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Ownership structure of vertical research collaboration: empirical analysis from an incomplete contract perspective

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Abstract

Property right literature suggests that ownership of the output of a joint research is assigned so as to enhance the research productivity, given that a research contract is significantly incomplete. This paper examines this view, exploiting rich information at the project level hand collected through a large scale inventor survey in Japan. We have found that the contribution of non-contractible research effort by a vertical partner (as measured by a provision of a co-inventor) dominates the contributions of more contractible inputs (ex-ante knowledge contribution for suggesting the research project and financial contribution) in accounting for the structure of ownership, while such is not the case in research productivity. We have also found that such gap is larger for a user co-inventor than a supplier co-inventor, which may reflect stronger necessity for a user or a downstream firm to combine the patents.

Key Words: collaborative research, incomplete contract, ownership, knowledge, inventor

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1. Introduction

Collaboration among organizations is an important mechanism for undertaking an R&D project, since it enables a combination of diverse skills, knowledge and the other resources. 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 examines empirically whether the contribution of non-contractible research effort by a vertical partner (as measured by a provision of a co-inventor) results in its ownership claim significantly more than the contributions of more contractible inputs (ex-ante knowledge contribution for suggesting the research project and financial contribution), relative to their effects on research productivity, as suggested by incomplete contract theory.

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 more 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 types of research collaborations (see section 3), we will examine whether the ownership is more significantly shared (co-owned) with a vertical collaborator when such party contributes an inventive human capital (that is, a co-inventor) than when it contribute more contractible inputs such as ex ante information provision to the project, relative to their effects on research productivity. An inventor is a core input to the invention process and its effort is likely to be substantially non-contractible.

For addressing this question, we use the dataset from a large scale inventor survey in Japan which was recently implemented in Japan by the Research Institute of Economy, Trade and Industry (the author was the principal investigator). The survey collected not only rich information of the project characteristics of the research but also the types of owners of a patent from the project (a user, a supplier, a university etc.) 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 assess their contributions to research productivity, using the (subjective) value of the focal patent, the number of patents from the project and the status of the commercialization of the focal patent.

The rest of the paper is organized as follows. Section 2 provides a theoretical framework and two 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 presents empirical evidence on how co-ownership is significantly related to the provision of a co-inventor and the other inputs as well as whether the ownership structure can be explained by the contributions of a partner to research productivity. 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, its production process 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 in the theoretical analysis, 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)[3], so that the level of its bargaining power is 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)). As in Aghion and Tirole (1994), if one party has higher marginal 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, relative to the other inputs such as knowledge for initiating the project.

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

Proposition 1 on the effect of non-contractible research effort *on ownership structure*

The contribution of non-contractible research effort by a vertical partner (as measured by a provision of a co-inventor) results in its ownership claim significantly more frequently than the contributions of more contractible inputs (ex-ante knowledge contribution for suggesting the research project and financial contribution), relative to their effects on research productivity.

On the other hand, productivity is an important determinant of ownership structure, once the nature of non-contractible input is controlled. In particular,

Proposition 2 on co-ownership claim by a user and that with a supplier

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

There are other explanations of ownership structure, which we need to take into account in empirical investigations and in interpreting the results. Ownership can serve as one instrument for providing an incentive for a collaborating party to provide new knowledge for initiating a research project. Although such ex-ante knowledge contribution to the research can be compensated by direct payment, providing a co-ownership may have an advantage when information asymmetry is important, since co-ownership amounts to a deferred payment contingent on the quality of its information. This effect, if significant, tends to make Proposition 1 to be less observable in reality. Another potential reason for co-ownership is the financial strength of a vertical collaborator. As pointed out by Aghion and Tirole (1994) and confirmed empirically by Lerner and Merges (1998), a vertical collaborator may obtain ownership, due to its financial strength, even if such party contributes less to the research and the innovation with respect to the invention. We will take this factor into account by introducing a measure of the financial contribution by a vertical collaborator to the R&D.

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 on the R&D projects which yielded randomly selected triadic patents with the earliest priority year from 1995 to 2001 (around 70% of all responses). 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]. Evidence suggests that there is no strong sample selection bias, although an inventor with more valuable patents seem to respond more. The follow-up survey was done in 2008 for the respondents of the 2007 survey, focusing on co-ownership 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, 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

We provide summary statistics of the incidence 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), based on Appendix Table 1[5]. We see that, in both Japan and the US about 13% of triadic patents have an external co-inventor (this statistics 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 firms in vertical relationships is very rare, each accounting for about 1% of the patents.

Collaboration in research other than co-invention (this covers both formal and informal collaborations) is even more prevalent. Such collaboration can cover the provision of data, materials, and testing. According to the Appendix Table 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 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 the other collaborations in research, 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].

3.3 Ownership structure of vertical research collaborations

Table 2 provides evidence on how frequently four types of vertical research collaborations (co-invention, collaboration in research other than co-invention, provision of important knowledge for initiating the project, and financial contribution) 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, since the vertical collaborators are clearly indentified only in those cases. In addition, we exclude those cases where the patent is co-owned by 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. The other collaboration in research with a user existed in 7.1 % of the cases while that with a supplier existed in 13 % of the cases. User's information was very important for initiating the research yielding the invention in 18% of the cases and supplier's information in 6.1 % 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 other collaboration in research is also positively associated with the co-ownership. Such collaboration with a user is associated with the increase of the incidence of co-ownership by 5 % points from 2.1 % to 7.2%. The other collaboration in research with a supplier is associated with the increase of the incidence of co-ownership by 3. 5 % points from 1.4 % to 4.9%. The impact is clearly much smaller than that of the provision of a co-inventor

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 again 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). Finally, the substantial financial contribution (covering 20 % or more of the research cost) by a vertical collaborator is also strongly associated with its co-ownership. 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. Since financial contribution by a vertical collaborator can be made in exchange for its acquisition of co-ownership (that is, the financial contribution is endogenous to the co-ownership), it is not surprising to see such high correlation between a significant financial contribution and co-ownership. But such correlation is still no stronger than that between co-invention and co-ownership. 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 equations for ownership and those for productivity. We use the sample of the patents with only a user co-inventor(s) and those with no external co-inventors for assessing the effects of a co-invention with a user. We use the sample of the patents with only a supplier co-inventor(s) and those with no external co-inventors, in order to focus on the effects of a co-invention with either a user or with a supplier. There are overlaps between the two samples.

4.1 Ownership equation

We use an indicator variable showing whether the patent is solely owned or co-owned with either a user or a supplier as the dependent variable for ownership equation: if it is co-owned with a vertical partner, the indicator is given a value of 1, and if not, 0. We use a Probit model for the ownership equation, with a clustering on the applicant firms. We estimate the model for a co-ownership with a user and that with a supplier separately. The main explanatory variables are a dummy for the presence of the co-inventor from a collaborating organization, a dummy for the presence of collaboration in research other than co-invention, a variable indicating the level of the importance of a user' knowledge or a supplier's 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), and a dummy variable indicating the important financial contribution of a vertical collaborator (20% or more of the research cost)

In addition to the above three variables, we introduce the following control variables: the importance of knowledge of the applicant organization (own knowledge), 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). The product innovation of a user would be less likely to be co-owned with a supplier than its process innovation, since a supplier would have a smaller chance for using or developing product innovation of a user. On the other hand, the product innovation of a supplier might be more likely to be co-owned with a user than its process innovation, since a user may have more chances for using or developing product innovation of a supplier than its process innotation.

4.2 Productivity equation

Since what matters for contracting is private value, we use the following three indicators of the R&D output in productivity equation: the economic value of the focal patent from R&D as assessed by the inventor (four ranks: top 10%, top 25%, top 50% and bottom 50% 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 granted or 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 conditional on commercialization and on the commercialization probability (one if already commercialized), the commercialization probability is one important component of the value of the patent. For estimation models, we use an ordered logit model for the value of the focal patent and the number of the patents from the project and a Probit model for the internal commercialization of the focal patent, all with a clustering on the applicant firms.

We use the same set of variables used in ownership equation as the main explanatory variables. A co-inventor from a vertical collaborator can improve research performance by expanding the scope of knowledge and skills of the inventor team. Similarly, the other collaboration in research such as provision from materials and testing service and the ex-ante knowledge contribution to the research project can improve research productivity. Financial contribution from a vertical collaborator can also improve research productivity by relaxing the financial constraint on research.

We introduce the R&D project size measured by the size of total research man months to control for research opportunities to mitigate endogeneity of collaborations, since better research opportunities will generate more patents and more valuable patents from a project and such project will utilize more resources of all kinds (more inventors, more knowledge sources and more collaboration). We also control for 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.

4.4 Detailed explanation of the construction of independent variables

The independent variables (*X)*, most of which are common to all estimations, are the following.

See Appendix table 3 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 also use a 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 inventor's recognition of the importance of knowledge contributed by a user or a supplier in initiating the R&D. It varies from non-use (0) to very important (5).

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

We also introduce an index variable (*rd_upstream*) which takes values from 1 to 4 to indicate where the research underlying the invention is positioned in the research process: from basic research (*rd_upstream* =4) , applied research (=3), development (=2) and the implementation stage such as technical service (=1). 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*.

(3) Project size and the triadic patent dummy

We use the number of inventors (*inventors*) for ownership equation and the total research labor months in logarithmic scale (*lnmonth2*) in productivity equation as a measure of the size of the R&D project. We pool the triadic patents and the other patents in our sample. Since they 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 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. It shows the marginal effects for all models and the coefficients for two select4ed models. Model 1 (Model 3) provides the base results for the ownership structure of a supplier invention (a user invention) 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 focusing whether the supplier fully owns the invention or whether it shares the ownership with a user, the marginal effects according to Model 1 show that the marginal effect of the co-inventor from a user is extremely significant and it is the only significant explanatory variable. In particular, user's knowledge contribution on initiating the project and its significant financial contribution is insignificant. The co-inventor from a user increases the incidence of the co-ownership with a user by almost 99 percentage points. On the other hand, 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 other 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, the marginal effect of which is only 1.1 percentage point. As the results of the estimations of the coefficients of Model 2 Probit model suggests (Model 2 (coefficients) in Table 3), not only the existence of a co-inventor from a user, but also the importance of user knowledge for initiating the project and the existence of the user collaboration other than co-invention are highly significant (significant at 1% level), in accounting for the incidence of co-ownership with a user. However, the marginal contributions of these inputs other than co-invention are very small.

Among the other control variables, the dummy for a triadic patent has a marginal effect, amounting to the reduction of 0.4 percentage point of the probability of co-ownership. 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. There is no significant tendency for a patent from the R&D oriented to new product development to be more co-owned with a user. There is no significant firm size effect. In particular, there is no tendency of a small independent 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, focusing on the invention by a user. Very similarly, only co-inventor from a supplier has a significant marginal effect (significant at 1% level) on the co-ownership with a supplier. A co-inventor from a supplier increases the incidence of the co-ownership with a supplier by 50 percentage points. The effect of a co-inventor from a supplier is very strong, although it is significantly smaller than that from a user. On the other hand, the supplier knowledge contribution to getting the idea for the research and the existence of the supplier collaboration in research other than co-invention does not have significant marginal effects. According to the marginal effects estimated for Model 3, the increase of 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 results of Model 4 suggest that the marginal effect of a supplier co-inventor also remains very significant and it remains to be the only explanatory variable with a significant marginal effect, although it declines significantly by 14 percentage points, if we introduce the dummies for a significant financial contribution by the supplier. The marginal effects 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) and remains non-significant.

Among the other control variables, the dummy for a triadic patent has a significant positive marginal effect (0.4 percentage point marginal effect in Model 3), in contrast with the result for the supplier invention. In addition, there is a tendency for the patent from R&D oriented to new product development by a user is less likely to be co-owned than that from an R&D oriented to new process development. This makes sense since a supplier is less likely to use the product technology of a user than the latter's process technology. There is no significant firm size effect. In particular, there is no tendency of a small independent user firm to acquire more co-ownership with the supplier.

These results show that the contribution of inventive human capital by a vertical research partner is the dominant determinant of the ownership structure of the research. The above results also show that such gap is larger for a user co-inventor than a supplier co-inventor. The basic conclusions do not change if we use linear probability models which are not dependent on the distribution assumptions on stochastic terms[7]. The next question to be analyzed is whether the inventive human capital contribution from a vertical research is more significant for research productivity than the other inputs and whether the user makes a larger contribution for the research performance.

5.2 Research productivity

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 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 and 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.

(Table 4)

Model 5 and 6 in Table 4 are for the value of the focal patent. A supplier co-inventor is significantly associated with higher value of the focal patent (increasing the probability of getting a patent of top 10 % by 5.9 percentage points) but a user co-inventor is not, controlling for the research inputs, including 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. That is, a user co-inventor does not significantly help improving the value of the patent, beyond expanding the research labor input. Although the latter effect is significant, it does not dominate the effects of the other collaborations (for an example, if the research labor input doubles due to the co-inventions with a user, the implied marginal effect is 0.01). On the other hand, a user's knowledge for initiating the project is significantly associated with higher value of the focal patent (2 percentage points for the increase of the importance of knowledge from “non-use” to “very important”), although the supplier’s knowledge is not. The other (non co-invention) collaboration in research with a user actually has significantly negative coefficients in the value of the patent, while the other collaboration in research with a supplier has a significantly positive coefficient (the marginal effect is 2.3 percentage points each). Dropping the total research labor input as a control variable does not change these results.

As for the effects of the control variables, the invention for new process development, the triadic patent and a small firm is significantly more likely to be very valuable. 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.

Models 7 and 8 are for the commercialization probability of the focal patent. The invention from a research project involving a user or a supplier as a co-inventor is significantly more likely to be used. Their marginal effects are both 11 percentage points. However, these are not dominant. Both the user’s knowledge and the supplier’s knowledge for getting the idea for the research have highly significant positive marginal effects. 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), which are close to the effects of co-inventors. The financial contribution by a user also has a significant productivity effect (15% points), while that by a supplier does not.

(Table 5)

As for control variables, research labor input has a highly significant positive marginal effect, while the scientific literature as knowledge input to getting the idea for the research has a highly negative marginal effect. The latter result is not surprising since the project embodying significantly the scientific research will be of more upstream nature so that it involves high uncertainty and its commercialization takes a long time. The triadic patent is significantly more likely to be used (by 20 percentage points more).

Finally, Model 9 and 10 in Table 5 are for the number of patents from a research project. 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 a 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[8]. The collaboration in research other than co-invention has a positive and significant coefficient for supplier collaboration. The importance of the knowledge of a user or a supplier (a vertical collaborator) for getting the idea for the research is not significant. The financial contribution by a vertical collaborator also does not significantly enhance the number of the patents.

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 marginal effects, consistent with our expectation. As for the effects of the other control variables (see Model 9 and 10), 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, a vertical co-inventor does not have 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.

In addition, two other inputs by vertical partners have significant effects on research productivity. First, a user's knowledge for initiating the project improves the value of the patent highly significantly and the financial contribution by a user also significantly enhances the value, although the supplier's knowledge does not. Second, both the knowledge of a user and that of a supplier (a vertical collaborator) for initiating the research project has a highly significant positive effect on the probability of the use of the patent. The financial contribution by a user also significantly enhances such probability. Thus, unlike in the ownership equation, these research inputs are also significant in productivity and vertical co-invention does not have a dominant impact on research productivity. These findings provides a strong support to Proposition 1

In addition, such effect is much stronger for a user co-inventor. That is, a user co-inventor is likely to acquire ownership than a supplier co-inventor, even if its contribution to research productivity is significantly lower. Thus, the evidence does not support Proposition 2. There exists an important gap between the productivity contribution and the ownership control by a user inventor. One potential explanation is a stronger need for a user to combine relevant patents. As shown in Table 2 in the Appendix, 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 may also suggest that a downstream firm may have more chances to engage in combinatorial innovations, although our empirical work does not. 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.

6. Conclusions

This paper has analyzed empirically whether the contribution of non-contractible research effort by a vertical partner (as measured by a provision of a co-inventor) results in its ownership claim significantly more than the contributions of more contractible inputs (ex-ante knowledge contribution for suggesting the research project and financial contribution), considering their effects on 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 vertical partner is a dominant predictor of the structure of ownership, while such is not the case in research productivity. While 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, so does the suppliers' ex-ante knowledge contribution for suggesting the research project and its financial contribution. However, only the supplier co-inventor has a significant marginal effect on ownership.

Such tendency for ownership control is even stronger for a user co-inventor. On the one hand, it affects the ownership structure predominantly, and on the other hand, it contributes much less to the productivity of a joint research than a supplier co-inventor. A user co-inventor significantly enhances the commercialization probability of a focal patent only 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 especially for a user.

Let us discuss limitations of our research and some implications for further research, policy and management. Our research has not identified the causes for the gap between the productivity contribution and the ownership control by a user. A potential explanation is that a user firm or a downstream firm may need to combine more relevant patents in order to address a patent thicket problem and to engage in combinatorial innovations. We have provided evidence that a user needs to combine more patents than a supplier in innovation. Exhaustion principle (or first sale doctrine) generally exempts a user from infringing the patent if it purchases the product embodying the invention from a supplier. However, if the invention and the patent cover the method of using the product, such might not be the case. As a result, a party which uses the intermediate product incorporating the invention for producing its final product would like to acquire its co-ownership, if the patent covers the method using the invention. This issue would need more investigations.

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, 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 other collaboration inputs, the fact remains that a user tends to gain much more ownership than a supplier even if a user contributes less to research productivity. In addition, even if we take into account the contribution through the potential expansion of research labor input, the estimated effect is not large enough to dominate the contributions of the other collaboration inputs.

Our results suggest that ownership of the output of a joint research is significantly designed to enhance the research productivity, given that a research contract is significantly incomplete, consistent with control rights right literature. 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 more efficiently implemented exclusively 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.

[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.

[3] This is the case in Japan as well as in major European countries. However, in the US a co-owner can also license the patent to a third party.

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

[5] This is based on all samples, including the inventions co-owned by related parties, although our econometric work excludes those cases where the patent is co-owned by related firms.

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.

[7] The results are available on request.

[8] If the number of inventors doubles due to co-invention with a user, the effect from a more research labor input balances out the negative dummy of the co-invention with a user.

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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

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

	Co-inventor from a vertical partner		The other collaboration in research (other than co-invention) by a vertical partner		The knowledge of vertical parnter is "very important" for initiating the research		Financial contribution by vertical partner, covering 20% or more of the project cost	
	yes	no	yes	no	yes	no	yes	no
Incidence of each type of collaboration, %	1.8%		7.1%		18%		2.0%	
Incidence of co-ownership, % and N	94%	0.8%	7.2%	2.1%	4.6%	2.0%	26%	2.0%
	17	952	69	900	175	794	19	950
Incidence of each type of collaboration, %	2.6%		13%		6.1%		2.5%	
Incidence of co-ownership, % and N	48%	0.6%	4.9%	1.4%	5.0%	1.6%	33%	1.0%
	25	954	123	856	60	918	24	955

Table 3. Ownership equation (Probit estimations, Marginal effects)

		Co-ownership with a user (1 for co-ownership), Probit								Co-ownership with a supplier (1 for co-ownership) , Probit							
		Model 1	359 clusters		Model 2	359 clusters		Model 2 (coefficients)		Model 3	300 clusters		Model 4	300 clusters		Model 4 (coefficients)	
	variable	Marginal effect	Rob Std. Err.		Marginal effect	Rob Std. Err.		Coef.		Marginal effect	Rob Std. Err.		Marginal effect	Rob Std. Err.		Coef.	
	Coinvention with a vertical partner (*user or supplier* here and after)	0.985	0.037	***	0.975	0.054	***	5.928	***	0.500	0.071	***	0.356	0.079	***	2.835	***
	Collaboration in research other than co-invention by a vertical partner	0.014	0.009		0.006	0.006		1.427	***	0.000	0.002		-0.001	0.001		-0.438	
	Importance of the knowledge of a vertical parnter for initiating the project	0.000	0.000		0.000	0.000		0.223	***	0.001	0.001		0.001	0.000		0.207	***
	Financial contribution by vertical partner (dummy)				0.011	0.013		1.600	***				0.055	0.040		1.579	***
Basic controls	Inventors	0.000	0.000		0.000	0.000		-0.019		-0.001	0.001		-0.001	0.001		-0.244	**
	Importance of the internal knowledge for initiating the project	0.000	0.000		0.000	0.000		-0.056		0.000	0.001		0.000	0.000		0.001	
	Upstream nature of R&D	0.000	0.000		0.000	0.000		0.588		0.000	0.000		0.000	0.000		0.131	*
Product vs. Process (base: new process)	Process improvement	0.012	0.017		0.004	0.008		1.352	*	0.000	0.002		0.000	0.001		-0.031	
	New Product	0.000	0.000		0.000	0.000		-0.067		-0.003	0.003		-0.003	0.002		-0.705	**
	Product improvement	0.003	0.004		0.000	0.001		0.729		-0.002	0.001		-0.001	0.001		-0.649	
	Other	0.000	0.000		0.000	0.000		-1.353	**	(omitted)			(omitted)			(omitted)	
	Triadic	-0.007	0.005		-0.004	0.005		-1.773	***	0.004	0.002	*	0.003	0.002		1.004	***
firm size (base: large firm)	Meduim firm	0.004	0.007		0.000	0.001		0.476		(omitted)			(omitted)			(omitted)	
	Small firm	0.000	0.000		0.000	0.000		-0.349		(omitted)			(omitted)			(omitted)	
	Smallest firm	0.000	0.000		0.000	0.000		-0.473		0.002	0.005		0.003	0.006		0.463	
	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.

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

		Value of the patent from 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	Marginal effects	Rob Std. Err.		Coef.		Marginal effects	Rob Std. Err.		Coef.		Marginal effects	Rob Std. Err.		Coef.		Marginal effects	Rob Std. Err.		Coef.	
	Coinvention with a vertical partner (user or supplier)	0.007	0.010		0.088		0.059	0.024	**	0.625	***	0.114	0.038	***	0.292	***	0.107	0.042	***	0.271	**
	Collaboration in research by a vertical partner (other than co-invention)	−0.023	0.008	***	−0.359	***	0.023	0.008	***	0.286	***	−0.020	0.036		−0.050		0.098	0.024	***	0.248	***
	Importance of the internal knowledge for initiating the project	−0.007	0.002	***	−0.091	***	−0.006	0.002	***	−0.083	***	−0.004	0.006		−0.010		0.001	0.006		0.003	
	financial contribution by a vertical collaborator (dummy)	0.032	0.018	*	0.377	**	0.011	0.023		0.144		0.148	0.063	**	0.381	**	0.028	0.082		0.071	
Basic control variables	Importance of the scientific literature as knowledge source	0.006	0.002	***	0.086	***	0.006	0.002	***	0.084	***	−0.029	0.006	***	−0.072	***	−0.031	0.006	***	−0.077	***
	Importance of the knowledge of a vertical parnter for initiating the project	0.004	0.001	***	0.054	***	0.002	0.002		0.029		0.028	0.005	***	0.071	***	0.013	0.006	**	0.033	**
	Research labor input (logarithm)	0.014	0.002	***	0.191	***	0.013	0.002	***	0.172	***	0.032	0.007	***	0.080	***	0.032	0.007	***	0.079	***
	PhD of the internal inventor	0.033	0.010	***	0.399	***	0.037	0.011	***	0.442	***	−0.014	0.034		−0.035		−0.063	0.036		−0.016	
	Upstream nature of R&D	−0.008	0.004	**	−0.108	**	−0.008	0.004	*	−0.107	**	−0.124	0.014	***	−0.312	***	−0.127	0.013	***	−0.318	***
Product vs. Process (base: new process)	Process improvement	−0.039	0.007	***	−0.680	***	−0.037	0.007	***	−0.635	***	0.013	0.044		0.033		0.040	0.038		0.101	
	New Product	−0.028	0.010	***	−0.374	***	−0.023	0.010	**	−0.313	**	−0.024	0.034		−0.061		0.010	0.031		0.025	
	Product improvement	−0.048	0.007	***	−0.798	***	−0.046	0.008	***	−0.747	***	−0.036	0.037		−0.089		−0.015	0.034		−0.038	
	Other	−0.020	0.017		−0.317		−0.002	0.021		−0.034		−0.165	0.078	**	−0.423	**	−0.110	0.089		−0.277	
Sample	Triadic patent	0.034	0.005	***	0.514	***	0.035	0.005	***	0.536	***	0.198	0.018	***	0.503	***	0.193	0.019	***	0.490	***
firm size (base: large firm)	Meduim firm	0.013	0.013		0.169		0.011	0.014		0.144		0.052	0.043		0.131		0.050	0.043		0.126	
	Small firm	−0.010	0.014		−0.145		−0.006	0.016		−0.087		0.150	0.048	***	0.387	***	0.182	0.048	***	0.473	***
	Smallest firm	0.074	0.027	***	0.765	***	0.074	0.027	***	0.758	***	0.073	0.048		0.185		0.095	0.048	**	0.242	*
	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 (Marginal effects for the highest value of the outcomes)

		Number of the patents from the project, Ologit									
		Model 9 for user collaobration (851 clusters)					Model 10 for supplier collaboration (850 clusters)				
	variable	Marginal effects	Rob Std. Err.		Coef.		Marginal effects	Rob Std. Err.		Coef.	
	Coinvention with a vertical partner (user or supplier)	−0.003	0.001	**	−0.306	**	0.000	0.002		−0.009	
	Collaboration in research by a vertical partner (other than co-invention)	0.002	0.001		0.176		0.002	0.001		0.156	*
	Importance of the internal knowledge for initiating the project	0.000	0.000		0.044	*	0.000	0.000		0.043	*
	financial contribution by a vertical collaborator (dummy)	−0.001	0.002		−0.093		0.002	0.003		0.190	
Basic control variables	Importance of the scientific literature as knowledge source	0.001	0.000	***	0.130	***	0.001	0.000	***	0.134	***
	Importance of the knowledge of a vertical parnter for initiating the project	0.000	0.000		0.003		0.000	0.000		0.017	
	Research labor input (logarithm)	0.004	0.001	***	0.451	***	0.004	0.001	***	0.450	***
	PhD of the internal inventor	0.031	0.001	**	0.278	**	0.034	0.001	**	0.299	***
	Upstream nature of R&D	0.000	0.000		0.015		0.000	0.001		0.014	
Product vs. Process (base: new process)	Process improvement	−0.005	0.002	***	−0.621	***	−0.005	0.001	***	−0.597	***
	New Product	0.000	0.002		0.020		0.001	0.001		0.081	
	Product improvement	−0.004	0.001	***	−0.437	***	−0.003	0.001	**	−0.350	**
	Other	−0.005	0.002	**	−0.633	**	−0.004	0.002	*	−0.489	
Sample	Triadic patent	0.002	0.001	***	0.256	***	0.002	0.001	***	0.256	***
firm size (base: large firm)	Meduim firm	−0.005	0.001	***	−0.588	***	−0.005	0.001	***	−0.629	***
	Small firm	−0.006	0.002	***	−0.848	***	−0.006	0.002	***	−0.898	***
	Smallest firm	−0.001	0.002		−0.143		−0.001	0.002		−0.158	
	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.

Appendix Table 1. Incidence of research collaborations

	External Co-inventors, by Organization Type, %		Formal or Informal Collaboration (other than co-inventions) with Outside Organizations, %	
	US	JP	US	JP
Suppliers	5.50	3.52	10.83	13.77
Customers and product users	4.25	3.64	9.13	7.38
Competitor	1.52	0.41	0.69	0.81
Non-competitor(s) within the same industry	1.33	1.19	1.26	1.78
Other firm(s)	2.01	1.97	3.05	2.14
University and education	2.65	2.45	4.43	4.04
Government Research Organization	0.62	0.52	1.7	1.52
External co-inventors	12.28	13.09	22.47	27.55

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)

Appendix Table 2. Distribution of the size of the bundle of the patents for commercialization (Supplier vs. user)

Size of bundle (no. of patents)	user, %	supplier, %
1	29.5	19.7
2 to 5	53.8	39.4
6 to 10	10.3	24.2
11 to 50	3.8	9.1
51 to 100	2.6	6.1
101 to 500		1.5

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 3.

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

		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
triadic patent	triadic	3,771	0.700	0.458	3,759	0.698	0.459	0	1
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