The nature of collaborative innovative activities

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Abstract
We investigate the determinants of governance for a sample of successful collaborative inventive activities. We find that firm size and incoming spillovers have a positive impact on the probability to co-operate. We then extend the analysis to four possible modes of governance: co-assignment, co-invention, formal agreement, and informal agreement. We find that higher project complexity and technological scope are associated to tighter modes of governance while licensing to less hierarchical ones. Inventor specific characteristics matter too. In particular, experience increases the probability of choosing less hierarchical governance modes while better education is associated to tighter modes.

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1. Introduction

Innovative activity often involves the formation of partnerships that span across a wide range of institutions (Chesborough, 2002), from firms to Universities and public and private research organizations (Poyago-Theotoky *et al.*, 2002). This is both a consequence of the fact that complex R&D activities in multi product firms demand the integration of different bodies of knowledge (Granstrand *et al.*, 1997) and the recognition by firms that the relevant knowledge should be found outside their own boundaries. During the last decade, collaborative innovative activity has become crucial within the wider context of research collaborations and the subject of extensive academic debate.

There is a very large theoretical and empirical literature examining R&D co-operation. This literature can be organized around three main approaches. First, there are the game-theoretical models developed following the seminal work of d'Aspremont and Jacquemin (1988). Second, there is the transaction const framework that emphasises the mix characteristics of co-operations (Williamson, 1996). Third, there are the strategic management approaches (or resource based theories of the firms) that study the reasons for the rapid development of this new from of company interaction since they started to be formed after the mid 1970s (Mowery, Oxley & Silverman, 1996). Parallel to the theoretical analysis, the field has also seen the development of a large number of empirical studies based on large databases of R&D co-operations (see Caloghirou *et al.*, 2003 for a review of this body of literature) and, most recently, econometric studies based on innovation surveys (see Cassiman and Veugelers, 2002 among others) and patents.

Collaborative innovative researches leading to patents may be of different nature depending on the different modes of governance employed (i.e. co-invention or co-assignment). While these alternative modes have become increasingly relevant (Hicks and Narin, 2001; Hagedoorn, 2003), little is known about why and when they are chosen. This paper aims at providing a first exploratory investigation of what drives their choice within the context of R&D co-operation. Our research question is the following: How do we explain that R&D cooperation agreements may entail different governance structure even within a regime of strong Intellectual Property Right (IPR) protection warranted by a patent? In other words, why do firms that engage in successful R&D cooperation (i.e. the outcome of the cooperation is a patent) may also choose to establish strict modes of governance such as co-invention or co-assignment in alternative to a more informal contractual agreements? In this paper we argue that the choice of a mode of governance is the consequence of the presence of a specific level of appropriability hazard underlying the R&D partnership. The higher the level of appropriability hazard is the higher the probability to choose a tighter (i.e. more hierarchical) mode of governance. Existing contributions (Oaxley, 1997; 1999) have mainly stressed the impact of project level attributes on the choice. We will consider both the role of project specific attributes and the impact of individual (i.e. inventor specific), and organizational (i.e. environment specific) attributes.

Our investigation is based on data from the PatVal database, a sample of 9017 European inventors and their associated patents registered at the European Patent Office (EPO) between 1993 and 1997 (Giuri, Mariani *et al.*, 2006). Relying upon this dataset, we select those patents that are the outcome of a collaborative research project, identify four possible modes of governance (ranked from the more to the less hierarchical): co-assignment, co-invention, formal agreement, and informal agreement and we run Ordered Probit analysis and a Multivariate Probit analysis with sample selection to study the choice of a governance mode conditional on the patent being the outcome of an innovative collaborative project. We find that firm size and incoming spillovers have a positive impact on the probability to co-operate and that project related characteristics impact instead on the choice of the governance mode. Higher complexity and technological scope are associated to tighter modes of governance while licensing to less hierarchical ones. Inventor specific characteristics matter too. In particular, experience increases the probability of choosing less hierarchical governance modes while better education is associated to tighter modes. The structure of the paper is as follows. Section 2 reviews the existing literature on the determinants of R&D cooperation and the mode of governance of R&D collaborative projects. Section 3 introduces the data, the variables and the econometric model that will be used in the empirical analysis. Section 4 presents the results and Section 5 concludes.

2. Background Literature

Within the context of R&D cooperation, patents are usually found to be the most frequently used mechanism for IPRs protection (Hertzfeld *et al.,* 2006). However, simple patenting by itself is far from being the only mechanism to share IPRs. Hagedoorn (2003) provides empirical evidence that other forms of governance such as co-assignment has increased in last couple of decades. Hagedoorn *et al.* (2003) distinguish co-assignment from other types of patent agreements such as cross-licenses and pooled patents. Their analysis provides evidence that the probability of co-assignment increases with previous engagement in collaboration activity. To the extent to what co-assignment entails joint ownership of an invention, they argue that it is based on mutual relational trust between separate companies. Contrary to the empirical evidence on the determinants of R&D cooperation, they do not find any significant positive correlation between firm size and co-patenting. The issues of the reason why firms and other types of organization such as universities and research organizations that engage in successful R&D cooperation (i.e. the outcome of the cooperation is a patent) may also choose to establish alternative modes of governance such as co-invention or co-assignment in alternative to a more informal contractual agreements is important and deserves close scrutiny.

One way of tackling the issue is by taking a transaction cost perspective. Transaction cost theory predicts that, in the context of R&D co-operation, the choice of a governance mode is mainly a function of the appropriability hazard of the R&D project which is, in turn, an inverse function of three dimensions: the extent of IPRs specification, contract monitoring, and enforcement. Better property right specification, better monitoring and better enforcement reduce the appropriability hazard level and decrease the probability of choosing a more hierarchical mode of governance. By devising suitable indicators for these dimensions it is possible to understand the determinants of the choice of a specific firm of governance through their impact on appropriability hazard level. Transaction cost theory claims that suitable indicators should be related only to the transaction (i.e. they should mainly be characteristics of the research project underlying the transaction). As argued by Teece (1986) definition of IPRs appears problematic when project entails a large change in the underlying technology (i.e. complexity is high), uncertainty on the outcome is high (i.e. incrementality is low), the technological know how that result from the underlying research is highly tacit (i.e. scope is large), and the underlying research project does not entail a prior licensing agreement. High complexity, low incrementality, large scope, absence of prior licensing agreement should therefore be associated with more hierarchical forms of governance. IPRs definition is also sectoral and country specific (Oaxley, 1999). Thus cross sectoral differences in the propensity to patent may also reflect in the choice of the form of governance with sectors more inclined to patent are also more likely to be associated to choose tighter forms of governance. Country differences in patent legislation or in the propensity to engage in R&D collaboration may also affect the choice. Concerning monitoring, existing empirical studies have highlighted that monitoring is problematic when the number of products or technologies characterizing the research project is large and geographical dispersion is high (Oaxley, 1997). The presence of these characteristic is therefore associated to tighter forms of governance

In this paper we consider project level attributes, as well as other determinants related to both the individual (i.e. the inventor) and the characteristics of the organization involved in the transaction. Concerning the role of individual characteristics, it has to be noted that few contributions have looked at the determinants of R&D collaborations from the viewpoint of the individual inventor actually involved in the collaborative project (Audretsch and Stephan, 1996; D'Este and Patel, 2007). Even fewer, to our knowledge, are the empirical works that have explicitly considered the connection between the inventors' background (i.e. education, experience, reputation, mobility) on the choice of the governance mode. This paucity of empirical works notwithstanding, the importance of the background can be grasped by relying on the idea that individuals, their social networks and mobility are the main responsible for the flow of innovative knowledge and that the size of the network in turn is affected by the ability and experience of the inventors (Breschi and Lissoni, 2001; Singh, 2005).

Concerning the role of social networks, Audretsch and Stephan (1996) for instance argue that more experienced researchers have a higher propensity to interact outside the boundaries of their firm and provide empirical evidence on the presence of a positive relationship between inventors' experience and the size of their network. Giuri and Mariani (2007) argue that better educated researchers have higher opportunities to enter larger networks and signal their ability to rely upon connections to establish interactions in their career. They find the presence of a positive relationship between educational background of the inventor and the size of their network. Individuals embedded in a dense network of relationships and interactions are more likely to increase monitoring problems. Thus we should expect better educated inventors to be associated to a tighter mode of governance.

Concerning mobility, it has been shown that labor mobility depends on a series of individual characteristics. Crespi *et al.* (2006) for instance consider a sample of academic researchers and look at the determinants of mobility from academia to the private sector. They find that, controlling for their productivity, younger and less experienced inventors are more likely to leave academia and move to the private sector. The positive role of experience for mobility is also stressed by Lenzi (2006) who works on a sample of Italian inventors in the pharmaceutical sector. She also finds that gender is important with male workers being more mobile than female. Finally better educational background has been found to increase mobility (Hoisl, 2007). Mobility is likely to increase potential geographical dispersion thus making monitoring more problematic. Again we should expect better educated and young inventors to be associated to a tighter mode of governance.

In this paper we account for education, experience, individual mobility and control for organization and project level characteristics such as complexity, scope, and licensing. First, we expect better education and mobility to be associated to tighter modes of governance. Looser modes of governance should instead be associated to previous experience. Second, we expect complexity and scope to be associated to tighter modes of governance. The presence of alternative mechanisms of compensation and/or IPR management such as licensing instead should lead to less hierarchical modes.

3. Empirical Analysis

The data used in this paper come from the PatVal database, a sample of 9017 European inventors and their associated patents registered at EPO between 1993 and 1997. Inventors are from six European countries (Germany, UK, France, Spain, Italy, and The Netherlands) and five sectors (electrical engineering, instruments, chemistry and pharmaceuticals, process engineering, and mechanical engineering). These six countries account for about 80% of patents whose first inventor has and address in EU-15 countries. Our main focus is whether the patent was the outcome of a collaborative innovative effort and whether the patent was associated to a specific mode of governance. We identify four main governance modes from the tighter 8i.e. more hierarchical) to the looser: Co-assignment, Co-Inventorship, Formal Agreements, and Informal Agreements.

3.1. Sample and Dependent Variable

In our sample, there are 553 patents that were co-assigned, of these only 323 are assigned to companies belonging to different groups. They represent 3.6% of our sample. There are 3261 patents with only one inventor, while 5756 have multiple inventors. 1309 patents are co-invented collaborative patents (i.e. they include inventors with employers from different companies). They represent 15% of our sample. It has to be noted that the two sets are partially overlapping. Indeed, 119 co-invented collaborative patents have a co-assignment from the employers of the inventors. 57 have a co-assignment from employers who differ from the one of the inventor. No information is available on the others. 1745 patents (20.5% of the sample) involved other forms of collaborative agreements either formal or informal. From the interplay of these categories we identify two other groups of patents. The first category is made of patents that involved a formal collaborative agreement but were neither co-invented nor co-assigned (no co-inventor or co-assignee from the same or different company group). 246 patents belong to this category. The second category includes patents that involved an informal collaborative agreement but were neither co-invented nor co-assigned (no co-inventor or co-assignee from the same or different company group) and zero otherwise. 102 patents belong to this category. Table 1 below summarizes the frequencies of patents in our sample.

[Table 1 approximately here]

To these categories we associate four possible governance modes: CO-ASSIGNMENT, CO-INVENTION, FORMAL AGREEMENT, INFORMAL AGREEMENT. Using this classification we create the variable MODE_J taking the value of (MODE_3= 3) if the patent has been co-assigned, (MODE_2= 2) if the patent has been co-invented, (MODE_1= 1*)* if the patent involved also a formal agreement, (MODE_0= 0) if the patent involved also an informal agreement.

The variable MODE_J takes on one of four values depending on the specific mode of governance associable to the patent. Each mode of governance is ranked on the basis of the degree of additional protection it warrants, from the tightest (i.e. co-assignment) to the loosest (i.e. only informal). The choice of a specific mode of governance is the consequence of the level of appropriability hazard associable to an innovative collaborative research project (and ultimately to its outcome: the patent). The assumption is that a tighter mode of governance derives from the need to protect against a higher level appropriability hazard. Thus, by looking at how each covariate influences the level of appropriability, we will gain a better understanding of the likelihood to observe a specific mode of governance.

3.2. Independent Variables

We consider two sets of covariates: a set of variables that influence the probability of engaging in R&D co-operation and a set of variables that influence the choice of the governance mode. More in general our covariates can be classified into three groups. First, we consider a set of variables related to the type of project underlying the specific patent. Second, we control for the influence of individual characteristics of the inventor as well as of the motivation to patent. We expect these two sets of covariates to influence the choice of a mode of governance mainly by impacting on the extent of property rights definition and contract monitoring. Third, we consider a set of 'environmental' characteristics associated with the organizational affiliation (i.e. firm and/or university) of the inventor and the presence of subsidies. We expect these covariates to impact on the probability of choosing a governance mode mainly through the propensity to patent. Finally we control for country and sector fixed effect. The country effect is likely to impact on the choice of a governance mode by influencing the extent patent enforcement. Sectoral dummies instead account for the role of property right specification.

Project related characteristics

The choice of a governance mode is affected by project related characteristics such as: complexity, breadth, R&D cost and the decision to license or not the patent to a third party. The PatVaL survey asked respondents to give an estimate of the time (measured in person months) required by the research leading to the patent. Responses were structured in eight asymmetric intervals ranging from less than one person month to more than seventy two person months. COMPLEXITY is constructed as the natural logarithm of the mean value of each interval plus the right border of the lowest interval and the left border of the top interval. Longer and larger projects usually bring about a large change in the underlying technology and are more likely to be associated to uncertain outcome. Thus we expect the more complex the project, the higher the probability that a tighter mode of governance is chosen.

The scope of the project is also likely to impact on the choice of a specific governance mode. Indeed, research projects demanding the integration of different bodies of knowledge are more uncertain and IPRs are more difficult to specify clearly at the start of co-operation activity. Higher uncertainty also makes monitoring more difficult and generally increases the probability of opportunistic behavior in the underlying R&D collaboration. The scope of the research is captured by the variable BREADTH which is constructed as the natural logarithm of the number of 4-digit technological classes (IPC) in which the patent was classified. We expect that the higher the breadth the higher the probability of choosing a tighter mode of governance.

The choice of the governance mode also depends on whether other alternative arrangements, such as economic rewards, concerning the individual returns from and/or the ownership of the patent are present. COMPENSATION is a dummy variable equal to 1 if the inventor received any personal monetary compensation expressly offered because of the production of the patent. We expect the presence of such monetary reward to be associated to the choice of a relatively less tight governance mode. Finally, the choice of the governance mode also depends on whether the patent has been licensed or not. LICENSING is a dummy variable that takes the value of 1 if the patent has been licensed, by one of the patent holders, to a third party. To the extent to what licensing is possible only when a clear definition of IPRs exist and/or the knowledge content of the underlying research project can be easily codified, we expect less hierarchical modes of governance to be associated to patents that have been licensed.

<u>Individual characteristics and the motivations to patent</u>
We control for the influence of individual characteristics of the inventor, such as age at time of application, level of education, mobility (i.e. whether the inventor has been previously employed in other organizations), work location and 'openness' as measured by the relative importance given to external sources of information both public (University laboratories and faculties, PROs, technical conferences, and scientific literature) and private (patent literature, customers, suppliers, and competitors) for the research activity leading to the patent.

AGE is the natural logarithm of the age of the inventor at the time of patent application. This is our proxy for experience. To the extent to what more previous experience leads to trust, it should be associated to the choice of less hierarchical modes of governance for co-operation. PHD is a dummy variable equal to 1 if the inventor's highest academic degree is a PhD. This is our measure of education. We expect better educated inventors to demand tighter modes of governance. MOBILITY is a dummy variable equal to 1 if the inventor moved organization in the year before the patent was taken. Mobility is associated to the establishment of a large network of colleagues as a result also of a higher probability of being involved in co-operative research. To the extent to what high mobility generally entails higher dynamism and job searching, it may increase monitoring problems therefore leading to the choice of more hierarchical modes of governance for the co-operation. Finally, CITY is a dummy variable equal to 1 if the inventor worked in a city of more than 100,000 inhabitants when the research leading to the patent was carried out. This variable can be considered a proxy, admittedly a coarse one, for geographic dispersion. High geographic dispersion is likely to increase monitoring problems therefore increasing the probability of choosing tighter modes of governance.

Particular attention is devoted to the relative importance of sources of knowledge (i.e. incoming spillovers) as a factor influencing the probability to co-operate. A question in the PatVal survey asked inventors to rank on a five-point scale from not important to very important external sources of knowledge relate to the innovation included in the patent. Following Cassiman and Veugelers (2002), PRIVATE (PUBLIC) SPILLOVERS is constructed by summing the scores of each type of information sources (University laboratories and faculties, PROs, technical conferences, and scientific literature for public; patent literature, customers, suppliers, and competitors for private) and re-scaling the total scores to a number between 0 and 1. We expect the presence of incoming spillovers to positively affect the probability of engaging in R&D collaboration.

Environmental characteristics

Further controls include 'environmental' characteristics related to the organizational affiliation (i.e. firm and/or university) of the inventor. A question in the PATVAL survey asked the respondent to state the nature of the employer when the researcher leading to the patent was performed. Five types of organizations were identified: firms, private research organizations (including hospitals and foundations), PROs (including government research organizations), universities, others. FIRM and UNIVERSITY are two dummy variables equal to 1 if the inventor was employed by a firm or a university respectively. Extensive evidence exists on the increasing involvement of Universities in the formation of research partnerships (Poyago-Theotoky *et al.*, 2002), thus we expect Universities to have a positive probability to team up with other organizations for carrying out the research leading to a patent. However, recent empirical analyses of the motivations underlying IPRs protection mechanism within research co-operation have found that partnerships involving universities are generally more problematic with respect to the negotiation of IPR agreements (Hertzfeld *et al.*, 2006). In line with these findings, and taking public and private research organizations as a reference category, we expect universities to have a relatively lower probability to choose a more hierarchical mode of governance.

The existing literature has found a positive relationship between firm size and the probability to cooperate (Tether, 2002; Leiponen, 2001). Further evidence has highlighted the non linear nature of the relationship (Cassiman and Veugelers, 2002). For those inventors who were employed by a firm, the survey asked whether the firm was large, medium, or small.[1] We use information on the boundaries of size intervals defined in

[1] Large firm are organizations with more than 250 employees. Medium firms (100-250 employees). Small firms (less than 100 employees).

terms of number of employees to construct our proxy for firm size. SIZE (and $SIZE^2$) are constructed as the natural logarithms (square of the logarithm) of the mean value of each interval plus the right border of the lowest interval and the left border of the top interval.

Finally we take into consideration the role of R&D subsidies. Co-operative research projects may and may or not have benefited from the allowance of monetary support from national governments and/or supranational institutions such as the European Union. As argued by Belderbos *et al.* (2004), the presence of subsidies may have a double impact on the probability to engage in R&D co-operation. On the one hand, they may stimulate firms to engage in co-operation of any kind especially when their availability is conditional on the establishment of the co-operation. On the other hand, their presence may ease financial bottlenecks and therefore reduce the propensity to engage in co-operation tout-court. This is more likely to occur when co-operations are created with the explicit intent of reducing costs. GOVFUNDS is a dummy equal to 1 if the research leading to the patent has benefited from government research programmes and/or other government funds. We expect this variable to impact positively on the probability to co-operate.

Technology fixed effects are included in the model. We expect that technological factors are most important as technologies (and sectoral innovation systems) are characterised by different propensities to rely upon collaborative innovative processes, and specific modes of governance depending on project related characteristics not captured by our covariates (i.e. for example we think that technologies in the pre-paradigmatic phase depends more on collaborative innovative agreements and tighter modes of governance). Country fixed effects are included too. We expect that certain national systems of innovations are more conducive to co-operation in research than others due to cultural and institutional reasons. Moreover, we also expect different institutional settings to influence the choice of the mode of governance through their support and provision of IPRs enforcement mechanisms. Descriptive statistics for the variables used in the regression are listed in Table 2. In the remaining of this Section we will present the econometric models that will be estimated.

[Table 2 approximately here]

3.3 Econometric Models

To study the determinants of the choice of a specific governance mode we carry out two types of analysis. First we estimate an Ordered Probit model. Second we apply a Multivariate Probit model to account for the possible presence of correlation between the governance modes. In both cases the choice of a governance mode is conditional on the probability of having been engaged in a collaborative innovative project.

Using only information on the sub-sample of patents resulting from a collaborative agreement may introduce a sample selection bias. To eliminate this potential source of misspecification we proceed in two-step. In the first step, we use a binary response model to explain the probability of engaging in collaboration as a function of a series of independent variables. In the second step, we focus only on collaborative patents and investigate the determinants of the choice of a specific governance mode as described by MODE_J and correct for selection bias. Our model can be specified as follows:

$$Mode_j^* = Z_j^{'}\gamma + \eta_j \quad (1),$$

where MODE_J* is the latent variable associated to the ordered variable MODE_J, *Z* contains the covariates, γ are the coefficients to be estimated, and η is a random error term.

MODE_J* is not directly observed. We observe instead the following intervals in its realization:

$$\begin{array}{llllll} Mode_0 = 0 & if & Coll = 1 & and & Mode_j^* \leq \mu_1 \\ Mode_1 = 1 & if & Coll = 1 & and & \mu_1 < Mode_j^* \leq \mu_2 \\ Mode_2 = 2 & if & Coll = 1 & and & \mu_2 < Mode_j^* \leq \mu_3 \\ Mode_3 = 3 & if & Coll = 1 & and & \mu_3 < Mode_j^* \end{array} \quad (2)$$

where μ are unknown parameters to be estimated together with γ.

This is the model estimated among others by Oaxley (1997; 1999). It has to be noted that in our case, the probabilities of falling into one of these intervals can be estimated only for that part of the sample for which the patent is the outcome of a collaborative engagement. To account for this we follow Heckman (1979), who suggests a two stage procedure that relies on a first estimation of a selection equation for the entire sample of patents

Let us call COLL_J a binary variable describing whether the patent is the outcome of a collaboration. A latent variable COLL_J* is associated to this binary variable:

$$Coll_j^* = X_j \beta + \varepsilon_j \quad (3)$$

in which *X* is a set of determinants of the probability to collaborate, β are the coefficients to be estimated, and ε is a random error term. The parameter β can be estimated by replacing COLL_J* with a dummy variable COLL_J which is equal to zero when no collaboration has occurred (i.e. COLL_J* is zero) and it is equal to one when a collaboration has occurred (i.e. COLL_J* is positive).

The selection equation is then treated as a binary probit model and estimated by maximum likelihood $(\hat{\beta})$. For all our sample we estimate the probability to collaborate $\Pr(Coll_j = 1)$ that can be computed as $\Phi(X_j^{'}\hat{\beta})$ where Φ is the cumulative distribution function of a standard normal. In the second stage we then estimate a regression model augmented by the selection variable $\hat{\lambda}_j = \varphi(X_j^{'}\hat{\beta}) / \Phi(X_j^{'}\hat{\beta})$ where $\varphi(\cdot)$ is the standard normal density function restricted to those firms who have adopted. In other words we estimate the following:

$$Mode_j^* = Z_j^{'}\gamma + \gamma_\lambda \hat{\lambda}_j + \eta_j \qquad (4)$$

for all *j* with $\text{COLL}_j^* > 0$.

It has to be noted that $\hat{\lambda}_j$ results from the estimation of the selection equation in the first stage. If parameters are estimated simultaneously the second stage estimation provides correct standard errors. While this is a standard estimation strategy (Mohnen and Horeau, 2003), it has to be noted that the results depend on the starting solution of the Ordered Probit model without sample selection. We therefore choose to compute the second stage separately and correct the estimation in the second stage via bootstrapping. Bootstrapping allows for re-sampling with replacement from the whole sample and carries out the whole two stage procedure for each resample (Efron and Tibshirani, 1993). We iterate this procedure for 1000 times to obtain different estimates of the parameters from which the correct standard errors can be calculated.

In the second set of estimations, we account for the likely presence of correlations between the modes of governance by carrying out a Multivariate Probit estimation. The Multivariate Probit is a generalization of the Probit approach that allows the estimation of more than one binary equation with correlated disturbances. Not accounting for the presence of likely correlation, by estimating for example separate Probit equations, would produce inefficient estimators. In our case, we include four equations in which each one of four modes of governance identified (CO-ASSIGNMENT, CO-INVENTION, FORMAL AGREEMENT, INFORMAL AGREEMENT) is modeled as a latent variable by a standard Probit model:

$$y_{ij}^* = \alpha_j + v_j^{'} x_{ij} + u_{ij} \qquad (5)$$

where:

$$y_{ij} = \begin{cases} 1 & if \quad y_{ij}^* > 0 \\ 0 & otherwise \end{cases} \qquad (6)$$

with: $i = 1,\ldots,n$ and $j = 1,\ldots, 4$ are the observations and the modes of governance respectively. The disturbances u_{ij} are distributed according to a multivariate normal distribution with mean 0 and covariance matrix with diagonal elements equal to 1 (Greene, 2003).

4. Empirical Analysis

To investigate the determinants of the choice of a governance mode for collaborative innovative research projects we have proceeded in several steps. First we have used a Probit model to estimate the probability that the patent resulted from an innovative collaborative activity. This estimate is our selection equation. Then we have used an

Ordered Probit model to estimate the probability to choose a specific governance mode. This equation includes the Inverse Mills Ratio from the selection equation to correct for possible selection bias and the corrected (i.e. bootstrapped) standard errors. Finally we have extended the analysis to account for correlation across the governance modes by estimating a Multivariate Probit model.

4.1. Preliminary Results

Preliminary results are reported in Table 3. Column (1) presents the estimates for the selection equation.

[Table 3 approximately here]

We observe a positive dependence on SIZE indicating that large firms are more likely to cooperate. However, the negative and significant coefficient of the squared value indicates that the relationship is not linear. Both results are consistent with previous works on the determinants of R&D cooperation (Cassiman and Veugelers, 2002). Coefficients for INCOMING SPILLOVERS are significant suggesting that innovators used to tap external sources for information are more likely to engage in cooperative R&D projects. Interestingly both coefficients are positive indicating that the different types of information seem to complement rather than substitute for each other. Again this result confirms previous works for Europe based on CIS surveys (Cassiman and Veugelers, 2002; Abramovsky *et al.*, 2005). Additional controls for the type of organization and the presence of funds are also positive and significant. Patents resulting from research funded by public funds are more likely to be the outcome of collaborative projects as indicated by the positive and significant coefficient of GOVFUNDS. Moreover, Universities are relatively more likely than other organizations (i.e. Firms, Private Research Organizations, Government Research Organisations) to engage in a collaborative project leading to a patent. Marginal effects are reported in column (2).

Results for the Ordered Probit model, conditional on the engagement in a collaborative innovative activity, are reported in the remaining columns. Column (3) reports the ordinary standard errors. Column (4) displays the boostrapped standard errors (1000 iterations). Results are generally robust to the implementation of the boostrapping procedure and both GOVFUNDS and UNIVERSITY are weakly or not significant, thus indicating that they were good instruments in the first stage equation. The coefficient of $\hat{\lambda}_j$ is negative and very significant suggesting that not correcting for sample selection would have produced biased estimations and that the decision to co-operate and the choice of a governance mode are not disjointed. More specifically, our findings indicate the significant role played by organizational, individual, and project level characteristics for the choice of a governance mode.

Concerning the impact of organizational characteristics, the negative and significant coefficient of FIRM suggests firms are more likely to choose less hierarchical governance modes than the reference category (i.e. public and private research organizations). Concerning the influence of individual characteristics of the inventor, we find a negative and significant coefficient of AGE and a positive and significant coefficient for PHD, suggesting that young and better educated inventors are more likely to choose hierarchical modes of governance. The coefficient of CITY is positive and significant albeit weakly. This result suggest that location of inventors in big towns is associated to the choice of more hierarchical modes of governance as a consequence of raising monitoring problems due to potential higher geographical dispersion. The coefficient for MOBILITY is not significant thus indicating that high mobile inventors, which in theory should increase monitoring problems, do not seem to lead to the choice of more hierarchical modes of governance. This result is surprising although it is probably related to the presence cross-country differences in labor market legislation which are captured by the dummy variables at the country level.

More interesting are the findings for the variables related to project level characteristics. The positive and significant coefficient of COMPLEXITY indicates that higher levels of project complexity, as measured by the man months required for the research, are associated to more hierarchical modes of governance. High uncertainty complicates property rights definition and leads organizations involved in the collaboration to further protect their interests by combining patenting with tighter forms of governance. BREADTH enters positively and significantly suggesting that patents spanning across several technological classes are associated to more hierarchical modes of governance. This result can be due both to property right definition and to the presence of monitoring issues. On the one hand, increasing the technology scope of a research project complicates the definition of the property rights. On the other hand, monitoring problems increases with the number of technologies involved in a project. In both cases, the stipulation of tighter modes of governance is required. COMPENSATION enters negatively and significantly suggesting that the presence of a personal monetary compensation for the production for the patent is associated to the choice of less hierarchical modes of governance. Finally the coefficient of LICENSED is negative and significant, indicating that patents that have been licensed are associated to relatively less tight modes of governance. Our explanation for these results is the following. Offering a monetary compensation is a way of rewarding the inventor above and beyond sharing the rights linked to the patent's ownership. The presence of such a reward fulfills inventor's reward expectations while preserving the rights of the organization that owns the patent. The presence of voluntary licensing instead is in itself an indication of the absence of problems in property right specification, monitoring and/or enforcement of within the context defined by the patent, either because of characteristics of the technology or because of the presence of mutual trust between the partners. Within this context less tight modes of governance are preferred to more hierarchical ones.

Altogether, our findings are as expected. First, availability of Government funds, presence of incoming spillovers (both public and private), and firm size increases the probability to engage in R&D cooperation. In the case of firm size, the relationship is not linear. Second, the choice of a specific mode of governance is mainly driven by project characteristics. In particular, project complexity and technology scope increase the probability of choosing more hierarchical modes of governance. The presence of licensing and compensation scheme is instead associated to less strict governance modes. Third, younger and better educated inventors have higher probability to choose tighter modes of governance. Finally, organizational characteristics such as the type of organization involved in the cooperation also matters, though to a lesser extent.

4.2. Robustness Check

To check the robustness of the results we carry out an additional estimation analysis by looking at the probabilities of choosing a specific mode of governance. To account for possible correlation between the alternatives, we run a Multivariate Probit estimation with and without country fixed effect with sample selection.

The estimation of the maximum likelihood function has been carried out using the recursive conditioning simulator implemented for STATA by Cappellari and Jenkins (2003). The number of recursive draws was equal to 50. This type of analysis allows us to gain further insights on the determinants of the choice of a specific governance mode as well as to account for the presence of interdependences (i.e. complementarity or substitutability) among the modes of governance.

[Table 4 approximately here]

The introduction of country fixed effect does not substantially change the results so we comment on the second estimation (columns (9) to (12)).

Our findings indicate that the predictive power of our model differs across modes of governance. Concerning the impact of organizational characteristics, we find that inventors located in universities and firms are engaged in co-assignment less than those working in Research Organizations (both public and private). Being funded by government decreases the probability of doing informal agreements and co-invention. Looking at the individual characteristics of the inventor, we find some evidence supporting the negative and significant effect of age on co-assignment. Results for education are interesting. Better educated inventors have a higher probability to co-invent, probably the consequence of the presence of an extensive network of trusted colleagues, but a lower probability to set up an agreement both formal and informal. Consistently with the previous results, we find that increasing project complexity and technology scope of the patent are associated to a lower probability of engaging in formal agreements. However, these project characteristics do not have statistically significant impact on more hierarchical modes of governance such as co-invention and co-assignment. Finally, licensing is more likely to be associated to the presence of a formal agreement and less likely to co-invention.

All in all these findings seem to suggest that different types of characteristics seem relevant for some governance modes but not for others. They are also informative on the relationship between the different modes of governance. Table 5 reports the estimates of the disturbance covariance matrix from the estimation with country fixed effect.

[Table 5 approximately here]

Coefficients are generally negative and some of them are highly significant thus suggesting that the modes of governance identified are substitute for each other rather than complement.[2] Substitutability is particularly high between co-invention and co-assignment and between co-invention and formal agreement. Indeed, while organizational characteristics matters for co-assignment, individual characteristics are significant determinants of co-invention and co-assignment to a certain extent, and project level characteristics for formal agreements an co-invention.

5. Conclusion

This paper has provided a preliminary analysis of the determinants of governance in successful collaborative inventive activities. First, we looked at the determinants of probability to engage in innovative collaborative projects. We found that firm size and incoming spillovers have a positive impact on the probability to co-operate. Second, we focused on four possible modes of governance: co-assignment, co-invention, formal agreement, and informal agreement. We found that higher project complexity and technological scope are associated to tighter modes of governance while licensing to less hierarchical ones. Inventor specific characteristics matter too. In particular, experience increases the probability of choosing less hierarchical governance modes while better education is associated to tighter modes.

[2] Interdependence may also be the consequence of omitted firm specific factors affecting the modes of governance.

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List of Tables

Table 1
Number of collaborations and mode of governance

	No of cases	Percent
Co-Assignment		
Single applicant	8460	93.80
Co-Assigned Non Collaborative (i.e. co-assignee same company)	230	2.60
Co-Assigned Collaborative (i.e. co-assignee different company)	323	3.60
Co-Invention		
Single inventor	3261	37.40
Co-Invented	4159	47.60
Co-Invented Collaborative	1309	15.00
Collaboration		
Collaborative Agreements	1745	20.50
Only Formal (i.e. no co-inventor or co-assignee)	102	
Only Informal (i.e. no co-inventor or co-assignee)	246	
Non Collaborative	6756	79.50

Table 2
Descriptive statistics

	Mean	S.D.	Min	Max
Coll.	0.27	0.444	0	1
Mode	1.929	0.736	0	3
Inf. Agrm.	0.011	0.106	0	1
Form. Agrm.	0.027	0.163	0	1
Co-Invention	0.124	0.33	0	1
Co-Assign.	0.036	0.186	0	1
Firm Size (Log)	4.985	1.39	0	5.521
Public Spillovers (Incoming)	0.315	0.24	0	1
Priv Spillovers (Incoming)	0.469	0.257	0	1
Age (Log)	3.814	0.215	2.639	4.454
Mobility	0.354	0.478	0	1
PhD	0.26	0.439	0	1
Firm	0.931	0.253	0	1
University	0.032	0.177	0	1
GovFunds	0.087	0.281	0	1
City	0.493	0.5	0	1
Complexity	1.976	1.063	0.693	4.277
Breadth (Log)	0.857	0.245	0.693	2.197
Compensation	0.416	0.4930	0	1
Licensing	0.114	0.318	0	1

Table 3
Determinants of Governance mode choice. Ordered Probit model. Estimates with sample selection.
Dependent variables: Mode

	Selection Equation (Probit)	Marginal Effects	Regression Equation (Ordered Probit)	
	(1)	(2)§	(3)	(4)‡
Firm Size (Log)	0.144	0.033		
	[0.070]**	[0.016]**		
(Firm Size)² (Log)	-0.043	-0.009		
	[0.012]***	[0.003]***		
Public Spillovers (Incoming)	0.765	0.175		
	[0.079]***	[0.027]***		
Priv Spillovers (Incoming)	0.134	0.031		
	[0.072]*	[0.017]*		
GovFunds	0.427	0.120	0.192	0.192
	[0.060]***	[0.021]***	[0.111]*	[0.115]*
University	0.364	0.099	-0.219	-0.219
	[0.124]***	[0.039]**	[0.166]	[0.163]
Firm			-0.380	-0.380
			[0.142]***	[0.142]***
Age (Log)			-0.526	-0.526
			[0.153]***	[0.151]***
Mobility			-0.072	-0.072
			[0.070]	[0.074]
PhD			0.206	0.206
			[0.070]***	[0.069]***
City			0.115	0.115
			[0.067]*	[0.065]*
Complexity			0.052	0.052
			[0.032]*	[0.031]*
Breadth (Log)			0.233	0.233
			[0.133]*	[0.130]**
Compensation			-0.003	-0.003
			[0.001]***	[0.001]***
Licensed			-0.149	-0.149
			[0.089]*	[0.089]*
$\hat{\lambda}$			0.572	0.572
			[0.174]***	[0.178]***
Sectoral Dummy	Yes		Yes	Yes
Country Dummy	Yes		Yes	Yes
Constant	-0.838			
	[0.145]***			
Observations	6963		1258	1258
Log Pseudo LL	-3750.27		-1249.87	-1249.87
Wald Chisq	597.93***		64.04***	74.26***
Pseudo Rsq	0.074		0.024	0.024

* denotes 10% significance level, ** denotes 5% significance level, *** denotes 1% significance level.
Robust standard errors.
§ Marginal effects calculated at the median. For dummy variables the effect is for a discrete change of variable from o to 1
‡ Bootstrapped standard errors in brackets (1000 iterations)

Table 4
Determinants of Governance mode choice. Multivariate Probit model. Estimates with sample selection.

	Inf. Agrm. (5)	Form. Agrm. (6)	Co-Invention (7)	Co-Assign. (8)	Inf. Agrm. (9)	Form. Agrm. (10)	Co-Invention (11)	Co-Assign. (12)
GovFunds	-0.737	-0.092	-0.012	0.019	-0.793	0.014	-0.185	0.009
	[0.252]***	[0.135]	[0.101]	[0.128]	[0.260]***	[0.143]	[0.108]*	[0.130]
University	0.023	-0.161	0.129	-0.366	0.031	-0.126	-0.021	-0.374
	[0.307]	[0.227]	[0.171]	[0.211]*	[0.326]	[0.229]	[0.176]	[0.216]*
Firm	-0.071	0.232	-0.315	-0.450	-0.090	0.041	-0.040	-0.381
	[0.227]	[0.179]	[0.143]**	[0.162]***	[0.269]	[0.199]	[0.156]	[0.178]**
Age (Log)	-0.266	0.031	-0.043	-0.372	-0.073	0.078	-0.003	-0.321
	[0.120]**	[0.081]	[0.063]	[0.076]***	[0.147]	[0.110]	[0.083]	[0.099]***
Mobility	0.172	-0.041	-0.027	0.007	0.173	-0.114	0.019	0.049
	[0.109]	[0.088]	[0.065]	[0.083]	[0.110]	[0.091]	[0.067]	[0.081]
PhD	-0.449	-0.319	0.301	-0.057	-0.347	-0.235	0.166	-0.003
	[0.150]***	[0.095]***	[0.070]***	[0.089]	[0.158]**	[0.099]**	[0.074]**	[0.094]
City	-0.194	-0.034	0.007	0.070	-0.168	-0.034	-0.018	0.053
	[0.118]*	[0.085]	[0.064]	[0.083]	[0.118]	[0.084]	[0.064]	[0.080]
Complexity (Log)	-0.030	-0.131	-0.037	-0.018	-0.052	-0.159	-0.011	-0.018
	[0.054]	[0.041]***	[0.029]	[0.038]	[0.056]	[0.042]***	[0.030]	[0.036]
Breadth (Log)	-0.259	-0.346	-0.164	0.222	-0.204	-0.339	-0.124	0.148
	[0.236]	[0.166]**	[0.120]	[0.149]	[0.236]	[0.167]**	[0.120]	[0.144]
Compensation	0.003	0.005	-0.001	-0.001	-0.000	0.003	-0.002	0.002
	[0.002]	[0.017]***	[0.001]	[0.001]	[0.002]	[0.002]	[0.001]	[0.001]
Licensed	0.187	0.199	-0.110	-0.120	0.212	0.205	-0.160	-0.088
	[0.142]	[0.107]*	[0.087]	[0.114]	[0.145]	[0.110]*	[0.063]*	[0.105]
$\hat{\lambda}$	-0.188	-0.780	0.437	0.451	-0.202	-0.340	-0.255	0.283
	[0.22]	[0.213]***	[0.162]**	[0.198]**	[0.332]	[0.277]	[0.199]	[0.255]
Count. Dum.	No	No	No	No	Yes	Yes	Yes	Yes
Observations	1711				1711			
L Pseudo LL	-2346.45				-2301.58			
Wald Chisq	4512.22***				4441.32***			

* denotes 10% significance level, ** denotes 5% significance level, *** denotes 1% significance level.
Robust standard errors.

Table 5
Estimates of the disturbance covariance matrix (1711 observations)

	Informal Agreement	Formal Agreement	Co-Invention
Informal Agreement	1		
Formal Agreement	0.096 [0.045]**	1	
Co-Invention	-0.426 [0.055]***	-0.526 [0.038]***	1
Co-Assigment	-0.018 [0.065]	-0.125 [0.039]***	-0.824 [0.046]***