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Ownership Structure and Productivity of Vertical Research Collaboration[*]

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Abstract

This paper analyzes empirically how significantly the existence of non-contractible research effort by a vertical partner (as measured by a provision of a co-inventor) affects the ownership structure of vertical collaborative research and whether such effort also significantly enhances research productivity, exploiting rich information at the project level provided by a large scale inventor survey in Japan. Participation of a supplier co-inventor significantly enhances research productivity and is also a very significant determinant of the ownership structure, controlling for the initial knowledge contribution and the financial contribution by a supplier. On the other hand, while a user co-inventor affects the ownership structure even more predominantly, it contributes much less to the productivity of joint research. Such a gap may be partly explained by the necessity of a user to combine relevant patents. Finally, the willingness to license is not lower for a vertically co-owned patent, even if co-ownership partly substitutes a license. This suggests that co-ownership does not significantly constrain licensing, even if ex-post agreement for a license becomes necessary.

Keywords: Collaborative research, Ownership, Incomplete contract, Productivity, Licensing
JEL Code: O31, D86

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1. Introduction

Collaboration across organizations is an important mechanism for undertaking an R&D project which is complex and requires a combination of diverse skills and knowledge. More than 10% of the triadic patents[1] involve an inventor from an external organization in both Japan and the US (see section 3). How to allocate the ownership of the output of such joint research is a critically important issue, since it can fundamentally affect the incentives of the participating organizations, given that a research contract is often incomplete, as discussed by Aghion and Tirole (1994). Assuming that the two parties cannot contract for the delivery of a specific innovation and the research and commercialization inputs are also not contractible, they show that the party with the complementary assets for commercializing the invention should own the invention if its marginal contribution to the generation of the innovation is larger than that of the party with no such asset (the upstream firm specialized in research), extending the insight of Grossman-Hart (1986)[2]. This paper aims at examining empirically how significantly the contribution of non-contractible research effort by a vertical partner (as measured by a provision of a co-inventor) can explain the productivity and the ownership structure of a vertical collaborative research.

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[1] The triadic patents constitute the patent families of the Japanese patents applications, the applications for European Patent Office and the US patent grants, sharing the priorities.

[2] Given the constraint of an incomplete contract, the incentive for at least one of the two parties is always too weak in their model. Although Nöldeke and Schmidt (1998) show that an option contracting for the transfer of the ownership might solve this problem in the case of sequential investments, the collaborative research often involves concurrent efforts of two or more independent parties.

Although there are many empirical literatures on the research collaborations (see, for an example, Siegel (2002), Cassiman and Veugelers (2002), Hagedoorn (2002 and 2007), and Miotti and Sachwald (2003), Belderbos, Carree and Lokshin (2004a and 2004b)), the empirical analysis of how the contribution of non-contractible research effort accounts for the ownership structure of a collaborative research is very scarce. Lerner and Merges (1999) provides some evidence on the effect of financial constraint on ownership structure by showing that the upstream firm has limited ownership when it is financially constrained, using the alliance data in biotechnology industry, supporting the view of Aghion and Tirole (1994). Lerner and Malmendier (2010) show that a termination option can deter researchers from opportunistic behaviors and that the contracts with such options are more common when research is non-contractible. Tao and Wu (1997) examine the choice between equity research joint ventures and non-equity co-development among horizontal competitors and show that equity research joint ventures are chosen when they compete in the same market. None of these studies examine a research productivity reason for the allocation of the ownership.

Focusing on vertical research collaborations which are most frequently engaged research collaboration(see section 3), we will examine whether the ownership is significantly shared (co-owned) with a vertical collaborator when such party contributes an inventive human capital (that is, a co-inventor) and whether the research productivity is also enhanced by a vertical co-inventor. An inventor is a core input to the invention process and its effort is likely to be substantially non-contractible. A vertical co-inventor may expand significantly the scope of knowledge and skill of the inventor team. In addition, we examine whether co-ownership may restrict licensing, due to the necessity of the agreement of both parties for a licensing. A patent law provides that a co-owned patent can be freely practiced by each co-owner, unless otherwise agreed. Since the use of an invention is non-rival, it does not produce a kind of inefficiency as clarified by Hart (2005) for a joint ownership of a physical asset. While both parties can have de facto veto rights for the use of a co-owned physical asset, such physical constraint does not exist for the case of a co-owned patent. As for a license, however, a co-owned patent can be licensed only if all co-owners agree, unless otherwise agreed, in Japan as in major European countries[3]. Thus, there is some concern that such rule on co-ownership may restrict licensing, due to the necessity of an agreement of both parties for licensing. However, if a license does not require a significant ex-ante effort of the patentee to search for a licensee and if the ex-post negotiation is efficient, the co-ownership of a patent does not significantly constrain licensing. This paper aims at empirically examining this issue too.

For addressing these questions, we use the dataset from a large scale inventor surveys in Japan which were recently implemented in Japan by the Research Institute of Economy, Trade and Industry. The survey collected not only rich information of the project characteristics of the research but also the types of owners (a user, a supplier, a university etc.)

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[3] In the US, a co-assignee can license his right to use the patent to a third party without the consent of his co-assignees. Perhaps, reflecting this, co-ownership is very limited in the US, since it could imply an almost complete loss of the control over the use of the invention. .

for close to 1,000 samples. A user is defined here as the party positioned in the downstream part of the transaction in the product market. The information available for the project characteristics include the organizational affiliations of co-inventors, the knowledge sources for getting the idea for the research project, the financial sources for the research, the stage of the research, whether the research is for product vs. process innovation or for the new development or improvement as well as whether the invention is used and/or licensed. Thus, it is uniquely suited to the analysis of the research collaboration at project level, including the ownership structure of the invention. In particular, we can measure the inputs from a vertical collaborator (a user or a supplier) in terms of human capital (the provision of a co-inventor), important knowledge for getting the idea for the research which yielded the invention and the research money. We can also access their contributions on research productivity, using the following output measures: the (subjective) value of the focal patent, the number of patents from the project and the status of the commercialization of the focal patent as well as whether it is licensed.

The rest of the paper is organized as follows. Section 2 provides a theoretical framework and three propositions which guide empirical analysis. Section 3 provides descriptive statistics on the research collaborations and ownership structure in Japan. Section 4 describes the models for estimations. Section 5 empirically analyzes how co-ownership is significantly related to the provision of a co-inventor as well as whether the ownership structure can be explained by the contribution of a partner to research productivity. It also analyzes whether a vertically co-owned invention is less likely to be licensed. Section 6 concludes.

2. Theoretical framework and propositions

We focus on research collaboration between the seller and the buyer of an intermediate product (that is, vertical research collaboration). Such collaboration would mainly target the intermediate product (such as component and the materials) transacted between the two parties for improving its quality, the process of producing such product or the process of using the product by the user. In such collaboration each of the two parties has the co-specialized complementary assets for commercializing the invention: the supplier owns the assets for producing the intermediate product and the user owns the asset for using that product for the production of the latter's final product. However, at the same time, we assume that the user can create an alternative supply (an internal or external second sourcing) if it has the patent right for that, while the supplier cannot create an alternative final production capacity, perhaps due to the difficulty of obtaining and combining all complementary intermediate products. Thus, the two parties have asymmetric power structure as in Aghion and Tirole (1994). However, a supplier still has some incentive to exert its R&D effort even if the patent is fully owned by a user, as long as it has some advantage in producing the intermediate product embodying the invention, unlike their model.

Hereafter, we focus on the research for producing a new intermediate product for simplicity. The allocation of the ownership of the research output (we exclusively focus on the patent right), that is, whether it is jointly owned or whether it is exclusively owned either by a supplier or by a user, affects the ex-post bargaining power by affecting vertical competition in negotiating the supply contract (see Table 1). If the user owns exclusively the patent right on a new component, it has the unilateral option to create a new external second-source by licensing the patent to a third party, so that its bargaining position is very strong in the negotiation of the contract with the supplier. On the other hand, if the supplier owns the patent right exclusively, it can significantly appropriate the surplus from the transaction by excluding the possibility of vertical competition. Finally, if it is jointly owned, the user still has the option to create an internal second-source (but not an external second source), so that the level of its bargaining power is positioned in-between.

(Table 1)

The allocation of the patent right affects the total surplus by affecting the ex-ante incentives of the two parties, in the context of incomplete contract (see Hart (1995) for a clear exposition). As in Aghion and Tirole (1994), if one party has higher research productivity, allocating more right to that party would increase the surplus, since such party will be able to appropriate more of the added surplus thanks to its stronger ex-post bargaining power. For an example, as the contribution of non-contractible effort by a user to the vertical research collaboration increases relative to that by a supplier, the ownership structure will shift from the sole ownership by a supplier, to the co-ownership between the supplier and the user, and then to the sole ownership by a user. Moreover, what matters in the choice of ownership structure is non-contractible effort or investment. Since a contribution of inventive human capital is likely to be substantially non-contractible, we expect that the contribution of an inventor to research productivity matters significantly for influencing the ownership structure.

The ownership structure of the patent may affect licensing. If licensing requires non-contractible search effort for a licensee, including some additional R&D efforts to improve the technology, the ex-ante incentive would matter. In addition, in the context of a vertical collaboration, while one of the parties may welcome the increased competition (for an example, a user would welcome the possibility of a second sourcing), another may well dislike it. Thus, if the ex-post negotiation for licensing fails, the vertically co-owned patent is less likely to be licensed, even if licensing is value enhancing for the two parties. If a license does not require a significant effort of the patentee to search for a licensee and if the ex-post negotiation is efficient, the co-ownership of the patent does not constrain licensing. If these two conditions were not met, co-ownership would result in too low level of licensing, either due to inactive search effort or due to inefficiency in ex-post negotiation.

We can summarize the above analysis by the following three propositions on the structure of ownership, which will guide our empirical testing:

Proposition 1 on productivity and ownership structure of vertical research collaboration

A co-inventor from a vertical collaborator is a key determinant of the ownership structure of vertical research collaboration, when his non-contractible research effort matters significantly for the productivity of such research.

Proposition 2 on co-ownership with a user vs. that with a supplier

Whether a user is more likely to secure ownership on the output of the collaborative research than a supplier depends on whether the user contributes more to the productivity of the joint research than the supplier, given other things equal.

Proposition 3 on licensing of co-owned invention

A co-owned patent is less likely to be licensed, if non-contractible search effort for a licensee is important or if the ex-post efficient negotiation among the parties when a profitable licensing opportunities arise is inefficient.

3. Research collaboration and its ownership structure in Japan

3.1 Dataset

The inventor survey in Japan was conducted by the RIETI (Research Institute of Economy, Trade and Industry) in 2007. It collected 3,658 responses (around 70% of all responses) on the R&D projects which yielded randomly selected triadic patents with the earliest priority year from 1995 to 2001. It also collected 1,501 responses for non-triadic patents with application year from 1995 to 2001 as well as for a small number of important patents. The survey response rate was 20.6% (27.1% adjusted for undelivered, ineligible, etc.)[4]. The follow-up survey was done in 2008 for the respondents of the 2007 survey, focusing on co-ownership

4 See the appendix of Nagaoka and Walsh (2009) for more details.

structure among others and collected 1,235 returns. The parallel survey in the US for the triadic patents was conducted by Georgina Tech in 2007, in collaboration with RIETI, and collected 1,919 patents, with 2000-2003 priority years. In the following section 3.2, we will present the summary data on the incidence of research collaborations (following Figure 1 and 2) based on the data from US-Japan surveys, in order to see how vertical research collaborations are important. In section 3.3 we will look at summary statistics of the ownership structure of vertical research collaborations.

3.2 Incidence of research collaborations : co-inventions and the other collaborations

Figure 1 gives the share of external co-inventions (that is, co-invention with an inventor affiliated with an external organization) for Japan and the US, broken out by their organizational affiliations, based on triadic patents (see Walsh and Nagaoka (2009) for more details). This is based on all samples, including the inventions co-owned by related parties[5]. We see that, in both Japan and the US about 13% of triadic patents have an external co-inventor (this Figure corrects the technology composition difference between the two countries). In both countries, vertical co-inventions (the co-inventions by the inventors from a supplier and from a customer or product user) are the most common among all types of co-inventions. If we add the co-inventions either with suppliers or with the users, they amount to more than 7% in Japan and 9% in the US. Co-inventions with university inventors represent about 2.5% in each country. Co-invention with competitors or the other firms in the same industry other than the

[5] However, our econometric work excludes those cases where the patent is co-owned across related firms.

firms in vertical relationships is very rare, each accounting for about 1% of the patents.

(Figure 1)

Cooperative R&D other than co-invention which includes formal and informal collaborations is even more prevalent. Such R&D can cover the provision of data, materials, testing and financial resources. As shown in Figure 2, overall, 28% of Japanese patents and 23% of US patents involved such research collaborations with external organizations. Since there are no significant overlaps between co-inventions and the other research collaborations, almost 40 % of the inventions use external capabilities or resources on the average (somewhat higher in Japan than in the US). Thus, invention is a very open process. Again, most of these formal and informal collaborations are with suppliers (10-14%) and customers (about 7-9%). Universities were involved in about 4% of inventions in both countries. Horizontal cooperation in both countries is limited. Even if we add co-inventions and formal or informal collaborations, the sum adds up only to around 2% of the inventions. This result is consistent with the difficulty of managing R&D collaborations among competitors in the context of incomplete contract (for an example, see Nelson and Winter(1986) for the difficulty of monitoring the activities of competitors and preventing free-riding)[6].

(Figure 2)

3.3 Ownership structure of vertical research collaborations

6 Co-ownership is likely to be problematic for horizontal collaboration, both because it causes the loss of the benefit of the exclusive use but also because it becomes a source for free-riding in the context of incomplete contract. Competitors may choose to establish a joint venture to centralize the research and to consolidate the ownership.

Table 2 provides evidence on how frequently four types of vertical research collaborations exist and how they are associated with co-ownership. The sample here focuses on the cases where the responding inventor belongs to the applicant firm as in the following econometric works, since the vertical collaborators are clearly defined only in those cases. In addition, we exclude those cases where the patent is co-owned across related firms, since a patent ownership may have only a limited effect on control rights in those cases.

Co-inventor from a user exists in 1.8% of the patents and that from a supplier exists 2.6% of the cases. User's information was very important for the getting the idea for the research yielding the invention in 18% of the cases and supplier's information in 6.1 % of the cases. A user collaborated formally or informally (excluding co-invention) in 7.1 % of the cases while the supplier did so in 13 % of the cases. A user provided more than 20 % of the research money in 2% of the cases, while the supplier in 2.5% of the cases.

(Table 2)

The provision of a co-inventor from a user or from a supplier is very strongly associated with a co-ownership with the user or the supplier. When a user provides a co-inventor, it co-owns the invention for 94% of the cases, while, if it does not provide a co-inventor, it co-owns the invention for only less than 1 % of the cases. Similarly, when a supplier provides a co-inventor, it co-owns the invention for 48% of the cases while, if it does not provide a co-inventor, it co-owns the invention for only less than 1 % of the cases. Thus, the provision of a co-inventor from a vertical collaborator, especially from a user, seems to be very influential for that party to secure the ownership. The provision of very important knowledge for suggesting the project is also positively associated with the co-ownership both for the collaboration with a user and with a supplier. However, its impact is apparently much smaller than that of the provision of a co-inventor (the incidence of co-ownership is 5% with such knowledge and 2 % without it). We observe the same results for the impact of a collaboration other than the provision of a co-inventor. Finally, the substantial financial contribution (covering 20 % or more of the research cost) is also strongly associated with co-ownership with the vertical collaborator. If the user provides 20% or more than of the research money, it co-owns the patent for 26% of the cases while if the supplier does so, it co-owns the invention for 33 % of the cases. This is not surprising, since the financial contribution by a vertical collaborator is often made in exchange for its acquisition of co-ownership (that is, the financial contribution is endogenous to the co-ownership), although it may also reflect the shortage of the research money for the focal firm. Since various types of collaborations can be provided jointly, we need to use econometric estimations to assess their marginal contributions, which we will do next.

4. Estimation models and variables

We estimate three types of equations: for ownership, for productivity and for license. We use two overlapping samples: the sample of the patents with only a user co-inventor(s) or with no external co-inventors and the sample of the patents with only a supplier co-inventor(s) or with no external co-inventors, in order to focus on the effects of a co-invention with either a user or with a supplier.

4.1 Ownership equation

Co-ownership is chosen if the total value for the two parties under the co-ownership is larger than that of the single ownership. From a perspective of incomplete contract, the presence of the co-inventor from a collaborating organization is a key determinant, since co-ownership enhances the incentive of such co-inventor. However, we also need to take into account the other inputs or reasons for the allocation of an ownership, since there can be important correlations between the presence of the co-inventor and the other factors. One potentially important reason for co-ownership can be to provide an incentive for a collaborating party to provide new knowledge for initiating a research project (that is, ex-ante knowledge contribution to the research). A collaborating party can be compensated by direct payment for such information, but providing a co-ownership can be more efficient than ex-ante payment when information asymmetry is important, since co-ownership is a deferred payment contingent on the quality of its information. Since the provision of important knowledge from a vertical collaborator for initiating the project would make it more likely for a co-inventor from such collaborator to join in the research team, an external co-inventor may become significant in ownership equation not because of its non-contractible research effort, but because of its ex-ante knowledge contribution to the research project. We introduce a variable indicating the level of the importance of such knowledge for getting the idea for the research yielding the invention measured in Lickert Scale (from 0 for no-use to 5 for very important), in order to control for such bias.

Another important reason for co-ownership with a vertical collaborator is the financial constraint of the focal firm. As pointed out by Aghion and Tirole (1994) and confirmed empirically by Lerner and Merges (1998), a collaborating party may obtain ownership, due to its financial strength, even if its inventor from such party does not significantly contribute to the research. In addition, a large financial stake by such party may make it eager to send its inventor to the research project. If this is important, an external co-inventor may become significant in ownership equation not because of his non-contractible research effort, but because of the financial stake of the collaborating party. We introduce a dummy variable indicating the important financial contribution of a vertical collaborator (20% or more of the research cost) in the second specification, in order to control for such effect. Note, however, that this can introduce a down-ward bias of the estimated coefficient of the vertical co-inventor, since the financial contribution by the collaborating party can be also made in exchange for its stronger ex-post bargaining power due to its co-ownership, which, however, is introduced to enhance the productivity contribution of the vertical co-inventor.

We use a Probit model for the ownership equation, with a clustering on the applicant firms. The dependent variable for ownership equation is an indicator variable whether the patent is co-owned with a vertical partner (1) or not (0).We estimate the model for a co-ownership with a user and that with a supplier separately. In addition to the controls for the (ex-ante) knowledge contribution and the financial contribution by a vertical collaborator (user or supplier), we also control for the existence of the collaboration other than co-invention, the project size (the number of inventors), the nature of the underlying R&D in terms of the stage of research, product vs. process innovation, the applicant firm size (four classes) and 6 technology classes (see section 4.4 for detailed explanations of these variables).

4.2 Productivity equation

As for productivity equation we use the following three variables as the performance indicators: the value of the focal patent from R&D (four ranks according to the evaluation by the inventor: top 10%, top 25% and top 50% and the rest in the relevant technology area during the period when the invention was made), whether the focal patent is commercialized or not by the applicant firm and the number of domestic patents expected to be granted from the R&D (6 ranks: 1, 2-5, 6-10,11-50, 51-100, 101-). Since the value of a patent depends both on the size of the value once commercialized and on the commercialization probability (one if already commercialized), the commercialization probability is one important component of the value of the patent.

A co-inventor from a vertical collaborator can affect research performance in two ways. It may help increasing the size of the research labor resource and it may also enhance its productivity by expanding the scope of knowledge and skill of the inventor team. We will focus on the second channel by using the model with the total research labor input as the basic control variable. Thus, we will test whether the presence of an external co-inventor improves research performance, even if the total research labor input in terms of man months (including that of the external co-investor) is controlled for. We will introduce the ex-ante knowledge contribution, the existence of the collaboration other than a co-invention and a significant financial contribution of the vertical collaborator, to control the endogeneity of the co-inventor due to the potential correlations with these variables. That is, we control for the following sources of endogeneity of the external co-investor: as more significant knowledge is provided for initiating the project, the better the research performance is and simultaneously the more likely the co-inventor from a collaborating organization is going to participate. Similarly, more financial contribution from the collaborating organization may be associated with better performance of the research due to a less restrictive financial constraint as well as the provision of a co-inventor. In addition, we introduce the following control variables: the importance of scientific literature as knowledge source, the level of the education of an inventor of the firm, the nature of the underlying R&D in terms of the stage of research, product vs. process innovation, the triadic patent dummy, firm size and technology classes. We use an ordered logit model for the value of the focal patent and the number of the patents from the project as well as a Probit model for the internal commercialization of the focal patent, all with a clustering on the applicant firms.

4.3 License equation

As for a license equation, we evaluate whether the co-ownership of the focal patent negatively affects the willingness of the applicant of the surveyed inventor to license (*will_license*) and the actual license (*licensed2*), conditional on the willingness to license. If non-contractible effort for searching a licensee is weakened due to co-ownership or if the ex-post efficient negotiation among the parties is inefficient, the actual license would be low. However, it can also be low simply because co-ownership already allows the two parties to use the invention, since our license variable does not differentiate whether the license is provided to those who are not the vertical collaborators. Co-ownership can be a substitute for a license. In order to control for this, we use the actual license conditional on willingness to license as a key dependent variable. If the coordination problem due to co-ownership inefficiently constrains the licensing, the willingness to license of the surveyed party predicts less the actual license when it is co-owned.

The survey asked the inventor to identify whether the invention had been licensed or not and, in case it had not been licensed, whether it is possible to license the invention. Variable *will_license* is set to be zero if the invention has not been licensed and will not be licensed, and it is set to be 1 otherwise. We control for the quality of the invention by introducing the forward citations and the number of claims of the focal patent. We also control for the research labor input (man months) and the inventor education which may help strengthen control for the quality, as well as the nature of the underlying R&D (stage of research and product vs. process innovation). For this estimation, we use the sample integrating the two samples: those with only co-inventor(s) from a user and those with only co-inventor(s) from a supplier. We use probit estimations for two dependent variables, with a clustering on applicant firms.

4.4 Detailed explanation of independent variables

The independent variables (*X)*, most of which are common to all estimations, are the following. We introduce the set of variables for human capital, financial and knowledge contributions by vertical collaborators, the stage of research and product vs. process innovation, project size and the triadic patent dummy, and the other control variables. See Appendix table 1 for descriptive statistics.

(1) Human capital, financial and knowledge contributions by vertical collaborators

As a measure of the human capital contribution of the partner, we use a dummy variable (0 or 1) for the co-invention when a user or a supplier provides co-inventor(s). We use another dummy to indicate whether 20 % or more than of the cost of R&D (including personnel cost) was financed by the vertical collaborators. We also use the importance of knowledge of the user or the supplier for getting the idea for the invention as recognized by the inventor as a measure of the knowledge contribution of the partner. The score of importance for a knowledge source varies from non-use (0) to very important (5). Since this measure is subjective, we adds the importance of knowledge of the applicant organization (own knowledge) as a control.

(2) Stage of underlying R&D and product vs. process innovation

We also introduce an index variable (*rd_upstream*) to indicate where the research underlying the invention is positioned in the research process: from basic research, applied research, development and the implementation stage such as technical service. A more upstream invention may require more balanced incentives for inventors of different organizations since exploratory efforts of all inventors are important. We introduce a dummy variable (*prodproc)*, indicating whether the invention targets new process, process improvement, new product, product improvement of the applicant firm, or the other. We use the new process *as a base*. Since the vertical collaboration would target mainly the intermediate product sold between the supplier and the user, co-ownership is less likely to happen if the invention targets the product of the user.

(3) Project size and the triadic patent dummy

We also introduce the number of inventors for ownership equation (*inventors*) or the number of research labor months in logarithmic scale (*lnmonth2*) as a measure of the size of the R&D project. We pool two samples: the triadic patents and the other patents, which would have different means. We control for this by a triadic patent dummy (*triadic*).

(4) Other controls

We also introduce the following control variables for the productivity equations: the importance of scientific literature as knowledge source for suggesting the project (*cncpt_sci*) and the level of the education (*phd*) of the inventor of the focal firm which are highly relevant for productivity. We control for the quality of the invention using the forward citations and the number of claim in license equation. We also use the indicators of the four classes of firm size (large: 501 or more employment, medium: 251-500, small: 101-250 and very small: 100 or less). A large firm is the base. Finally we use 6 broad *technology class dummies* for inventions. We also account for the potential correlation of error terms across the inventions of the same firm by clustering based on the identity of applicant firm.

5. Estimation results

5.1 Determinants of vertical co-ownership

Table 3 provides the results for ownership equation. Model 1 (Model 3) provides the base results while Model 2 (Model 4) introduces the dummy for a significant financial contribution by the vertical partner (either a user or a supplier). According to Model 1 for the incidence of ownership with a user, the existence of a co-inventor from a user, the importance of user knowledge for suggesting the project and the existence of the user collaboration other than co-invention are highly significant (significant at 1% level), in accounting for the co-ownership with a user. The marginal effects according to Model 1 (fourth column for Model 1) suggest that the effect of the co-inventor from a user is extremely significant, even controlling for the effects of user's knowledge contribution for initiating the project. It increases the incidence of the co-ownership with a user by almost 99 percentage points. The increase of the importance of the user knowledge by 5 points (from "not used" to "very important") increases it only by less than 1 percentage point. The collaboration by a user other than co-invention also increases it only by 1.4 percentage point. Thus, the effect of a co-inventor is dominant. Model 2 shows that the size and the significance of the coefficients of a user co-inventor remains essentially the same (the marginal effects are only slightly down by 1 percentage point), even if we introduce the dummy for a significant financial contribution by the user, which is highly significant (1% level) but implying a marginal effect of only 1.1 percentage point (see note of Table 3).

Among the other control variables, the dummy for a triadic patent has a highly significant negative coefficient, implying -0.7 percentage point marginal effect. Thus, a less important patent is more co-owned, although the effect is not so strong. Consistent with this, the patent from an improvement R&D tends to be more co-owned than that from an R&D for a new product or process. This implies that a user is less likely to participate in the joint research for an R&D for a new product or process, or if it does, it is less likely to gain the ownership. There is no significant firm size effect. In particular, there is no tendency of a small supplier firm to provide more co-ownership with the user.

(Table 3)

Model 3 provides the corresponding results for the co-ownership with a supplier. Very similarly, the existence of a co-inventor from a supplier and the importance of supplier knowledge for the initiation of the project are highly significant (significant at 1% level and 5% level respectively) in accounting for the co-ownership with a supplier. On the other hand, the existence of the supplier collaboration other than co-invention is not significant. A co-inventor from a supplier increases the incidence of the co-ownership with a supplier by 50 percentage points, controlling for the effects of supplier knowledge contribution to getting the idea for the research. The effect of a co-inventor from a supplier is very strong, although it is significantly smaller than that from a user. The results of Model 4 suggest that the size and the significance of the coefficients of a supplier co-inventor also remains essentially the same, although the marginal effects decline significantly by 14 percentage points, if we introduce the dummies for a significant financial contribution by the supplier. According to the marginal effects estimated for Model 3, the importance of the user knowledge by 5 points (in 5 points Likert scale) increases the incidence of co-ownership only by less than 1 percentage points. The marginal effects estimated for Model 4 suggest that if the supplier provides a financial contribution of 20% or more of the research money, it results in 5.5 percentage point increase of the incidence of co-ownership. This is relatively large, but still considerably smaller than the marginal effect of the co-inventor (36% points).

Among the other control variables, the dummy for a triadic patent has a highly significant positive coefficient, implying 0.4 percentage point marginal effect. Consistent with this, there is no tendency for the patent from an improvement R&D to be more co-owned than that from an R&D for a new product or process, although the product innovation by a user is less likely to be co-owned. This implies that a supplier is more likely to participate in the joint research for a relatively important R&D, or if it does, it is more likely to gain the ownership. There is no significant firm size effect. In particular, there is no tendency of a small user firm to provide more co-ownership with the supplier.

These results show that the contribution of inventive human capital by a vertical research partner is highly significant in determining the ownership structure of the research. The results hold after controlling for the effects of the ex-ante knowledge contribution, the collaborations other than co-invention and the financial contribution by a vertical partner, and the effects of co-inventor on co-ownership are very strong. A natural interpretation of these results is that the inventive human capital contribution by a vertical collaborator to a joint research matter for its co-ownership since it is a core input and substantially non-contractible, as stated in Proposition 1. The basic conclusions do not change if we use linear probability models which are not dependent on the distribution assumptions on stochastic terms[7].

5.2 Research productivity

The above results show that the inventive human capital contribution from a vertical research collaborator is very significant in accounting for its co-ownership and the user is more likely to secure co-ownership. The next question to be analyzed is whether the inventive human capital contribution from a vertical research is significant for research productivity and whether the user makes a larger contribution for the research performance. Table 4 and 5 provide the results. The marginal effects are for the outcome of the highest performance, that is, the highest economic value for the Models for the patent value and the largest number of patents from the project, given that the value of a patent as well as the number of patents from a research project have highly skewed distributions so that the projects in the top rank account for a significant share of the economic value. Model 5, 7 in Table 4 and Model 9 in Table 5 focuses on a user collaboration and the rest of the Models focus on a supplier collaboration. We control for the research labor input (logarithm of the man months). Since the size of research labor input is likely to be correlated with the incidence of vertical co-inventions (since a larger project would result in more mobilization of both internal and external

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[7] The results are available on request.

resources of the firm), we control for the research labor input. Since a vertical collaborator also contributes to the expansion of the research labor input, the estimated coefficient of the vertical co-inventors in these Tables tend to underestimate the effects of vertical co-inventor, covering only the productivity effects through the change of the composition of the inventor team.

(Table 4)

Model 5 and 6 are for the value of the focal patent. The importance of the scientific literature as knowledge input to getting the idea for the research project, the size of the research labor input, and a PhD degree of the inventor have highly significant positive coefficients (1% level), consistent with our expectation. Controlling for these research inputs, according to Model 5 and 6, while the supplier co-inventor increases the value of the focal patent highly significantly (increasing the probability of getting a patent of top 10 % by 5.9 percentage points) a user co-inventor does not. That is, a user co-inventor does not significantly help improving the value of the patent through improving research productivity, beyond expanding the research labor input. Consistent with this, the collaboration with a user other than co-invention actually negatively affects the value of the patent, while the collaboration with the supplier increases it significantly (the marginal effect is 2.3 percentage points). On the other hand, while a user's knowledge for initiating the project improves the value of the patent highly significantly, the involvement of a user as a co-inventor does not. Dropping the total research labor input as a control variable does not change these results. As for the effects of the other control variables, the invention for new process development, the triadic patent and the patent the inventor of which belongs to a small firm is significantly more likely to be the most valuable patents.

Models 7 and 8 are for the commercialization probability of the focal patent. Research labor input has a highly significant positive coefficient, while the scientific literature as knowledge input to getting the idea for the research has a highly negative coefficient. The latter result is not surprising since the project embodying significantly the scientific research will be of more upstream research project involving high uncertainty. The triadic patent is significantly more likely to be used (by 20 percentage points more). On the other hand, the importance of the knowledge of a user or a supplier (a vertical collaborator) for getting the idea for the research has a highly significant positive coefficient. The project using user or supplier knowledge for initiating the project generates an invention which is likely to be commercialized significantly more (more than 10 percentage points in the case where user knowledge is very important than the case where it was not used, and more than 6 percentage points more in the case of very important supplier knowledge). Controlling for these, the invention from a research project involving a user as a co-inventor is significantly more likely to be used and involving a supplier is also highly significant. Their marginal effects are both 11 percentage points and the difference of the coefficients are not statistically significant.

Finally, Model 9 and 10 are for the number of patents from a research project. As in the case for the value of the patent, the importance of the scientific literature as knowledge input to getting the idea for the research project, the size of research labor input, and PhD degree of the inventor have highly significant positive coefficients, consistent with our expectation. The importance of the knowledge of a user or a supplier (a vertical collaborator) for getting the idea for the research is not significant. Model 9 and 10 also show that the involvement of neither a supplier nor a user as a co-inventor enhances the research productivity in terms of the number of patents significantly (negative for the user co-inventor at 5% level). This does not necessarily mean that they do not matter, since the number of patents increases significantly with the total research labor input which includes those by co-inventors. However, the user co-invention does not seem to result in more number of the granted patents from that project, even taking this effect into account, since the size of the estimated negative marginal effect for a user co-inventor is fairly large (equivalent to a reduction of 55% of research man months). As for the effects of the other control variables, the invention for new process or product development, the triadic patent and the project from a large firm (as well as from a very small firm) is significantly more likely to generate the largest number of patents, as expected.

(Table 5)

In sum, even controlling for major research inputs, including the total size of the research labor input, a vertical co-inventor increases the probability of the commercialization of the invention highly significantly. In addition, it enhances significantly the value of the focal patent in the case of a supplier co-invention, thus, increasing the productivity of the research labor input, although it does not have such productivity effect in the case of a user co-invention. Neither a supplier co-inventor nor a user co-inventor has a productivity effect on the number of patents (actually, the user co-inventor has a negative coefficient), although the number of patents from a project increases significantly with the total research labor input which includes co-inventors. This provides a strong support to Proposition 1 in the case of a supplier co-invention, since the co-inventor from a supplier significantly enhances the research productivity and an important determinant of the ownership structure. On the other hand, a user co-inventor is more influential for determining the ownership structure, while a supplier co-inventor contributes more than a user co-inventor. Thus, the evidence does not support Proposition 2.

Thus, there exists an important gap between the productivity contribution and the ownership control by a user. One potential explanation is a stronger need for a user to combine relevant patents. As shown in Figure 3, a “user” needs a significantly larger bundle of patents for implementing his invention than the “supplier” firm. While a supplier needs to combine 6 or more patents in less than 20 % of the cases, the user needs to combine 6 or more patents in more than 40% of the cases. This would imply a larger risk of being held up due to an unanticipated infringement sue against a user firm. It also suggests that a downstream firm may have more chances to engage in combinatorial innovations. Such risk and opportunity in turn may encourage a user firm to own more patents. In addition, a supplier may be financially constrained more often. Which will give a good explanation requires a further study, which will go beyond an individual patent level analysis.

(Figure 3)

5.3 Licensing of co-owned invention

Table 6 provides the results on licensing: model 11 for the willingness to license and model 12 for the actual license conditional on willingness to license. The results show that the patent with higher forward citation is more likely to be offered for a license as well as more likely to be actually licensed once offered for a license (significant at 10%), while the invention from more upstream R&D is both less offered for a license and less actually licensed once offered for a license (significant at 5%). The dummy of co-ownership does not have significant coefficients not only for the actual license conditional on willingness to license but also for the willingness to license itself. Both coefficients (marginal effects) are positive and are relatively large in the actual license. Thus, we do not find evidence that a vertically co-owned patent is less likely to be licensed, even controlling for the quality of the invention, using the forward citations and the number of claim as well as controlling for the research labor input (man month) and the inventor education, which may represent missing quality, in addition to the stage of research.

(Table 6)

6. Conclusions

This paper has analyzed empirically how significantly the existence of non-contractible research effort by a vertical partner (as measured by a provision of a co-inventor) affects the ownership structure of a vertical collaborative research and whether such effort also significantly enhances the research productivity, exploiting rich information at project level which is newly available from a large scale inventor survey in Japan. Incomplete contract theory suggests that a party which provides a significant non-contractible input to the vertical research collaboration can be efficiently rewarded by ownership. Consistent with this, we have found that human capital contribution (provision of a co-inventor) by a supplier (the party positioned in the upstream part of the transaction) is a highly significant determinant of the ownership structure, controlling for the supplier's initial knowledge contribution and its financial contribution to the project. We have also found that a supplier co-inventor significantly enhances the research productivity in terms of the value of the focal patent and its commercialization possibility, controlling for the size of research labor input and the other key inputs to the research.

On the other hand, a user co-inventor affects the ownership structure even more predominantly. On the other hand, it contributes much less to the productivity of a joint research. A user co-inventor significantly enhances the commercialization probability of a focal patent just as much as a supplier co-inventor, but does not enhance the value productivity of the focal patent and negatively affects the productivity in terms of the number of the patents from a joint research. Thus, there exists an important gap between the productivity contribution and the ownership control by a user, relative to those of a supplier. We have also provided evidence that a user needs to combine more patents than a supplier in innovation, which may suggest that a user may need to combine more relevant patents in order to address a patent thicket problem and to engage in combinatorial innovations.

Finally, a firm is no less likely to provide a license for a vertically co-owned patent, controlling for the invention characteristics such as its quality and the nature of underlying R&D, given the willingness to license. In addition, the willingness to license is not lower for a vertically co-owned patent, even if co-ownership partly substitutes a license. This suggests that co-ownership does not significantly constrain licensing, even if ex-post agreement for a license becomes necessary.

Let us discuss limitations of our research and some implications for further research, policy and management. Our research has not controlled the endogeneity of key inputs to the research such as the size of research labor input. This tends to reduce the significance of the other inputs to research, including the coefficient of co-inventor. Thus, this endogeneity does not affect our finding that a supplier significantly contributes to research productivity. On the other hand, our finding that a user does not significantly contribute to research productivity needs to be qualified. However, since endogeneity of the same nature exists for the estimations both for user collaboration and for supplier collaboration, the fact remains that a user tends to gain more ownership than a supplier even if a user contributes less to research productivity. Our research has not identified the causes for the gap between the productivity contribution and the ownership control by a user. One potential explanation is that a user needs to integrate more patents than a supplier, since a user combines various inputs from many sources of suppliers, as shown in this paper. Another potential explanation is that a supplier may be financially constrained more often. Which will give a good explanation requires a further study, which will go beyond an individual patent level analysis.

Our results suggest that the co-ownership rule requiring ex-post agreement among co-owners for a license does not constrain licensing, as far as a vertically co-owned patent is concerned. This does not imply that co-ownership is always an efficient ownership structure. Since commercialization of an invention significantly involves additional investment, co-ownership may not be efficient for encouraging such investment if it can be efficiently implemented by either of the two parties. A flexible design of ownership structure, such as the option contract for the transfer of ownership structure from co-ownership to a single ownership, as suggested by Nöldeke and Schmidt (1998), may play an important role for such investment.

Reference

Aghion Philippe and Jean Tirole, 1994,"The Management of Innovation,“ *The Quarterly Journal of Economics*, Vol. 109, No. 4 , pp. 1185-1209

Belderbos Rene, Martin Carree and Boris Lokshin, 2004a, “Cooperative R&D and firm performance,” *Research Policy*, Volume 33, Issue 10, December 2004, Pages 1477-1492

Belderbos Rene, Martin Carree and Boris Lokshin, 2004b, “Heterogeneity in R&D Cooperation strategies,” *International Journal of Industrial Organization*, Volume 22, Issues 8-9, November 2004, Pages 1237-1263

Cassiman Bruno and Reinhilde Veugelers, 2002,” R&D Cooperation and Spillovers: Some Empirical Evidence from Belgium,” *The American Economic Review*, Vol. 92, No. 4 (Sep., 2002), pp. 1169-1184

Giuri, P., Mariani M.et al, 2007, “Inventors and invention processes in Europe: Results from the PatVal-EU survey,” *Research Policy*, 36, 1107–1127

Grossman, Sanford, and Oliver Hart, 1986,"The Costs and Benefits of Ownership: A Theory of Lateral and Vertical Integration," *Journal of Political Economy*, LXXXXIV,691-719. Hart, O., and J. Moore,

Hagedoorn, J., 2002, "Inter-firm R&D Partnerships: An Overview of Major Trends and Patterns Since 1960", *Research Policy*,31-4, 477-492.

Hagedoorn, J., Hesen, G., 2007, "Contract Law and the Governance of Inter-Firm Technology Partnerships :An Analysis of Different Modes of Partnering and Their Contractual Implications", *Journal of Management Studies*, 44-3, 342-366.

Hart Oliver, 1995, *Firms, Contracts and Financial Structure,* Oxford University Press

Lerner Josh and Robert Mergers, 1998,"The Control of Technology Alliances: An Empirical Analysis of the Biotechnology Industry", *The Journal of Industrial Economics*, Vol. 46, No. 2,pp. 125-15

Lerner, J., Malmendier, U., 2010, "Contractibility and the Design of Research Agreements", *American Economic Review, 100:1, 214–246*

Miotti L. and Sachwald F., 2003, "Co-operative R&D; why and with whom? An integrated framework of analysis," *Research Policy,* September 2003, v. 32, iss. 8, pp. 1481-99

Nagaoka Sadao and John P. Walsh, 2009a, "The R&D process in the US and Japan: Major findings from the RIETI-Georgia Tech inventor survey," *RIETI Discussion Papers*, 09-E-010.

Nelson, Richard R. and Sidney G. Winter.1982. *An Evolutionary Theory of Economic Change,* Cambridge, Mass.: Harvard University Press.

Nöldeke , G., Schmidt K. M.,1998, "Sequential investments and options to own", *RAND Journal of Economics*, 29, 633-653.

Siegel, Donald, 2002, "Strategic Research Partnerships and Economic Performance: Data Considerations," *Strategic Research Partnerships: Proceedings from an NSF Workshop*, NSF 01-336 (http://www.nsf.gov/statistics/nsf01336/)

Tao Zhigang and Changqi Wu, 1997, "On the organization of cooperative research and development: theory and evidence," *International Journal of Industrial Organization*, 15, 573-596

Walsh John P. and Sadao Nagaoka, 2009, "How "Open" is Innovation in the US and Japan?: Evidence from the RIETI-Georgia Tech inventor survey," *RIETI Discussion Paper*, 2009-E-010

Table 1. Ownership structure and vertical competition

	Exclusive ownership by a user	**Joint ownership**	**Exclusive ownership by a supplier**
Alternatives available for a user	Licensing to a third party for second sourcing, in addition to internal second sourcing	Internal second sourcing	None
Level of vertical competition against a supplier	High, due to external second sourcing by a user	Some, due to internal second sourcing by a user	None

Table 2. Incidence of co-ownership by four channels of vertical collaborations

		Co-inventor from a vertical partner		The knowledge of vertical parnter is "very important" for initiating the research		Collaboration by a vertical partner (other than co-invention)		Financial contribution by vertical partner, covering 20% or more of the project cost	
		yes	no	yes	no	yes	no	yes	no
Collaboration with a user	Incidence of each type of collaboration, %	1.8%		18%		7.1%		2.0%	
	Incidence of co-ownership, % and N	94%	0.8%	5%	2.0%	7%	2.1%	26%	2.0%
		17	952	175	794	69	900	19	950
Collaboration with a supplier	Incidence of each type of collaboration, %	2.6%		6.1%		13%		2.5%	
	Incidence of co-ownership, % and N	48%	0.6%	5%	1.6%	5%	1.4%	33%	1.0%
		25	954	60	918	123	856	24	955

Table 3. Ownership equation (Probit estimations)

		Co-ownership with a user, Probit							Co-ownership with a supplier, Probit						
		Model 1	359 clusters			Model 2	359 clusters		Model 3	300 clusters			Model 4	300 clusters	
	variable	Coef.	Rob Std. Err.		marginal effects	Coef.	Rob Std. Err.		Coef.	Rob Std. Err.		marginal effects	Coef.	Rob Std. Err.	
	Coinvention with a vertical partner (*user or supplier* here and after)	5.841	1.248	***	0.985	5.928	1.353	***	3.054	0.269	***	0.500	2.835	0.227	***
	Importance of the knowledge of a vertical parnter for initiating the project	0.175	0.053	***	0.0001	0.223	0.082	***	0.207	0.087	**	0.001	0.207	0.078	***
	Importance of the internal knowledge for initiating the project	-0.055	0.088		0.000	-0.056	0.116		-0.029	0.100		0.000	0.001	0.111	
	Collaboration other than co-invention by a vertical partner	1.484	0.417	***	0.014	1.427	0.479	***	-0.053	0.472		0.000	-0.438	0.435	
	Financial contribution by vertical partner (dummy)					1.600	0.573	***					1.579	0.363	***
	Inventors	-0.012	0.077		0.000	-0.019	0.093		-0.192	0.097	**	-0.001	-0.244	0.117	**
	Upstream nature of R&D	0.509	0.304	*	0.000	0.588	0.377		0.074	0.064		0.000	0.131	0.079	*
Product vs. Process (base: new process)	Process improvement	1.412	0.691	**	0.012	1.352	0.705	*	-0.003	0.351		0.000	-0.031	0.355	
	New Product	0.065	0.362		0.000	-0.067	0.348		-0.538	0.318	*	-0.003	-0.705	0.301	**
	Product improvement	1.023	0.489	**	0.003	0.729	0.472		-0.576	0.416		-0.002	-0.649	0.445	
	Other	-0.667	0.462		0.000	-1.353	0.690	**	(omitted)				(omitted)		
	Triadic	-1.599	0.330	***	-0.007	-1.773	0.487	***	1.028	0.386	***	0.004	1.004	0.328	***
firm size (base: large firm)	Meduim firm	0.914	0.524	*	0.004	0.476	0.453		(omitted)				(omitted)		
	Small firm	-0.471	0.914		0.000	-0.349	0.859		(omitted)				(omitted)		
	Smallest firm	-0.107	0.270		0.000	-0.473	0.352		0.231	0.483		0.002	0.463	0.495	
	Number of obs	975				975			881				881		
	Log pseudolikelihood	-31				-27			-41				-36		
	Pseudo R2	0.729				0.757			0.535				0.586		

*** 1% significant, ** 5% significant and * 10% significant The coefficients of 6 technology class dummies not shown.

The marginal effects of the financial contribution dummies for Model 2 and 4 are 0.011 and 0.055 respectively. The corresponding marginal effects of the co-inventor are 0.98 and 0.36.

Table 4 Collaboration and the research performance (Marginal effects for the highest value of the outcomes)

		Value of the patent out of the project, Ologit								Use of the patent, Probit							
		Model 5 for user collaobration (686 clusters				Model 6 supplier collaboration (683 clusters)				Model 7 for user collaobration (851 clusters)				Model 8 for supplier collaboration (850 clusters)			
	variable	Coef.	Rob Std. Err.		Marginal effects	Coef.	Rob Std. Err.		Marginal effects	Coef.	Rob Std. Err.		Marginal effects	Coef.	Rob Std. Err.		Marginal effects
	Coinvention with a vertical partner (user or supplier)	0.088	0.130		0.007	0.625	0.201	***	0.059	0.292	0.098	***	0.114	0.271	0.109	**	0.107
	Importance of the knowledge of a vertical parnter for initiating the project	0.054	0.021	***	0.004	0.029	0.022		0.002	0.071	0.012	***	0.028	0.033	0.014	**	0.013
	Importance of the internal knowledge for initiating the project	−0.091	0.026	***	−0.007	−0.083	0.027	***	−0.006	−0.010	0.016		−0.004	0.003	0.016		0.001
	Collaboration by a vertical partner (other than co-invention)	−0.359	0.138	***	−0.023	0.286	0.095	***	0.023	−0.050	0.089		−0.020	0.248	0.063	***	0.098
	financial contribution by a vertical collaborator (dummy)	0.377	0.191	**	0.032	0.144	0.288		0.011	0.381	0.171	**	0.148	0.071	0.207		0.028
Basic control variables	Importance of the scientific literature as knowledge source	0.086	0.025	***	0.006	0.084	0.027	***	0.006	−0.072	0.014	***	−0.029	−0.077	0.014	***	−0.031
	Research labor input (logarithm)	0.191	0.028	***	0.014	0.172	0.028	***	0.013	0.080	0.019	***	0.032	0.079	0.018	***	0.032
	PhD of the internal inventor	0.399	0.108	***	0.033	0.442	0.109	***	0.037	−0.035	0.085		−0.014	−0.016	0.089		−0.063
	Upstream nature of R&D	−0.108	0.054	**	−0.008	−0.107	0.054	**	−0.008	−0.312	0.035	***	−0.124	−0.318	0.033	***	−0.127
Product vs. Process (base: new process)	Process improvement	−0.680	0.158	***	−0.039	−0.635	0.152	***	−0.037	0.033	0.110		0.013	0.101	0.097		0.040
	New Product	−0.374	0.130	***	−0.028	−0.313	0.127	**	−0.023	−0.061	0.087		−0.024	0.025	0.079		0.010
	Product improvement	−0.798	0.138	***	−0.048	−0.747	0.137	***	−0.046	−0.089	0.092		−0.036	−0.038	0.084		−0.015
	Other	−0.317	0.311		−0.020	−0.034	0.300		−0.002	−0.423	0.212	**	−0.165	−0.277	0.231		−0.110
Sample	Triadic patent	0.514	0.085	***	0.034	0.536	0.085	***	0.035	0.503	0.048	***	0.198	0.490	0.049	***	0.193
firm size (base: large firm)	Meduim firm	0.169	0.164		0.013	0.144	0.173		0.011	0.131	0.109		0.052	0.126	0.110		0.050
	Small firm	−0.145	0.214		−0.010	−0.087	0.229		−0.006	0.387	0.129	***	0.150	0.473	0.135	***	0.182
	Smallest firm	0.765	0.213	***	0.074	0.758	0.215	***	0.074	0.185	0.122		0.073	0.242	0.124	*	0.095
	Number of obs	2,732				2,729				3,761				3,749			
	Log pseudolikelihood	−3,353				−3,346				−2,409				−2,408			
	Pseudo R2	0.035				0.037				0.076				0.073			

Note *** 1% significant, ** 5% significant and * 10% significant. The coefficients of 6 technology class dummies not shown.

Table 5 Collaboration and the research performance

		Number of the patents from the project, Ologit							
		Model 9 for user collaobration (851 clusters)				Model 10 for supplier collaboration (850 clusters)			
	variable	Coef.	Rob Std. Err.		Marginal effects	Coef.	Rob Std. Err.		Marginal effects
	Coinvention with a vertical partner (user or supplier)	−0.306	0.142	**	−0.003	−0.009	0.160		0.000
	Importance of the knowledge of a vertical parnter for initiating the project	0.003	0.020		0.000	0.017	0.020		0.000
	Importance of the internal knowledge for initiating the project	0.044	0.027	*	0.000	0.043	0.025	*	0.000
	Collaboration by a vertical partner (other than co-invention)	0.176	0.128		0.002	0.156	0.086	*	0.002
	financial contribution by a vertical collaborator (dummy)	−0.093	0.187		−0.001	0.190	0.216		0.002
Basic control variables	Importance of the scientific literature as knowledge source	0.130	0.021	***	0.001	0.134	0.022	***	0.001
	Research labor input (logarithm)	0.451	0.031	***	0.004	0.450	0.031	***	0.004
	PhD of the internal inventor	0.278	0.111	**	0.031	0.299	0.111	***	0.034
	Upstream nature of R&D	0.015	0.048		0.000	0.014	0.052		0.000
Product vs. Process (base: new process)	Process improvement	−0.621	0.182	***	−0.005	−0.597	0.175	***	−0.005
	New Product	0.020	0.155		0.000	0.081	0.144		0.001
	Product improvement	−0.437	0.147	***	−0.004	−0.350	0.149	**	−0.003
	Other	−0.633	0.314	**	−0.005	−0.489	0.316		−0.004
Sample	Triadic patent	0.256	0.070	***	0.002	0.256	0.069	***	0.002
firm size (base: large firm)	Meduim firm	−0.588	0.141	***	−0.005	−0.629	0.145	***	−0.005
	Small firm	−0.848	0.192	***	−0.006	−0.898	0.196	***	−0.006
	Smallest firm	−0.143	0.173		−0.001	−0.158	0.174		−0.001
	Number of obs	3,771				3,759			
	Log pseudolikelihood	−4,738				−4,721			
	Pseudo R2	0.070				0.071			

Note *** 1% significant, ** 5% significant and * 10% significant. The coefficients of 6 technology class dummies not shown.

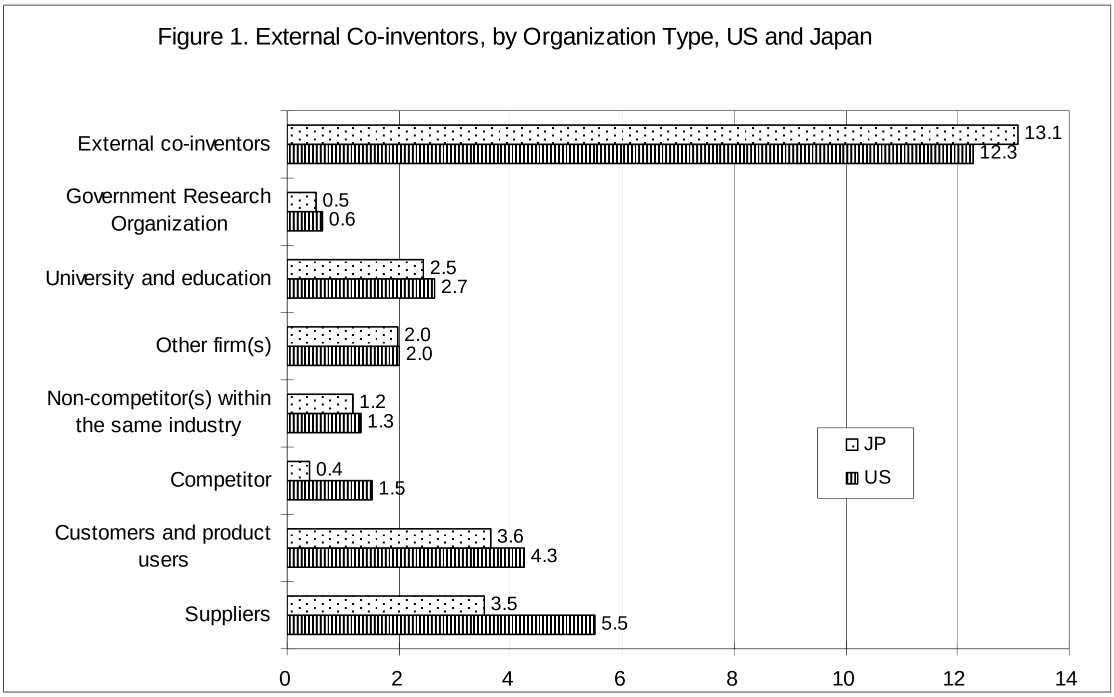
Table 6. Licensing and co-ownership (Probit estimation, marginal effects)

	Model 11 (Willingness, 370 clusters)			Model 12 (License conditional to willing to license, 189 clusters)		
variable	Coef.	Rob Std. Err.		Coef.	Rob Std. Err.	
Ln(1+forward citations)	0.045	0.023	*	0.056	0.031	*
Ln(claims)	0.023	0.017		−0.017	0.032	
co_ownership with a user	0.030	0.066		0.171	0.116	
co_ownership with a supplier	0.065	0.065		0.132	0.131	
Research labor input	0.002	0.012		0.005	0.020	
PhD of the internal inventor	0.045	0.055		−0.074	0.110	
Upstream nature of R&D	−0.057	0.024	**	−0.087	0.037	**
Process improvement	−0.132	0.060	**	0.145	0.119	
New Product	−0.073	0.056		−0.010	0.079	
Product improvement	−0.129	0.055	**	−0.012	0.100	
Other	−0.167	0.103		−0.273	0.204	
Meduim firm	0.069	0.093		−0.210	0.121	*
Small firm	−0.007	0.105		−0.014	0.205	
Smallest firm	−0.010	0.085		−0.070	0.141	
Number of obs	1,032			380		
Log pseudolikelihood	−666			−251		
Pseudo R2	0.019			0.044		

Note. *** : 1% significant, **: 5% significant and *: 10% significant .

The coefficients of 6 technology class dummies not shown.

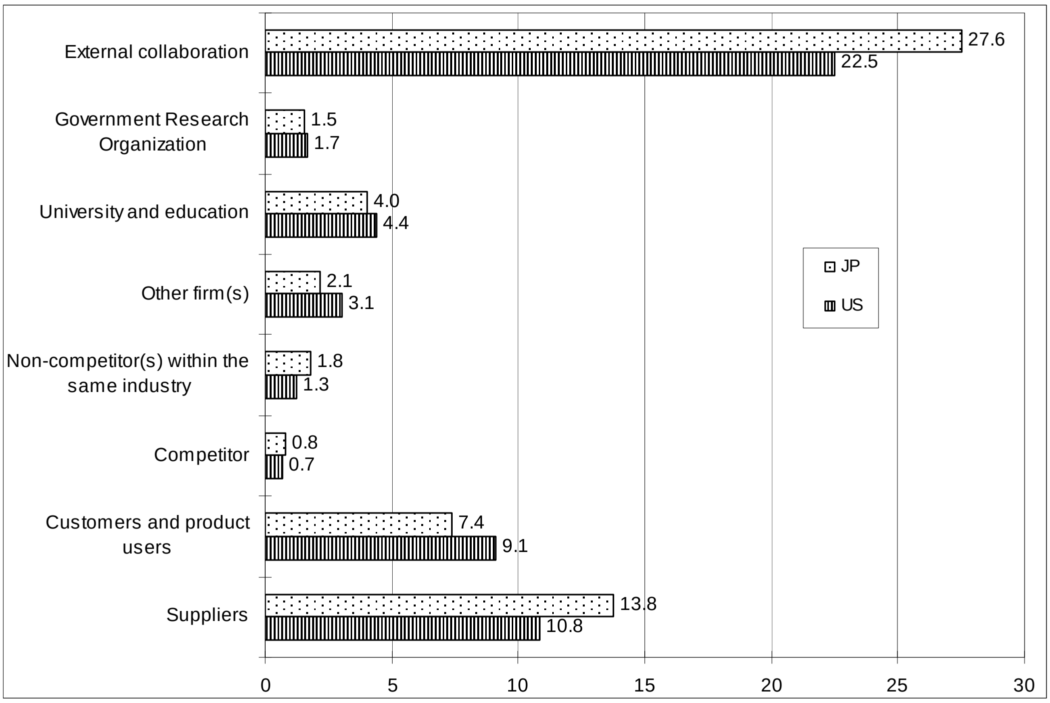
Figure 1. External Co-inventors, by Organization Type, US and Japan (Harmonized technology structure across the US and Japan)



Note. This table adjusts fully the technology composition difference between the two countries, based on the common technology structure. It does not display some minor sources of external co-inventions and other category.

From Walsh and Nagaoka (2009)

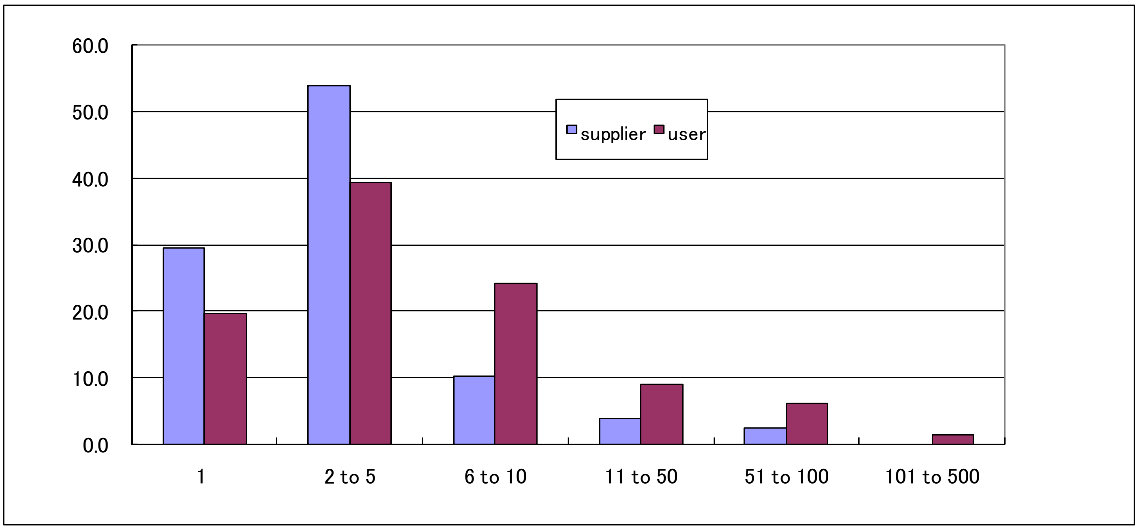
Figure 2. Formal or Informal Collaboration with Outside Organizations, by Organization Type, US and Japan (Harmonized technology structure across the US and Japan).



Note. This table adjusts fully the technology composition difference between the two countries, based on the common technology structure. It does not display some minor sources of external co-inventions and other category.

From Walsh and Nagaoka (2009)

Figure 3 Distribution of the size of the bundle of the patents for commercialization (Supplier vs. user)



Note. A supplier firm is identified as an applicant firm who used the invention within a firm and had a co-inventor of a user. Similarly, a user firm is identified by an applicant firm who used the invention within a firm and has a co-inventor of a supplier.

Appendix Table 1

		Co-inventor only from a user			Co-inventor only from a supplier			Common	
		Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.	Min	Max
Variable	icapp_sum	967	0.042	0.202	976	0.042	0.201	0	1
co-ownership with a user	icapp_user	967	0.025	0.156	976	0.009	0.096	0	1
co-ownership with a supplier	icapp_supp	967	0.006	0.079	976	0.018	0.135	0	1
coinventor from with a user	icinv_user_s	3,771	0.021	0.144	3,759	0.000	0.000	0	0
coinventor from a supplier	icinv_supp_s	3,771	0.000	0.000	3,759	0.019	0.138	0	1
Importance of the knowledge of a user	cncpt_user	3,771	2.828	1.880	3,756	2.803	1.881	0	5
Importance of the knowledge of a supplier	cncpt_supp	3,761	2.084	1.739	3,759	2.103	1.750	0	5
Importance of the internal knowledge of the focal firm	cncpt_own	3,771	3.317	1.499	3,759	3.319	1.504	0	5
Importance of the scientific literature as knowledge source	cncpt_sci	3,771	2.932	1.758	3,759	2.928	1.760	0	5
significant financial contribution by a user	userfin_d	3,771	0.025	0.158	3,759	0.023	0.149	0	1
significant financial contribution by a supplier	supfin_d	3,771	0.016	0.126	3,759	0.019	0.138	0	1
inventors	inventors	3,771	2.463	1.638	3,759	2.464	1.641	1	21
Research labor input (logarithm)	lnmonth2	3,771	2.294	1.346	3,759	2.295	1.344	0.405	4.963
phd	phd	3,771	0.082	0.275	3,759	0.083	0.276	0	1
Upstream nature of R&D	rd_upstream	3,771	2.235	0.720	3,759	2.239	0.723	1	4
Ln(1+forward citations)	prodproc	3,771	2.993	0.818	3,759	2.987	0.826	1	5
triadic patent	triadic	3,771	0.700	0.458	3,759	0.698	0.459	0	1
Ln(forward citations+1)	ln1cited_inv	3,771	0.419	0.703	3,759	0.418	0.702	0	6
Ln(claims)	lnclaims	3,771	1.680	0.835	3,759	1.682	0.834	0	5
Economic value	valued2	2,722	3.078	0.928	2,719	3.083	0.930	2	5
Internal use	use2	3,743	0.512	0.500	3,731	0.510	0.500	0	1
License	licensed2	3,684	0.179	0.383	3,671	0.181	0.385	0	1
Wiling to license	will_license	3,684	0.370	0.483	3,671	0.373	0.484	0	1

Note. Based on Model 9 and 10 of Table 5.