department of economics
"S. Cognetti de Martiis"

Via Po, 53 – 10124 Torino (Italy)
Tel. (+39) 011 6704917 - Fax (+39) 011 6703895
URL: http//www.de.unito.it

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THE NATURE OF COLLABORATIVE PATENTING ACTIVITIES

Roberto Fontana e Aldo Geuna

Dipartimento di Economia “S. Cognetti de Martiis”

LEI & BRICK - Laboratorio di economia dell'innovazione "Franco Momigliano"
Bureau of Research in Innovation, Complexity and Knowledge, Collegio Carlo Alberto

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The Nature of Collaborative Patenting Activities

Roberto Fontana*

Department of Economics, University of Pavia
& KITeS - Bocconi University

&

Aldo Geuna**

Department of Economics S. Cognetti De Martiis, University of Torino
BRICK, Collegio Carlo Alberto
& Grenoble Ecole de Management

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* Corresponding author: Department of Economics, University of Pavia, Via San Felice 5, 27100, Pavia, Italy and KITeS - Bocconi University, Via Sarfatti 25, 20139, Milan, Italy. Tel: +39 02 58 36 30 37; Fax: +39 02 58 36 33 99; email: roberto.fontana@unibocconi.it

** Department of Economics S. Cognetti De Martiis, University of Torino, Via Po 53, 10124 Torino, Italy. Tel: +39 0116703870, Fax: +39 011 6703895; email: aldo.geuna@unito.it

Abstract

We investigate the reasons why different governance modes are used in a sample of successful collaborative patenting activities in Europe. First we show that collaboration activities in the patenting process are much more common than one may expect by looking only at information on co-assignment. Indeed, collaborative patenting activity accounts for more than a quarter of all patents in our sample. This figure is about eight times higher than that from co-assignment data (usually considered to assess co-operation in patenting). We then examine the impact of organizational, individual and project determinants on the choice of three possible modes of governance: co-assignment, co-invention, collaborative agreement. We find that higher project complexity and technological scope are associated to tighter modes of governance. We also find a significant negative relationship between licensing and co-assignment, thus providing some support to the view that some licensing can be the result of ex-ante legal agreements rather than of the presence of a market for technology. Finally, inventor specific characteristics matter too. In particular, age increases the probability of choosing looser governance modes while better education is associated to tighter modes.

JEL: O31, O34, L24
Key words: Patenting, Cooperation, Governance structure, Spillovers

1. Introduction

The process of innovation has been increasingly relying upon collaborative activities between firms and between firms and other research organizations such as universities and public and private research institutes. This process has made the traditional internal lab based R&D organization less central to the process of innovation. The recognition by firms that sourcing relevant knowledge outside their own boundaries can be cost effective (at least in the short term), and the most recent attempts to rely on the 'open innovation' model (Chesbrough, 2003) have created strong incentives for the downsizing of internal R&D labs. Also, complex R&D activities in multi product firms demand the integration of different bodies of knowledge that cannot easily be mastered within a single laboratory (Granstrand *et al.*, 1997). Therefore, only very few large multinational companies may achieve the necessary lab size to have the required variety of research competences. Finally, the possibility of protecting and codifying (at least partially) knowledge in new fields and of technologies (such as biomedical) with patents has accelerated the development of some forms of market for technology.

During the last decade, collaborative innovative activity resulting in patents has become crucial within the wider context of research collaborations and the subject of extensive academic debate. Collaborative innovative research leading to patents can be based on different modes of governance of Intellectual Property Rights (IPRs) resulting in a formal co-assignment[1] or in other forms such as co-invention and/or other types of agreements. 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 an R&D co-operation leading to a patent. Our research question is the following: How do we explain that R&D cooperation agreements may entail different modes of governance even within a regime of strong Intellectual Property Right (IPR) protection warranted by a patent? In other words, why do firms and other organizations that engage in successful R&D cooperation (i.e. the outcome of

[1] In the rest of the article we will use interchangeably co-assignment and co-ownership meaning that a patent has more than one assignee/owner (individual or organization to which the patent has been assigned therefore becoming the legal owner(s) of the patent rights).

the cooperation is a patent) may choose to establish 'tight' modes of governance such as *co-assignment* in alternative to 'loose' modes such as *co-invention* and *research agreement* that does not generate a specific property right on the invention for at least one of the partners?

Existing contributions (Oaxley, 1997; 1999) have stressed that in collaborative contexts, the choice of a mode of governance is the consequence of the presence of a specific level of appropriability hazard underlying the collaboration and therefore the choice should mainly be explained in terms of project level attributes. In this paper we argue that other determinants and institutional factors matter in the definition of a mode of governance. Specifically, we focus on the role of organizational (i.e. environment specific), individual (i.e. inventor specific), and legal factors.

Our investigation is based on data from the PatVal database, a sample of 9,017 European inventors and their associated patents granted at the European Patent Office (EPO) between 1994 and 2002 (Giuri, Mariani *et al.*, 2007). 88% of the patents in our sample were granted in the five year period 1997-2001. Relying upon this dataset, we identified those patents that are the outcome of a collaborative R&D project as those involving: co-assignment, co-invention, or some form of collaborative agreement (as identified by a question in our questionnaire). On the basis of this original measurement of successful R&D collaboration we highlight the remarkable difference in the level of co-assignment compare to the other forms of collaboration (there is much more collaboration that what has traditionally been measured only on the basis of co-assignment data) and analyze how co-patenting varies across countries, technological classes, and types of organizations (firms, universities, public research organizations and other organizations). Finally, we run a set of econometric analyses (with sample selection) to study the choice of a governance mode conditional upon the patent being the outcome of an innovative collaborative project. We find that project related characteristics such as higher complexity (as measured by the cost of the project) and technological scope impact on the choice of the governance mode, thus confirming the result of the existing literature. However, we also find that other factors play an important role. The characteristics of the research or development unit (such the size of the firm or being it a public research organization) have an impact on the propensity to collaborate and only marginally affect the governance structure. Inventor specific characteristics that could affect monitoring costs and/or investment risk also matter. In particular, younger inventors with a PhD, living in large cities are associated to a higher probability of co-assignment. We also find a significant negative relationship between licensing and co-ownership, thus providing some support to the view that a portion of licensed transactions is the result of ex-ante legal agreements between research unit (asking for the ex-post license to conduct further research but not willing/interested to bear the cost of patenting) and development unit rather than the instrument through which markets for technology work.

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 and provides the preliminary detailed descriptive analysis of collaborative patenting activities in Europe. Section 4 discusses the variables and the econometric models used in the empirical analysis. Section 5 presents the results and Section 6 discusses some of the findings. Section 7 concludes.

2. The governance of collaborative patenting activities

There is a very large theoretical and empirical literature examining the determinants of R&D co-operation. This literature can be organized around three main approaches. First, there are game-theoretical models developed following the seminal work of d'Aspremont and Jacquemin (1988). Second, there is the transaction cost framework that emphasizes the different types of co-operations (Williamson, 1996). Third, there are the strategic management approaches (or resource based theories of the firm) that study the reasons for the rapid development of this new form of company interaction since they appeared in the second half of the 1970s (Mowery, Oxley & Silverman, 1996). Parallel to the theoretical analysis, the field has also seen the development of a 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). With the exception of Hagedoorn *et al.* (2003) and Hagedoorn (2003), very few papers have studied collaborative activities on the basis of patents data. Hagedoorn *et al.* (2003) develop an econometric estimation that provides evidence that the probability of co-assignment increases with previous engagement in collaborative activity. No other variable in their analysis impacts on the probability and, contrary to other empirical evidence on the determinants of R&D cooperation, no significant positive correlation between firm size and co-patenting is found. Such a limited amount of evidence and the growing importance of the phenomena (Hicks and Narin, 2001; Hagedoorn, 2003) calls for further scrutiny of the possible determinants. This paper is the first systematic attempt to analyze them.

On the basis of the existing evidence we argue that collaborative innovative activities resulting in patents can be 'symmetric' or 'asymmetric'. Symmetric collaborations entail a real collaborative effort between two or more partners to develop an invention/innovation. Asymmetric collaborations occur instead when one of the partners demands a specific research service to another organization. A specific case of asymmetric collaboration is the one in which a Development Unit buys the research service of a Research Unit (a typical situation in the biomedical and instrument fields). Within this framework we investigate the factors affecting the choice of the mode of governance such as the decision of co-assigning a patent.

We identify four sets of factors. First, there are the *characteristics of the project* that determine the appropriability hazard level and consequently impact on the choice of the governance mode. Second, there are the *characteristics of the organizations* involved in the transaction that can directly impact on the co-assignment decision or indirectly through the propensity of collaborating. Third, there are the *individual characteristics* (i.e. the inventor) that impact on monitoring costs and affect the level of investment risk. Finally, there are *legal aspects* since it has become common practice to involve attorneys from the starting of the collaboration therefore shaping the process of patent ownership allocation.

Project characteristics

The choice of a governance mode for an R&D project is mainly a function of its appropriability hazard which is, in turn, an inverse function of three dimensions: the extent of IPRs specification, contract monitoring, and enforcement. Better IPRs specification, better monitoring and better enforcement reduce the level of appropriability hazard and decrease the probability of choosing a tighter mode of governance. By devising suitable indicators for these dimensions it is possible to understand the determinants of the choice of a specific form of governance through their impact on the appropriability hazard. Suitable indicators have traditionally been related to the transaction and specifically to the *characteristics of the project*. As argued by Teece (1986) definition of IPRs appears problematic when projects entail 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 results 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 tight forms of governance such as co-ownership. IPRs definition is also sector and country specific (Oaxley, 1999). Thus cross sectoral differences in the propensity to patent and in co-assignment may also be reflected in the choice of the form of governance with sectors more inclined to patent also more likely 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 characteristics should therefore increase the probability to co-assign or co-invent.

Organizational characteristics

Increased collaboration between firms and other organizations such as universities and PROs as well as public policy support for patenting by the latter group of institutions call for an assessment of whether organizational characteristics affect the governance structure of collaborative patenting activities. On the one hand, the development of technology transfer infrastructures within universities and the increased use of patents as metrics for the evaluation of the performance of PROs have created incentives for these institutions to claim a share of the ownership of the invention. On the other hand however, small private research units may want to be allowed in the future to do further research in the area covered by the patent (for example by a license) but they may not want (or have no interests in) the co-ownership of the patent especially in those cases, such as with the European Patent Ofiice (EPO), in which ownership costs are high.

Individual characteristics

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) and the choice of the governance mode. Individuals, their social networks and mobility have been proven to be the main responsible for the flow of innovative knowledge and the size of the network is in turn 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 create monitoring problems. Thus we should expect better educated inventors to be associated to a tighter mode of governance such as co-assignment. It has also to be noted that the age of the inventors is likely to impact on the choice of a governance mode too. Young researchers have been found to be linked to higher mobility and therefore conducive to increasing monitoring costs. Crespi *et al.* (2007) 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. Mobility is likely to increase potential geographical dispersion thus making monitoring more problematic. Assuming the presence of a negative relationship between age and mobility, we should therefore expect young inventors to be associated to co-assignment.

Legal aspects

Finally, to explain the governance structure of collaborative patenting activities, and more precisely to explain why organizations decide to co-assign a patent we need to take into account also the important role played by legal aspects. Anecdotal evidence, supported by a set of interviews to patent attorneys and academic researchers experts in patenting practices, highlights that in certain cases private agreements are designed in such a way that the ownership of the patent stays with one assignee only. The other partner(s) (being them the inventor herself or the organization employing the inventor or being involved in the collaboration), may get a monetary compensation and/or an agreement setting the right for ex-post licensing of the invention at zero or near zero costs. A paramount example of this type of practice is the case of academic patents in which there is an academic inventor who receives compensation but the patent is owned by a company (Geuna and Nesta, 2006). Interviews in Spain and Italy have also confirmed that this practice applies to private research units too. Anecdotal evidence from Germany, France, Spain and Italy confirms that ex-ante private agreements to share the property rights are becoming common practice not only when one of the parties is a university or a research unit but also across other types of organizations. Instead of choosing co-ownership, the use, the benefits, and the administration of the invention by the second/third/etc. inventor(s) are regulated by a private contract that may grant, alongside rights and duties, an ex-post license on the invention. The reason for using the ex-post license contracts is that in this way it is possible to define the use of the patent by the partners in a clearer way.[2] This form of legal agreement is used to avoid the problems in the filing process and the high transaction costs associated to the management of licenses of co-owned patents, costs and problems that can be particularly important in the case of international collaborations for which different legal property rights systems may apply (Feldges and Kramer, 2007). Practitioners sometimes refer to licensing a co-owned patent as having to rent an apartment from two owners, indicating how the situation for the licensee is undesirable. Indeed, contrary to the US, in the case of German and UK patents a owner must ask the consent to all other co-owners before licensing the patent to a third party (the license cannot be exclusive either). The rules that apply to the joint ownership of real property also apply to intellectual property (Feldges and Kramer, 2007; Marchese, 1999). A similar approach is also present in the case of Dutch, French (co-owners can ask compensation for the use), Italian and Spanish property right regulation. When co-ownership rights require the need for the consent (and compensation) for the use of the patent there is a risk of under-utilization of the patent due to strategic behavior. Mergers and Lawrence (1989) show with a simple game theory model set-up (the 'chicken' game) that, under certain conditions, the optimal solution is the one in which no one will decide to go head and use the patent. Ex-ante agreements, when the exact final value of the invention is not known to the involved actors, can help in solving this kind of problems (Scotchmer, 1996).

3. Patterns of collaborative patenting activity

The literature and evidence discussed above suggest that after controlling for project and organization level characteristics, we need to account for individual characteristics as well as for the strategies on IPR management and licensing. The data used for our econometric estimations allow us to develop a detailed analysis of inventor's characteristics while controlling with simple proxies for the other factors.

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[2] The source of this information is a discussion with Dr. Ulrich Schmoch, Dr. Patrick Llerena and Dr. Massimiliano Granieri on current practices in the German, French and Italian patent system as well as a set of discussion with patent attorneys in those countries and Spain. This said, it is quite common that also in the case of co-ownership the owners sign an ex-ante agreement that specifies the right of use of the patent which may include the possibility of licensing without the need to ask for consent.

The data used in this paper come from the PatVal database, a sample of 9,017 European inventors and their associated patents registered at EPO between 1993 and 1997 and granted in the period 1994-2002 (88% in the five years period 1997-2001). 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 an address in EU-15 countries.[3] We have decided to use this database because it allows us to focus on the patent as the unit of analysis but also to have information on some of the characteristics of the organization(s) that own the patent and the characteristics of the patent inventor. Furthermore, specific patent information enables us to develop for the first time a detailed characterization of collaborative patenting activities in Europe.

In our sample, there are 553 patents that are co-assigned (6.1% of our sample), of these only 323 are assigned to companies belonging to different groups (***Co-assigned Collaborative Patents***). They represent 3.6% of our sample. There are 3261 patents with only one inventor, while 5756 have multiple inventors. Of the 5468 that responded to a question on their employment, 1309 patents include inventors with employers from different organizations.[4] These are ***Co-invented Collaborative Patents*** and represent 15% of our sample. It has to be noted that the two sets are only 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. Finally, 1745 patents (20.5% of the sample) involved research collaborations either formal or informal (we were able to ascertain this on the basis of a specific question of the PatVal questionnaire, see the Appendix). We define these patents ***Collaborative Agreement Patents***. Most of the cases in which the research leading to the patent was based on collaboration have resulted in a co-invention or co-assignment.

[3] For a detailed discussion of the basic characteristics of the PatVal database, the methodology and response bias see Giuri and Mariani *et al.* (2007).

[4] The question used to classify *co-invented collaborative patents* is: "Were one or more of your co-inventors listed in the patent employed by organizations other than your primary employer at the time of the invention"? On the basis of this question, we cannot rule out that some of the organizations may be linked to each others by some form of ownership. The ownership structure was instead checked in the case of the assignee.

However we identified also 348 patents (***Agreement Only***) in which this was not the case. Overall, if we include all the possible definitions of collaborative patenting activity and we sum those respondents saying that there was a collaboration with those respondents that have a co-assignment or a co-invention but they answered that there was not a collaboration, we obtain that more than one quarter of our sample of patents involved some form of collaboration (2403 ***Overall Collaborative Patents*** or 28.9% of the sample). Table 1 below summarizes the frequencies for the patents in our sample. Using the total number of patents filed in the six countries between 1993 and 1997 at the EPO we find a share of co-assignment of 6.2%. The share of co-invented patents in the same countries over the same time period equals 55.4% instead. Both shares confirm the representativeness of our sample.

[Table 1 approximately here]

As pointed out in previous work (Giuri, Mariani *et al.*, 2007) our figures clearly highlight that the process of R&D collaboration originating a patent is much more common than what one could guess from the 'standard' information on co-assignment. The previous analysis by Giuri, Mariani *et al.* (2007) briefly reports about some fixed effects characterizing different levels and modes of collaboration, in this section we develop a detailed analysis of country, technology and organizational effects.

[Table 2 approximately here]

Table 2 presents the distribution of the collaborative patenting activities across countries. We find small cross country differences looking at *co-assigned collaborative patents* with France being the country with the highest share at 5.4%. This finding is consistent with the general figure in the EPO database that sees France as the country with the highest incidence of co-ownership (Malerba *et al.*, 2007). Moving from co-assignment to the other two forms of collaborative patenting there is an increasing level of diversity, the standard deviation increases from 1 to 4.5 and 6.9 indicating that, as we move toward looser forms of governance, countries tend to display a more heterogeneous behaviour. Indeed, we also find extreme values in the shares of the different forms of collaborative patenting activities. For example, UK is the country with the maximum share of *co-invented collaborative patents* (21%) while Spain has the minimum with 9.4%. When we consider those *collaborative agreement patents* that were based on some form of research collaborations The Netherlands has the highest value with 34.5% and Germany has the lowest with 13.3%. Overall, about 40% of Dutch patents were the result of some form of research agreement while only 22% in Germany.

Technological classes differ very little in term of their share of *co-assigned collaborative patents*, however more heterogeneity is present when we consider the other two forms of collaborative patenting (see Table 3).

[Table 3 approximately here]

Compared to the previous table, changes in the standard deviation are less large and values tend to be similar for the two loosest forms of collaboration. Also, the ranking of the technological classes tends to be quite stable across alternative governance modes. Consistently with the literature on R&D collaboration, Chemical and Pharmaceutical technologies and Instruments are the sectors in which collaborative patenting is more frequent with more than 30% of patents in those technological classes being based on some form of agreement.

A question in the PATVAL survey asked respondents to state the nature of the employer where the researcher leading to the patent was performed. Five types of organizations were identified: Firms, Universities, Public Research Institutes (PROs - including government research organizations), Private Research Organizations (including hospitals and foundations) and Others. 93% of the inventors were employed by a firm. 72% were employed by Large firms (>250 employees) and 22% by Medium (100 – 250 employees) or Small (< 100 employees) enterprises. 3.2% worked for Universities; 2% for PROs; and the remaining 1.8% for private research centers, hospitals, foundations, and other organizations. This prevalence of firms notwithstanding, some specificity can be highlighted. Table 4 provides a fascinating picture of the differences in the relative importance of collaborative patenting activity according to the type of organization of the inventor.

[Table 4 approximately here]

As expected, large firms rely less on all the forms of collaborative patenting. Still about a quarter of patents by Large firms were based on some form of collaborative agreement (*Overall collaborative patenting*). PROs display the highest share of *co-assigned collaborative patents* with about 14%. However, as it will be discussed further, this result seems to be driven more by appropriability issues rather than by the propensity to collaborate. When we look at all the other forms of collaborative patenting, Universities outperform PROs in terms of collaborations reaching the staggering figure of almost ¾ of all patents with an academic inventor being based on some form of collaborative agreement (while only 5.6% are *co-assigned collaborative*). As in the previous tables, the propensity to co-assign tends to be more homogeneous across organizational types, while less tight typologies of collaborative patenting activities display higher levels of collaboration as well as much higher variance. For example, Medium Firms have slightly higher levels of *co-assigned collaborative* patents (3.7%) than Large and Small Firms, while Small Firms have higher levels of collaborative patenting in the other two forms (15.2% and 23.9% respectively). Overall, about one third of total patents involving a Small Firm were based on some form of collaborative research.

These striking results raise a number of interesting questions concerning the reasons why major differences exist between the various forms of collaborative patenting activity. In the next section we develop an econometric analysis to test for project, organization, and individual characteristics that can affect the probability of choosing a different governance mode.

4. Empirical Analysis

To develop our econometric analysis we have chosen to classify the data in three non-overlapping categories to capture the three possible alternative governance modes: CO-

ASSIGNED, CO-INVENTED ONLY, AGREEMENT ONLY. The first category includes all the ***Co-assigned Collaborative Patents*** (323), the class CO-INVENTED ONLY includes the ***Co-invented Collaborative Patents*** (1118) that did not result in a co-assignment of the patent, finally the group AGREEMENT ONLY includes patents (348) that were neither co-assigned nor co-invented.

To examine the factors affecting the choice of the governance mode in a collaborative patenting project we first have to account for what influences the probability of engaging in co-patenting (selection bias). Thus we define two sets of covariates: a set of variables that influence the probability of engaging in collaborative patenting and a set of variables that influence the choice of the governance mode. The original contribution of this paper resides mainly in modeling the governance modes, applying a control for the selection bias.

Below we introduce the variables used in the econometric exercise. Following our theoretical framework, they are classified into four groups. First, we consider a set of variables related to the type of *project* underlying the specific patent. In line with previous literature we expect a significant and important impact of these variables on the choice of the governance mode. Second, we consider a set of 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 both through the propensity to co-operate and the choice of form of governance. Third, we test for the influence of *individual* characteristics of the inventor as well as of the motivation to patent. Fourth, we use a simple, and admittedly indirect, proxy for *legal* aspects impacting the co-assignment of the patent.

Project characteristics

The choice of a governance mode is affected by project related characteristics such as: complexity (or costs) and breadth. 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 larger the investment, 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 and broader mode of governance.

Organizational characteristics

Organizational characteristics affect both the probability to co-operate and the mode of governance.

A set of 'environmental' characteristics related to the organizational affiliation of the inventor can affect the probability of carrying out an innovative collaborative activity. 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. We use information on the boundaries of size intervals defined in 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.

The relative importance of sources of knowledge (i.e. incoming spillovers) can influence 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.[5]

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). Also, evidence from the analysis of French patenting of public research institutions (including universities and PROs) highlight the high propensity of PROs to take co-patents also due to visibility and measurement of research output reasons (Lissoni *et al.*, 2007). Finally, in Europe is very common to have university invented patents assigned to companies instead than co-owned or owned by the university (Geuna and Nesta, 2006; Lissoni *et al.*, 2007). In line with these findings, and taking into account the statistical results on PROs results presented before, we take the combination of public and private research organizations as a reference category expecting universities and firms to have a relatively lower

[5] An alternative interpretation of the spillover proxy based on the relative importance of external sources of information would refer to the 'openness' of the firm to the external environment (Fontana *et al.*, 2006; Larsen and Salter, 2006).

probability to co-assign the patent. **FIRM** and **UNIVERSITY** are two dummy variables equal to 1 if the inventor was employed by a firm or a university respectively.

Finally we take into consideration the role of R&D subsidies. Co-operative research projects may or may 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. The involvement in government sponsored R&D project is most often associated with the requirement of defining a pre-agreement on how to share property rights. The high level of uncertainty before the start of the research project creates strong incentives for all the actors asking the ownership of the eventual IPR, therefore in the case of public R&D subsidies we would expect to have a higher probability to choose a tighter mode of governance. **GOVFUNDS** is a dummy equal to 1 if the research leading to the patent has benefited from government research programs and/or other government funds.

Individual characteristics

We control for the influence of individual characteristics of the inventor, such as age, level of education, work location and motivation to patent. **AGE** is the natural logarithm of the age of the inventor at the time of patent application. Younger inventors are relatively more dynamic and mobile. To the extent that higher mobility generally entails higher job searching, it may increase monitoring problems therefore leading to the choice of tighter modes of governance for the 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. 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.

Legal aspects

The governance mode can also be related to the existence of an ex-post license. **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 looser modes of governance to be associated to patents that have been licensed. Also, both the anecdotal evidence collected interviewing patent attorneys and the theoretical analysis discussed in Section 2 stress that firms involved in R&D agreements may decide to have private legal agreements in which a single company is chosen to be the applicant and future owner of the patent and the other individuals/organizations part of the R&D project are granted the right to become licensees of the patent. Thus, an ex-post license is the result of an ex-ante private agreement. If ex-ante private agreements resulting in ex-post license rights are an increasingly common practice, we would expect relatively looser modes of governance to be associated to patents that have been licensed.

Technology fixed effects are included in the model. We expect that technological factors are important in the decision of collaborating as technologies (and sectoral innovation systems) are characterized by different propensities to rely upon collaborative innovative processes (i.e. for example, technologies in the pre-paradigmatic phase should depend more on collaborative innovative agreements). Concerning the choice of specific modes of governance, on the basis of our descriptive statistics, we would expect technological factors to be relatively less important. Country fixed effects are included too. We expect that certain national systems of innovations should be 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 and employment contracts and incentives. The definitions for the variables used in the regression and the descriptive statistics are listed in Tables A1 and A2 respectively (see Appendix). In the remaining of this Section we present the econometric models that are estimated.

4.1. Econometric models

To study the determinants of the choice of a specific governance mode we carry out two types of analysis. First we estimate a Multinomial Logit regression. Second, on the basis of the result of the first part of the analysis and to provide a robustness check, we develop a further set of estimations applying an Ordered Probit model. In all 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 and correct for selection bias. Our Multinomial Logit model can be specified as follows:

$$\Pr\left(Mode_j^* = j\right) = \frac{\exp\left(\gamma_j^{'} Z_i\right)}{\sum_{k=0}^{2} \exp\left(\gamma_k^{'} Z_i\right)} + \eta_j \qquad (1),$$

where MODE$_j$* is the latent variable associated to the modes of governance, Z contains the covariates, γ are the coefficients to be estimated, η is a random error term.

MODE$_j$* is not directly observed but we assume that it takes the value of (MODE$_2$= 2) if the patent is *Co-assigned*, (MODE$_1$= 1) if the patent is *Co-invented Only*, (MODE$_0$= 0) if the patent is *Agreement Only*. The probabilities of assuming one of these values 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 collaboration.[6] A latent variable COLL$_J$* is associated to this binary variable:

$$Coll_j^* = X_j \beta + \varepsilon_j \qquad (2)$$

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 $\left(\hat{\beta}\right)$. In the second stage we then estimate a regression model augmented by the selection variable $\hat{\lambda}_j$. In other words we estimate the following:

$$\Pr\left(Mode_i^* = j\right) = \frac{\exp\left(\gamma_j^{'} Z_i\right)}{\sum_{k=0}^{2} \exp\left(\gamma_k^{'} Z_i\right)} + \gamma_\lambda \hat{\lambda}_j + \eta_j \qquad (3)$$

for all j with COLL$_J$* > 0.

$\hat{\lambda}_j$ is obtained from the estimation of the selection equation in the first stage. If parameters are estimated simultaneously the second stage estimation provides correct

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6 COLL$_j$ is equal to one if the patent is either co-assigned collaborative, co-invented collaborative, or collaborative only.

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 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.

5. Results of the analysis

To investigate the determinants of the choice of a governance mode for collaborative innovative research projects we estimated two equations. First we used a Logit model to estimate the probability that the patent resulted from an innovative collaborative activity. This estimate is our selection equation.[7] Then we used a Multinomial Logit to estimate the probability of choosing one specific mode of governance with respect to the others. 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. These results are reported in Table 5 below.[8]

[Table 5 approximately here]

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[7] This equation includes a series of covariates which the literature has identified as important determinants of the probability to engage in collaboration (see Section 4) as well as country and sector fixed effects. Our results, not fully reported here for the sake of brevity, indicate a positive dependence on SIZE indicating that large firms are more likely to cooperate. However, a negative and significant coefficient of $SIZE^2$ 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). The coefficient for PUBLIC INCOMING SPILLOVERS is significant suggesting that innovators who tap external sources for information are more likely to engage in cooperative R&D projects. The coefficient for PRIVATE INCOMING SPILLOVERS instead is not significant. However 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.*, 2009). 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.

[8] Results reported in Table 5 and in Table 7 are robust to the inclusion of variables attempting to capture the value of the innovation such as the subjective evaluation by the inventor or the number of forward citations received by the patent. Both variables were never significant when included in the model.

Generally, results for both GOVFUNDS and UNIVERSITY are weakly or not significant, thus indicating that they were good instruments in the first stage equation. The coefficient of $\hat{\lambda}_j$ when significant indicates that not correcting for sample selection would have produced biased estimations and that the decision to co-operate and the choice of a specific governance mode are not entirely disjointed. More specifically, our findings indicate the significant role played by project, organizational, individual characteristics as well as legal aspects for the choice of a governance mode.

Column (1) presents coefficients from the comparison between *Co-assigned and Agreement Only* patents. Our findings for the variables related to project level characteristics are the following. The positive and significant coefficient of COMPLEXITY indicates that higher levels of project complexity, as measured by the man months required for the research, increase the probability to lead to co-assigned collaborative patents rather than to patents based on agreement only. High uncertainty complicates property rights definition and leads organizations involved in the collaboration to further protect their interests by developing patents involving tighter forms of governance such as co-assignment. BREADTH enters positively and significantly suggesting that patents spanning across several technological classes tend to be relatively more co-assigned than based on collaborative agreements only. This result can be the consequence of both property right definition and the presence of monitoring costs. 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 may increase with the number of technologies involved in a project. In both cases, the stipulation of a tighter mode of governance is required.

Concerning the impact of organizational characteristics, the negative and significant coefficient of FIRM suggests that firms are less likely than the reference category (i.e. public and private research organizations) to file co-assigned collaborative patents, when compared to patents based on agreements only. More interesting are our results for the influence of individual characteristics of the inventor. We find a negative and significant coefficient of AGE. Young inventors are more mobile and relatively more likely to change job. This is likely to increase monitoring problems and lead to co-assigned collaborative rather than collaborative only patents.[9] The coefficient of PHD is positive and significant, suggesting that better educated inventors are relatively more likely to engage in co-assigned collaborative than in collaborative only patents. The coefficient of CITY is also positive and significant albeit weakly. This result indicates that location of inventors in big towns increases the probability to engage in co-assigned collaborative patent activity when compared to collaborative only. This is the likely consequence of raising monitoring problems due to potential higher geographical dispersion.

Finally the coefficient of LICENSING, our proxy for the legal aspects, is negative and significant, indicating that patents that have been licensed are associated to a relatively lower probability of being co-assigned. A possible explanation for this result is that the presence of voluntary licensing instead is in itself an indication of the absence of problems in property right specification, monitoring and/or enforcement. Within this context of relative low uncertainty, rights can be shared through ex-ante private agreements which do not entail co-ownership but give rise to an ex-post license.

Column (2) reports the comparison between *Co-invented Only* and *Agreement Only* patents. The coefficient of PhD is positive and significant, suggesting that better educated inventors are more likely to become involved in projects leading to co-invented collaborative than collaborative only patents. COMPLEXITY enters positively and significantly. This result suggests that more complex projects are more likely to end up in a collaborative co-invented rather than a collaborative only patent. Finally, the coefficient of LICENSING is negative and significant. This result indicates that

[9] To probe further into the relationship between mobility and the choice of a governance mode, we constructed a more direct measure for mobility. We used the information contained in the questionnaire to understand whether the inventor had changed job before filing the patent and used it to construct a dummy variable. The coefficient of this variable was always not significant in all the specifications we tried. We also built another categorical variable indicating how many times the inventor did move after the filing of the patent, an indicator of ex-post mobility. Also in this case the variable turned out to be not significant.

collaborative patents that have been licensed are associated to a relatively lower probability of being co-invented. Also this result is consistent with the previous one.[10]

Finally, column (3) compares the results for *Co-invented Only* and *Co-assigned* patents. The coefficient of BREADTH is negative and significant. This suggests that patents covering several technological classes tend to be relatively more collaborative co-assigned than collaborative co-invented only. AGE enters positively, indicating that the younger the inventor, the more likely to engage in co-assigned collaborative than in co-invented collaborative patents. Both these results corroborate our previous evidence from the comparison between collaborative only and co-assigned patents. Finally, the positive and significant coefficients of both UNIVERSITY and FIRM suggest that both universities and firms are more likely to file collaborative only patents, when compared to co-assigned collaborative, than the reference category (i.e. public and private research organizations).

At the bottom of the table we provide the results of two tests. 'Combined' tests the null hypothesis that two categories (i.e. *Co-invented Only* and *Agreement Only*) can be combined for all combinations of outcomes. Our results show that the null hypothesis can be rejected. We then test the validity of the independence of irrelevant alternatives (IIA) by performing a Hausman test. In this case the null hypothesis is that the categories are independent from each other. On the basis of our results we cannot reject the null hypothesis.

Table 6 reports the predicted probabilities for each of the governance mode. These probabilities have been calculated by setting the values of the explanatory variables at their mean. We can observe that for the patents in our sample the overall probability of being co-assigned is 16.5%, the probability of being co-invented is 64.0% and the probability of being based upon a simple agreement is 19.5%. To assess the difference in the impact of the explanatory variables upon these probabilities we have then computed the marginal effects only for the significant variables. For dichotomous variables,

[10] The inclusion of country fixed effects does not change substantially these results. In particular, contrary to our expectations, project related and individual characteristics generally maintain their significance.

marginal effects have been computed for a change from zero to one. In the case of continuous variables the change in the predicted probability has been computed for a variation of two quintiles around the mean. These marginal effects have been calculated as discrete change when holding the other explanatory variables constant at their median values. For each variable we report the absolute and the relative change in probability.

[Table 6 approximately here]

The following observations are in order. First, the relationship between the explanatory variables and the choice of a mode of governance is generally linear. Changes in the marginal effects vary monotonically going from symmetric forms to asymmetric forms of governance. The only exceptions are UNIVERSITY, PHD, and LICENSING, for which the relationship is non linear. Interesting is the case of LICENSING for which the relative change is large. In particular, a patent that has been licensed decreases its probability of being co-assigned or co-invented by 8.7% and 11.9% respectively while it increases its probability of entailing an agreement of 38.4% (though the coefficient was not significant in this case). This result confirms that, for the patents in our sample at least, the use of a private contract that may grant rights and duties on the invention is generally preferred to co-ownership. This result contributes to a better understanding of the increased reliance on licensing witnessed in recent years in a variety of sectors. The main explanation for this phenomenon relies upon the concept of 'markets for technology' (Arora *et al.*, 2002) according to which an easier codification of knowledge (also due to the diffusion of ICT) has allowed the creation of a market for patented technology (knowledge) via licensing. Our result provides some evidence that licensing can be interpreted *both* as a result of the development of a market for knowledge *and* as a result of ex-ante private agreements for the sharing of the knowledge created within R&D cooperative projects. An increased number of collaborative innovative activities associated with more complex and quickly changing knowledge production (for example the development of the ICT and biotechnology industries during the 1980s and

1990s as well as the growth of the nanotech industry in recent years) have resulted in an increase in the number of licenses.

As mentioned above, in the case of PhD the effect is also non linear and particularly large. Patents involving inventors with a PhD have a 20.7% higher probability of being co-invented and a 51% lower probability of being based on a simple agreement than patents taken by inventors without a PhD. This result indicates that better education is conducive to symmetric collaborations requiring the involvement of the inventor to prevent that she will not diffuse the knowledge produced. However, this involvement does not include a share of property rights given that when better educated inventors are involved, the probability that the patent is co-assigned decreases by almost 7%.

Finally, results for project characteristics suggest that they impact more on co-assignment than on the other two modes of governance. In the case of COMPLEXITY, a 20% increase in the man months required for the research leads to a 9.1% increase in the probability of co-assigning the patent while widening the patent breadth of 20% leads to a 21% increase in the probability to co-assign against a 1.57% and 11% decline in the probability to co-invent or establish a simple agreement respectively. These results are in line with exiting contributions (Oaxley, 1997; 1999) highlighting that an increase of the appropriability hazard generally tends to increase the probability of establishing better defined property rights in the transactions.

5.1. Further estimations and robustness check

In most cases the opposite sign of the variable in columns 1 and 2 compared to column 3 seem to suggest the presence of a 'rank' in the governance modes of collaborative patenting activities going from *Co-assignment* to *Agreement Only*. To test whether our findings hold in the presence of this underlying assumption concerning the 'hierarchy' of the modes of governance we perform an additional Ordered Probit analysis, in which the choice of a specific mode of governance is the consequence of the level of appropriability hazard associable to an innovative collaborative research project. The assumption is that a more hierarchical mode of governance derives from the need to protect against a higher level appropriability hazard. Results are reported in Table 7 below.[11]

[Table 7 approximately here]

Column (4) reports the marginal effects for the selection regression (Probit). Column (5) reports instead the results from the Ordered Probit regression. Altogether, these findings seem to confirm the previous ones. First, availability of Government funds, presence of incoming (public) spillovers, and firm size increases the probability to engage in R&D cooperation. In the case of firm size, the relationship is not linear (see footnote 7 for a comparison). Second, the choice of a specific mode of governance is driven by project characteristics. In particular, broader technology scope increases the probability of choosing relatively more hierarchical modes of governance such as co-assignment or co-invention. Organizational characteristics such as the type of organization involved in the cooperation also matters, though to a lesser extent. Third, younger and better educated inventors have higher probability to be associated to more hierarchical modes of governance. Finally, the presence of licensing is associated to less strict governance modes such as the absence of co-assignment or co-invention, indicating instead that other forms of private agreement for the sharing of the right (e.g. giving a license instead of co-ownership) are at work.[12]

6. Conclusion

This paper has provided a preliminary analysis of the determinants of the governance structure in successful collaborative inventive activities. We have focused our analysis on three possible modes of governance: co-assignment, co-invention, research collaboration (that does not generate any property right on the invention for at least one

[11] Again we have followed a two stages procedure, with COLL_j as dependent variable in the first stage. In the second stage the dependent variable takes the value of ($\text{MODE}_2 = 2$) if the patent is co-assigned collaborative, ($\text{MODE}_1 = 1$) if the patent is co-invented collaborative, ($\text{MODE}_0 = 0$) if the patent is collaborative only.

[12] As an additional check, we have also run a Multivariate Probit with sample selection to account for the likely presence of correlations between the modes of governance. Not accounting for the presence of likely correlation, by estimating for example separate Probit equations, would produce inefficient estimators. In our case, we have included three equations in which each one of three modes of governance identified is modeled. Again our previous findings have been confirmed.

of the partners). The latter two forms can be interpreted as either the result of an asymmetric collaboration (i.e. a 'service') that did not give rise to a stake in the IPRs but was probably financially compensated or as a symmetric collaboration that was privately regulated by an ex-ante agreement linked to a specific ex-post licence for the use of the invention.[13] The other form of governance considered (co-assignment) can instead be interpreted as the result of a symmetric collaboration that has given rise to the formal co-ownership of the patent.

The first contribution of this paper has been to show that the transformation of the innovative process into a more collaborative endeavour can be traced in the patents statistics. Indeed, more than a quarter of the patents in our sample were related to some form of research collaboration across different organisations. Co-assignment figures, traditionally used to measure collaboration, capture only a marginal part of this phenomenon. Furthermore, the statistical analysis has highlighted that when we look at country, technology and organisation fixed effects, we found a low variance in the co-assignment data and much higher variance for the other types of collaborative patenting consistently with expectations based on national, industrial and organisational heterogeneity.

We have developed a set of econometric models without imposing a hierarchical ordering of the governance modes and, after providing some evidence for this ordering, we also have estimated a set of ordered models. The econometric estimations have provided robust evidence confirming the conclusions of previous literature that higher project complexity and technological scope are associated to tighter modes of governance. We have also found evidence confirming the importance of organisational characteristics, though the results of our study are constrained by the use of poor proxies for the type of organisation involved in the collaboration. More detailed information on the characteristics of the organisation would be desirable but was not available for our large sample.

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[13] This can be, for example, the case of a research unit that carries out a collaborative project with a development unit and wants to keep the rights of using the invention for its future research.

Alongside organisational characteristics, other factors such as inventor specific characteristics and legal were also important in explaining the choice of knowledge governance structure of collaborative patenting activities. In particular we gave foiund that researcher's age increases the probability of choosing less hierarchical governance modes while better education is associated to tighter modes hinting at the relationship between knowledge spillovers (for example through mobility of young researchers or network relationships) and the appropriability of the innovation. Individual costs and risks related considerations influence the decision of using a more structured and costly governance of knowledge transaction. Finally, we also find a significant negative relationship between licensing and co-ownership, thus providing some statistical support to the view (highlighted by the qualitative evidence) that some licensing can be the result of ex-ante strategic decisions on the assignment of IPRs implemented with private legal agreements among collaborative partners rather than the indication of a transaction on a market for technology. This result contributes to the ongoing discussion on the development of the market for technology (Gambardella et al, 2007), underscoring the fact that licences may indeed be the result of a collaboration rather then a market transaction such as in the case of a research company (a small biotech/nanotech research company) that has developed a collaborative innovation with a large company and does not have interest in making the product but want to keep the right to further develop the research.

The results of our study should be appraised within the broader understanding that research collaborations are increasingly becoming internationalized (Guellec and van Pottelsberghe de la Potterie, 2001). In such a context one could expect that given national regulation differences in European countries patent law concerning co-ownership, but also between European countries and the US, it is becoming more common to have ex-ante agreements with no co-ownership to avoid across countries co-assignment. Similarly, individual knowledge spillovers can be easier controlled in the case of national collaborations in which the cultural background is more similar.

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Table 1: Number of collaborations and mode of governance

	No of cases	Percent
CO-ASSIGNMENT		
Single applicant	8460	93.80
Co-Assigned Non Collaborative	230	2.60
Co-Assigned Collaborative	323	3.60
CO-INVENTION		
Single inventor	3261	37.40
Co-Invented	4159	47.60
Co-Invented Collaborative	1309	15.00
RESEARCH COLLABORATIONS		
Non Collaborative	6756	79.50
Collaborative Patents	1745	20.50
Overall Collaborative Patents	2403	28.90

The number of observations differs across variables due to missing values. It ranges between 8326 and 9013.

Table 2: Country specificities in collaborative patenting activity (percent)

	Co-assigned Collaborative	*Co-invented Collaborative*	*Collaborative*	*Overall Collaborative*
FR	5.4	12.3	22.7	30.7
GER	3.1	15.4	13.3	22.4
IT	4.0	9.6	21.9	27.7
NL	3.3	15.9	34.5	40.1
SP	3.0	9.4	19.6	26.4
UK	2.8	21.1	23.3	34.4
TOTAL	3.6	15.0	20.5	28.9

Table 3: Technological specificities in collaborative patenting activity (percent)

	Co-assigned Collaborative	*Co-invented Collaborative*	*Collaborative*	*Overall Collaborative*
Instruments	3.8	17.7	25.6	34.6
Chem & Pharma	3.7	19.6	22.2	31.6
Process eng	3.8	15.7	21.7	30.0
Electrical Eng	3.0	12.0	18.0	25.6
Mechanical eng	3.6	12.2	17.9	25.7
TOTAL	3.6	15.0	20.5	28.9

Table 4: Organisational specificities in collaborative patenting activity (percent)

	Co-assigned Collaborative	*Co-invented Collaborative*	*Collaborative*	*Overall Collaborative*
Firms	3.3	13.0	18.1	26.0
Large	3.3	12.7	16.6	24.4
Medium	3.7	12.3	21.1	28.7
Small	2.9	15.2	23.9	33.0
Universities	5.6	47.8	56.1	72.0
PROs	13.8	37.6	48.6	59.3
Priv Research Org	7.5	21.0	39.0	52.5
Others	2.7	21.4	23.4	36.5
Total	3.6	15.0	20.5	28.9

Table 5: Determinants of Governance mode choice. Multinomial model. Estimates with sample selection

	(1) [Co-Asg vs. Agr]	(2) [Co-Inv vs. Agr]	(3) [Co-Inv vs. Co-Asg]
Complexity (Log)	0.184	0.141	-0.042
	[0.092]**	[0.072]**	[0.072]
Breadth (Log)	0.769	0.253	-0.516
	[0.384]**	[0.319]	[0.298]*
Firm (dummy)	-1.189	-0.494	0.695
	[0.419]**	[0.360]	[0.363]**
University (dummy)	-0.783	0.016	0.799
	[0.567]	[0.444]	[0.455]*
GovFunds (dummy)	0.202	0.028	-0.173
	[0.331]	[0.255]	[0.263]
Age (Log)	-0.596	-0.044	0.552
	[0.198]***	[0.157]	[0.149]***
PhD (dummy)	0.646	0.904	0.259
	[0.227]***	[0.179]***	[0.178]
City (dummy)	0.351	0.202	-0.149
	[0.199]*	[0.152]	[0.162]
Licensing (dummy)	-0.416	-0.452	-0.036
	[0.251]*	[0.196]**	[0.220]
$\hat{\lambda}$	1.018	0.528	-0.491
	[0.327]***	[0.252]**	[0.267]*
Observations	1279		
LR Chisq (20)	4448.74***		
Pseudo Rsq	0.190		
Log Pseudo LL	-1138.021		
IIA	1.322	3.855	
Combined	293.042***	251.588***	42.074***

* denotes 10% significance level, ** denotes 5% significance level, *** denotes 1% significance level.
Bootstrapped standard errors in brackets (1000 iterations)
Sectoral and country dummies not included.

Table 6: Marginal effects of explanatory variables on the mode of governance.

	Co-assignment	Co-invention	Agreement
Predicted probability	0.165	0.640	0.195
COMPLEXITY			
Absolute change	0.0137	0.0209	-0.0346
Relative change	+9.15%	+4.92%	-15.27%
BREADTH			
Absolute change	0.0349	-0.0096	-0.0253
Relative change	+21.36%	-1.57%	-11.17%
FIRM			
Absolute change	-0.1410	0.0430	0.0980
Relative change	-46.32%	+7.58%	+76.32%
UNIVERSITY			
Absolute change	-0.0823	0.0630	0.0193
Relative change	-50.37%	+10.33%	+8.52%
AGE			
Absolute change	-0.0224	0.0142	0.0081
Relative change	-12.69%	+2.36%	+3.65%
PHD			
Absolute change	-0.0110	0.1268	-0.1157
Relative change	-6.73%	+20.78%	-51.08%
CITY			
Absolute change	0.0265	0.0167	-0.0432
Relative change	+19.35%	+2.81%	-16.02%
LICENSING			
Absolute change	-0.0142	-0.0728	0.0870
Relative change	-8.70%	-11.93%	+38.41%

Table 7: Robustness check. Ordered Probit model. Estimates with sample selection.

	Selection Equation (Probit)§ (4)	Regression Equation (Ordered Probit) ‡ (5)
Firm Size (Log)	0.036	
	[0.013]***	
(Firm Size)^2 (Log)	-0.009	
	[0.002]***	
Public Spillovers (Incoming)	0.101	
	[0.021]***	
Priv Spillovers (Incoming)	0.016	
	[0.013]	
Complexity (Log)		0.057
		[0.031]*
Breadth (Log)		0.222
		[0.132]*
Firm (dummy)		-0.468
		[0.151]***
University (dummy)	0.044	-0.260
	[0.027]*	[0.162]
GovFunds (dummy)	0.048	0.049
	[0.015]***	[0.114]
Age (Log)		-0.473
		[0.156]***
PhD (dummy)		0.211
		[0.071]***
City (dummy)		0.119
		[0.067]*
Licensing (dummy)		-0.174
		[0.095]*
$\hat{\lambda}$		0.598
		[0.209]***
Sectoral Dummy	Yes	No
Country Dummy	Yes	No
Constant	-1.024	
	[0.153]***	
Observations	6963	1279
Log Pseudo LL	-3317.19	-1144.27
Wald Chisq	354.69***	45.50***
Pseudo Rsq	0.051	0.020

* denotes 10% significance level, ** denotes 5% significance level, *** denotes 1% significance level.

§ Marginal effects

‡ Bootstrapped standard errors in brackets (1000 iterations)

Sectoral and country dummies not reported for clarity.

Appendix

Was there any formal or informal collaboration between your employer/organisation and other partners for the research leading to this patent? Please also include collaborations with applicants to this patent. (By formal we mean collaborations involving defined contracts among the parties)

Yes - No

If yes, please list the following information:

Name of partners, Objective of the collaboration, Formal, Informal

Table A1: Variable definition

Variable Name	Defined as:
Co-assigned Collaborative	Patents assigned to companies belonging to different groups
Co-invented Collaborative	Patents involving inventors with employers from different organisations
Collaborative Patents	Patents involving research collaboration either formal or informal
Co-invented Only	Patents that have inventors from different groups but were not co-assigned
Collaborative Only	Patents based on collaborative research not leading to co-assignment or co-invention
$Coll_j$	Equal to one if the patent is either co-assigned collaborative, co-invented only, or collaborative only.
$Mode_j$	($MODE_2$= 2) if the patent is co-assigned collaborative, ($MODE_1$= 1) if the patent is co-invented only, ($MODE_0$= 0) if the patent is collaborative only
Project characteristics	
Complexity (Log)	Man-months required by the research. Responses were structured in 8 asymmetric intervals ranging from less than one man-month to more than 72 man-months. We took the natural log of the mean value of each interval plus the right border of the lowest interval and the left border of the top interval
Breadth (Log)	Natural log of the number of 4-digit technological classes (IPC) in which the patent was classified
Organisational characteristics	
Firm Size (Log)	Number of employees. Responses were structured in 3 asymmetric intervals ranging from less than 100 employees to more than 250 employees. We took the natural log of the mean value of each interval plus the right border of the lowest interval and the left border of the top interval Natural log of themean value of
Public Spillovers (Incoming)	Sum of the scores of the importance of Universities, PROs, technical conferences, scientific literature as external sources of knowledge rescaled to a number between 0 and 1
Private Spillovers (Incoming)	Sum of the scores of the importance of patent literature, customers, suppliers competitors, as external sources of knowledge rescaled to a number between 0 and 1
Firm (dummy)	Equal to one if the inventor was employed by a Firm
University (dummy)	Equal to one if the inventor was employed by a University
GovFunds (dummy)	Equal to one if the financing of the research came from the Government Research Funds
Individual characteristics	
Age (Log)	Natural log of the age of the inventor at the time of patent

	application
PhD (dummy)	Equal to one if the inventor's highest academic degree is a PhD
City (dummy)	Equal to one if the inventor worked in a city of more than 100,000 inhabitants when the research leading to the patent was carried out
Legal aspects	
Licensing (dummy)	Equal to one if the patent has been licensed, by one of the patent holders, to a third party

Table A2: Descriptive statistics

	Mean	S.D.	Min	Max
$Coll_j$	0.202	0.401	0	1
$Mode_j$	1.436	0.775	0	2
Firm Size (Log)	4.985	1.39	0	5.521
Public Spill (Incoming)	0.315	0.24	0	1
Priv Spill (Incoming)	0.469	0.257	0	1
GovFunds	0.087	0.281	0	1
University	0.032	0.177	0	1
Firm	0.931	0.253	0	1
Age	45	9.75	13	85
PhD	0.26	0.439	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
Licensing	0.114	0.318	0	1