = 1, \ldots, 4\\
&\Omega_{21} = \Omega_{12} = K_{i2}\, K_{i1}\, \rho_{21}\\
&\Omega_{31} = \Omega_{13} = K_{i3}\, K_{i1}\, \rho_{31}\\
&\Omega_{32} = \Omega_{23} = K_{i3}\, K_{i2}\, \rho_{32}\\
&\Omega_{41} = \Omega_{14} = K_{i4}\, K_{i1}\, \rho_{41}\\
&\Omega_{42} = \Omega_{24} = K_{i4}\, K_{i2}\, \rho_{42}\\
&\Omega_{43} = \Omega_{34} = K_{i4}\, K_{i3}\, \rho_{43}
\end{aligned} \tag{5}$$

In the empirical analysis the Geweke-Hajivassiliou-Keane (GHK) smooth recursive conditioning simulator is used to compute the maximum likelihood function. This also offers options for cross-equation tests and restrictions in parameters (Böorsch and Hajivassiliou, 1993; Geweke et al. 1997; Hajivassiliou et al. 1996). The results are obtained with a Stata routine and are based on 200 random draws from the truncated standard normal distribution (Cappellari and Jenkins, 2003).

The GHK simulator is based on the fact that a multivariate normal distribution function can be represented as the product of sequentially conditioned univariate normal distribution functions. The "mv probit" command estimates M-equation probit models by the simulated maximum likelihood method (SML). The off-diagonal elements in the variance-covariance matrix of the cross-equation error terms are correlations that have to be estimated (ϱ_{jM}). "mvprobit" uses the GHK simulator to evaluate the M-dimensional normal integrals in the likelihood function. For each observation, a likelihood contribution is calculated for each replication, and the simulated likelihood contribution is the average of the values obtained from all the replications. The simulated likelihood function for the whole sample is then maximized using maximum likelihood methods. The number of draws specifies the number of random variates drawn when calculating the simulated likelihood.

This simulator represents an accurate tool to compute the multiple integrals in multivariate probit models with more than two dependent variables. Due to these multiple integrals the maximum likelihood method cannot be applied so that the incorporation of the simulator into the maximum likelihood method can be used for the parameter estimation.

4.1 *Estimation results*

Table (3) shows the results of the multivariate probit.[3] The correlation coefficients of the equation error terms (*rho*) in the multivariate probit are statistically significant except for the $COLL_{CENTRES}$-$COLL_{FIRMS}$ coefficient. This supports the hypothesis of interdependence between the four cooperation decisions considered in this sample of 1231 Italian firms. Interestingly, when there are universities among the partners, the sign of the correlation for the equation error terms coefficients is always positive, indicating complementarities among R&D collaboration strategies.

Correlations become negative for the remaining combinations, suggesting substitution effects between partnership with small centres, and with both institutional research centres and other firms. Coefficients also differ appreciably across the equations, revealing that the cooperation strategies are quite heterogeneous, hence the appropriateness of the disaggregate cooperation decision analysis. The robustness of the model is checked by applying the Wald test on the hypothesis that the four equations have equal slope coefficients (table A.2).[4] The test allows to reject the null hypothesis suggesting that the four cooperation strategies considered in the analysis are heterogeneous enough and it is appropriate to consider them separately in this sample (Fritsch and Lukas, 2001; Janz et al. 2003).

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[3]Alternatively, the cooperation decision can be specified as a sequential process where firms decide whether they cooperate or not in the first step and successively decide which form of cooperation. However, a sequential process would imply that the profits of cooperation strategies at the second stage do not influence cooperation decision of the first stage which does not seem to be realistic (Bonte and Keilbach, 2005).

[4]Given the strong heterogeneity on the variable coefficients the test is carried out on pair wise comparisons.

The analysis shows that participating to a public R&D programme has a positive and statistically significant impact on a firm's decision to cooperate with universities and other firms, although it does not affect the two other forms of partnership. This result is even more significant in its implications for government policies, especially when one considers that the research incentives studied in this work do not explicitly require any prior joint research activity.

The researchers intensity measure positively affects the probability of partnerships but not in the case of collaboration with research centres. Apart from this latter case, which is somewhat surprising, the results confirm that stable research expenditure may be an incentive for firms to share the risks and costs of R&D activities with external partners.[5] This supports the hypothesis that there is a positive interaction between internal technical capability and collaboration with external partners.

Firm size has a positive and significant impact on the choice of a strategy with the exception of partnerships with small centres. The capital intensity variable does not offer a clear cut off. It is negative for alliances with small centres, positive for universities and non-significant for the other two. Being credit rationed, export oriented or receiving other forms of public support have no impact on their choice of strategy.

Interestingly, the effect of the outsourcing variable on collaboration is positive only for partnership with other firms. This seems to support the hypothesis that firms relying on outsourcing agreements for their production can take advantage of the intra-industry network they are part of. For the other forms of collaboration outsourcing shows to be highly insignificant.

Finally, industry dummies suggest that there are some sectoral differences in all the equations with the exception of partnerships with small centres. To be more precise, the analysis shows that high-tech and also mid-high-tech firms are more keen to participate in R&D partnerships than do firms in less technologically advanced sectors (coefficients are always negative). Differences in the probability of R&D collaboration among industries are confirmed by the test of joint significance of the industry dummy variables.

For comparison, individual univariate probit results are also reported in the appendix (table A.3). There is only a small difference in the coefficients when compared to the multivariate results. This can be

[5] It is worth noting that Miotti and Sachwald (2003) and Cassiman and Veugelers (2002) find that a firm's permanent R&D does not affect its propensity to cooperate with vertically related firms.

explained by the fact that the correlations between the equation error terms (*rho*) in the multivariate probit estimate, though almost all are significant, are relatively small in size. Nevertheless the Likelihood Ratio test confirms the superiority of the MVP over the single independent probit model ($\chi^2_{(12)}$=58.302; Prob>$\chi^2_{(12)}$=0.000). The same table also depicts the results for the aggregated group of firms with at least one R&D cooperation ($COLL_{ALL}$) and further confirms the hypothesis of heterogeneity in collaboration.

5 Concluding remarks

This work presents empirical evidence on the determining factors for firms' R&D cooperation strategies, based on a sample of 1231 Italian manufacturing firms. Four types of collaboration are considered jointly: collaboration with other firms, with research institutions, universities and other small centres. A multivariate probit model is employed to account for the fact that such firms may consider the various forms of collaboration simultaneously. This allows for systematic correlations between choices of different forms of cooperation and allows for the fact that firms may consider different cooperation agreements simultaneously.

The results support the idea of interdependence between the four cooperation decisions considered in this sample. In particular, when there are universities among the partners there are significant correlations between the equations in the model, which indicates that the various R&D cooperation decisions tend to be viewed by the firms as complementary. Correlations become negative for the remaining combinations, which suggest that there is a substitution effect between partnership with small centres, and with both institutional research centres and other firms.

The analysis also shows that that determining factors for R&D cooperation differ significantly across the cooperation options considered, which suggests that the cooperation strategies are quite heterogeneous. This reinforces the appropriateness of the multivariate analysis used in this work.

Estimation results show that receiving public R&D support has a positive impact on a firm's decision to cooperate with universities and other firms, while it does not affect the two other forms of joint research activity. Larger numbers of researchers increases the probability of partnerships, except in the case of collaboration with research centres. Apart from this latter case, this essentially confirms the idea that stable R&D activity might encourage firms to share the risks and costs of research. This is in line with the idea that an effective absorption capacity is required to understand and use effectively knowledge coming from external partners.

Firm size has a positive impact on the choice of a strategy, with the exception of partnerships with small centres, while the capital intensity variable does not supply a clear cut off point. Credit constraints, export orientation and being the recipient of other forms of public support have no impact on the choice of collaboration strategy. Finally industry differences emerge in all the equations, with the exception of partnership with small centres.

Although the cross-sectional structure of the data does not allow long term considerations, the analysis supplies some implications for policy. In particular, public aid specifically aimed at research activity plays an important and significant role in increasing a firm’s willingness to share its know-how. 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. In the sample of Italian firms used here, public grants appear to be significantly influential in strengthening both the private-private (with other firms) and private-public (with universities) relationships. This may represent a crucial competitive condition in research activity. From this perspective it can represent an important tool to help firms to overcoming their financial constraints deriving from market failures in real and financial markets. By contrast public financial aid not specifically aimed at R&D does not have a statistically significant influence on collaboration supporting the need of dedicated R&D public policy to incentivate joint research activity.

Lastly, particularly considering the low commitment to R&D and innovation in Italy and the substantial dominance of small-medium sized enterprises, significant incentives to research and policies aimed at stimulating mergers appears to be strongly desirable.

Table 1: variables and descriptive statistics (total # of firms: 1231; # of collaborating firms: 591[(*)]

Variable	NO-*COLL* obs: 640	$COLL_{ALL}$ obs: 591	$COLL_{CENTRES}$ obs: 142	$COLL_{FIRMS}$ obs: 303	$COLL_{OTHER}$ obs: 149	$COLL_{UNI}$ obs: 158
	mean (s.e.)	mean (s.e.)	mean (s.e.)	mean (s.e.)	mean (s.e.)	mean (s.e.)
Continuous:						
EMP_{2001}= number of employees (2001)	129.34 (328.82)	182.00 (600.29)	234.16 (429.48)	207.21 (776.74)	132.66 (269.01)	263.58 (463.22)
R&D per worker (triennium average)	2517.41 (3607.41)	2857.43 (3875.91)	3225.8 (4016.21)	3663.75 (4386.01)	2957.97 (3776.79)	3851.01 (4272.75)
$COLL\text{-}R\&D_{INT}$= R&D collaboration intensity (€ per worker, average 2001-03)	0	1205.21 (2334.25)	1019.08 (1614.39)	1422.82 (2815.39)	961.13 (1571.57)	1169.12 (1754.37)
$EMP_{R\&D\text{-}EMPL(2001)}$=R&D employees over total employees (€, 2001)	0.07 (0.07)	0.07 (0.08)	0.06 (0.07)	0.07 (0.08)	0.08 (0.09)	0.07 (0.08)
$KAPINT_{2001}$= fixed capital per worker (€, 2001)	46.47 (47.16)	51.76 (65.14)	54.17 (65.93)	51.12 (63.98)	47.08 (63.19)	64.61 (84.34)
$DEBT_{AVY}$= Bank credit over value added (€, average 2001-03)	0.76 (0.84)	0.64 (2.11)	0.7 (0.59)	0.55 (2.87)	0.72 (0.71)	0.8 (0.71)
Dummies:						
RATION =1 if firm is credit rationed (average 2001-03)	0.06 (0.24)	0.07 (0.25)	0.06 (0.24)	0.07 (0.25)	0.09 (0.28)	0.04 (0.19)
$GRANT_{R\&D}$ =1 if firm receives public R&D incentives (average 2001-03)	0.24 (0.43)	0.34 (0.47)	0.3 (0.46)	0.39 (0.49)	0.32 (0.47)	0.43 (0.5)
$GRANT_{OTHER}$ =1 if firm has received other types of public grants (average 2001-03)	0.14 (0.35)	0.2 (0.4)	0.15 (0.36)	0.2 (0.4)	0.21 (0.41)	0.23 (0.42)
EXPORT=1 if firm has exported (average 2001-03)	0.88 (0.32)	0.89 (0.31)	0.89 (0.31)	0.89 (0.31)	0.91 (0.28)	0.89 (0.31)
EXT_{SOU} =1 if firm has purchased input goods and services from outsourcing agreements (average 2001-03)	0.20 (0.40)	0.27 (0.44)	0.25 (0.43)	0.31 (0.36)	023 (0.42)	0.27 (0.45)
$PAVITT_1$ = 1 if supplier dominated	0.44 (0.5)	0.43 (0.5)	0.35 (0.48)	0.46 (0.5)	0.47 (0.5)	0.31 (0.46)
$PAVITT_2$ = 1 if scale-intensive	0.16 (0.36)	0.13 (0.33)	0.13 (0.34)	0.1 (0.3)	0.15 (0.36)	0.16 (0.37)
$PAVITT_3$= 1 if specialized equipment suppliers	0.36 (0.48)	0.37 (0.48)	0.41 (0.49)	0.37 (0.48)	0.34 (0.47)	0.41 (0.49)
$PAVITT_4$ = 1 if science based	0.04 (0.2)	0.07 (0.26)	0.11 (0.31)	0.07 (0.26)	0.05 (0.21)	0.12 (0.33)
$COLL_{CENTRES}$=1 if alliances with research institutions			1	0.12 (0.32)	0.07 (0.25)	0.3 (0.46)
$COLL_{FIRMS}$=1 if alliances with other firms			0.25 (0.43)	1	0.15 (0.36)	0.35 (0.48)
$COLL_{OTHER}$=1 if alliances with other small centres			0.07 (0.26)	0.08 (0.27)	1	0.18 (0.38)
$COLL_{UNI}$=1 if alliances with universities			0.33 (0.47)	0.18 (0.39)	0.19 (0.39)	1

[(*)]161 firms have multiple cooperation forms

Table 2: descriptive statistics: collaboration forms

COLLABORATION FORM	N°
$COLL_{CENTRES}$ (only)	74
$COLL_{FIRMS}$ (only)	215
$COLL_{OTHER}$ (only)	102
$COLL_{UNI}$ (only)	52
$COLL_{CENTRES}$ & $COLL_{FIRMS}$ (only)	16
$COLL_{CENTRES}$ & $COLL_{OTHER}$ (only)	3
$COLL_{CENTRES}$ & $COLL_{UNI}$ (only)	29
$COLL_{FIRMS}$ & $COLL_{OTHER}$ (only)	14
$COLL_{FIRMS}$ & $COLL_{UNI}$ (only)	14
$COLL_{OTHER}$ & $COLL_{UNI}$ (only)	20
$COLL_{CENTRES}$ & $COLL_{FIRMS}$ & $COLL_{OTHER}$ (only)	2
$COLL_{CENTRES}$ & $COLL_{FIRMS}$ & $COLL_{UNI}$ (only)	13
$COLL_{FIRMS}$ & $COLL_{OTHER}$ & $COLL_{UNI}$ (only)	3
$COLL_{CENTRES}$ & $COLL_{OTHER}$ & $COLL_{UNI}$ (only)	1
$COLL_{CENTRES}$ & $COLL_{FIRMS}$ & $COLL_{OTHER}$ & $COLL_{UNI}$ (only)	4

Table 3: Multivariate probit regressions on R&D collaboration

	$COLL_{CENTRES}$		$COLL_{FIRMS}$		$COLL_{OTHER}$		$COLL_{UNI}$	
Variable	Coef.	(s.e.)	Coef.	(s.e.)	Coef.	(s.e.)	Coef.	(s.e.)
$GRANT_{R\&D}$	-0,004	(0,107)	0,305***	(0,086)	0,078	(0,103)	0,330***	(0,101)
$LogEMP_{R\&D\text{-}EMPL(2001)}$	0,033	(0,037)	0,098***	(0,031)	0,060	(0,038)	0,087**	(0,037)
$LogEMP_{2001}$	0,225***	(0,048)	0,103***	(0,041)	-0,042	(0,049)	0,299***	(0,047)
$Log(KAPINT)_{2001}$	0,067	(0,049)	0,052	(0,041)	-0,094**	(0,045)	0,139***	(0,052)
$DEBT_{AVY}$	0,000	(0,034)	-0,061*	(0,039)	0,007	(0,039)	0,078	(0,057)
$RATION$	0,079	(0,197)	0,065	(0,161)	0,208	(0,180)	-0,318	(0,229)
$EXPORT$	-0,085	(0,162)	0,025	(0,133)	0,242	(0,163)	-0,160	(0,159)
$GRANT_{OTHER}$	-0,108	(0,134)	0,085	(0,104)	0,150	(0,121)	0,174	(0,123)
EXT_{SOU}	0,015	(0,114)	0,301***	(0,092)	-0,022	(0,112)	0,059	(0,113)
$PAVITT_1$	-0,510***	(0,196)	-0,077	(0,174)	0,148	(0,220)	-0,689***	(0,190)
$PAVITT_2$	-0,453**	(0,221)	-0,409**	(0,201)	0,181	(0,243)	-0,487**	(0,212)
$PAVITT_3$	-0,308	(0,194)	-0,154	(0,176)	0,045	(0,222)	-0,373**	(0,188)
Cons	-1,862***	(0,318)	-1,091***	(0,270)	-0,926***	(0,324)	-2.311***	(0.321)
rho_{21}	-0.036	(0.066)						
rho_{31}	-0.133*	(0.081)						
rho_{41}	0.378***	(0.064)						
rho_{32}	-0.180***	(0.064)						
rho_{42}	0.137**	(0.063)						
rho_{43}	0.206***	(0.072)						
# of obs.	1231							
Log likelihood	-1918.21							
Wald $\chi^2_{(48)}$	181.48***							
Wald test on joint ignificance of industry dummies χ^2 (12)	31.18***							

Likelihood ratio test of $rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0$: $\chi^2_{(6)}$= 58.3031, Prob>χ^2=0.0000
# of random draws in the simulator = 200
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

APPENDIX

Table A.1: Durbin–Wu–Hausman (augmented regression test) for endogeneity

Equation	Estimated coefficient of residuals	t value
$GRANT_{R\&D(\text{residuals})}$	.22	0.47
Hy: coeff. residuals = 0		
F (1, 1221) = 0.22 Prob> F = 0.64		
Since the coefficient of residuals is highly insignificant the hypothesis of exogeneity cannot be rejected		

Table A.2: testing results

Constrain:	Wald tests H_0: equality of slope coefficients (β_X^s)
β_X^s, $COLL_{CENTRES}$ = β_X^s, $COLL_{FIRMS}$	$\chi^2_{(12)}$= 27.12; Prob>χ^2 = 0.007
β_X^s, $COLL_{CENTRES}$ = β_X^s, $COLL_{OTHER}$	$\chi^2_{(12)}$= 37.05; Prob>χ^2 = 0.000
β_X^s, $COLL_{CENTRES}$ = β_X^s, $COLL_{UNI}$	$\chi^2_{(12)}$= 19.89; Prob>χ^2 = 0.069
β_X^s, $COLL_{FIRMS}$= β_X^s, $COLL_{OTHER}$	$\chi^2_{(12)}$= 25.78; Prob>χ^2 = 0.011
β_X^s, $COLL_{FIRMS}$= β_X^s, $COLL_{UNI}$	$\chi^2_{(12)}$= 39.99; Prob>χ^2 = 0.000
β_X^s, $COLL_{OTHER}$= β_X^s, $COLL_{UNI}$	$\chi^2_{(12)}$= 72.41; Prob>χ^2 = 0.00
	Always reject H_0 in favour of the unconstrained model

Table A.2: single univariate probit regressions on R&D collaboration

	$COLL_{ALL}$		$COLL_{CENTRES}$		$COLL_{FIRMS}$		$COLL_{OTHER}$		$COLL_{UNI}$	
Variable	Coef.	(s.e.)	Coef.	(s.e.)	Coef.	(s.e.)	Coef.	(s.e.)	Coef.	(s.e.)
$GRANT_{R\&D}$	0,229***	(0,081)	-0,004	(0,107)	0,304***	(0,086)	0,082	(0,103)	0,336	(0,101)
$LogEMP_{R\&D\text{-}EMPL(2001)}$	0,143***	(0,029)	0,034	(0,038)	0,100***	(0,032)	0,062*	(0,038)	0,079	(0,037)
$LogEMP_{2001}$	0,134***	(0,038)	0,224***	(0,047)	0,104***	(0,040)	-0,042	(0,049)	0,300	(0,047)
$Log(KAPINT)_{2001}$	0,034	(0,037)	0,067	(0,050)	0,050	(0,041)	-0,095**	(0,046)	0,141	(0,052)
$DEBT_{AVY}$	-0,046	(0,035)	-0,001	(0,034)	-0,061*	(0,038)	0,008	(0,039)	0,062	(0,057)
$RATION$	0,051	(0,151)	0,067	(0,198)	0,059	(0,162)	0,200	(0,181)	-0,278	(0,228)
$EXPORT$	0,044	(0,119)	-0,094	(0,161)	0,026	(0,133)	0,235	(0,163)	-0,145	(0,160)
$GRANT_{OTHER}$	0,205**	(0,098)	-0,084	(0,132)	0,089	(0,104)	0,162	(0,121)	0,171	(0,123)
EXT_{SOU}	0,212**	(0,087)	0,007	(0,114)	0,306***	(0,091)	-0,019	(0,112)	0,054	(0,113)
$PAVITT_1$	-0,257	(0,169)	-0,508***	(0,195)	-0,076	(0,174)	0,163	(0,222)	-0,697	(0,191)
$PAVITT_2$	-0,388	(0,188)	-0,470**	(0,221)	-0,406**	(0,201)	0,208	(0,244)	-0,501	(0,214)
$PAVITT_3$	-0,251	(0,17)	-0,318*	(0,194)	-0,152	(0,176)	0,061	(0,224)	-0,390	(0,189)
Cons	-0,281	(0,248)	-1,844***	(0,315)	-1,087***	(0,269)	-0,930***	(0,324)	-2,332	(0,323)
# of obs.	1231		1231		1231		1231		1231	
Log likelihood	-819.52		-421.02		-658.43		-445.93		-422.01	
Wald test on joint significance of industry dummies χ^2 (3)	4.34		8.21**		7.12*		1.69		16.02***	

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

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